Astroengineering Technologies LLC
Unitsky String Technologies Inc.

NON-ROCKET NEAR SPACE INDUSTRIALIZATION: PROBLEMS, IDEAS, PROJECTS

Proceedings
of the VII Global Conference
on Near Space Industrialization
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Anatoli Unitsky

**An author of the fundamental EcoSpace program,
the Chief Investor and Chairman of the Organizing Committee
of the Global Conference on Near Space Industrialization.**

A scientist, engineer and visionary who has dedicated over 50 years to preventing world ecological disaster and preserving the environment for future generations, and who has also developed a unique ground (Unitsky String Transport – uST) and a geocosmic (General Planetary Vehicle – GPV) transport, along with other engineering technologies and biotechnologies that are friendly to the Earth's biosphere.

An entrepreneur who has established a robust engineering corporation with offices in the Republic of Belarus, the Russian Federation, Indonesia, the United Arab Emirates and the United States of America. Anatoli Unitsky's team consists of over 1,000 highly qualified designers, engineers, scientists and researchers who have achieved significant advancements in the construction, certification and operation of innovative transportation and infrastructure complexes.

The author of more than 300 scientific articles and over 20 scientific monographs. Additionally, he holds more than 200 patents and certificates for inventions, industrial designs and trademarks across various sectors, including construction, transportation, mechanical engineering, agriculture and the electronic and chemical industries. More than 50 of Anatoli Unitsky's inventions have been implemented in production in many countries. He is a head of two projects of the United Nations Human Settlements Programme (UN-HABITAT) and is a member of the USSR Federation of Cosmonautics as well as an Academician of the Russian Academy of Natural Sciences.

The anthropogenic oppression of the biosphere and the depletion of natural resources have now reached a disastrous level. If the current rate of growth and development of the Earth's industrial technosphere persists, we risk leaving a lifeless desert unfit for existence as a legacy to our grandchildren. My EcoSpace program is justified and conceptualized in the research centers of Belarus and the UAE. By joining our efforts, we are able to refocus the Earth's technosphere on the cosmic vector of civilization development. Thus, we will eliminate the anthropogenic factor of the biosphere oppression.

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Welcome Speech by Anatoli Unitsky,

Doctor of Philosophy in Information Technologies (Transport), Chief Investor and Chairman of the Organizing Committee of the VII Global Conference on Near Space Industrialization

Dear friends, colleagues and partners,

I warmly welcome participants and guests of the VII Global Conference on Near Space Industrialization. Today, for the first time, our forum is held under a new name, expanding beyond the international level to a truly global scale. And the change underscores the significance of the projects presented at the conference and their vital importance for all of humanity.

This year, we have received a record number of applications from those eager to take part in the event. Our platform has brought together leading experts, scientists, engineers and innovators to discuss key issues and prospects for the development of near space. The presentations will focus on finding solutions to pressing social, biological, environmental and engineering challenges. We are confident that through joint efforts, we can create a sustainable and healthy future.

I would like to extend a special welcome to the thousands of guests who are currently connected to our live broadcast, available in three languages – Russian, English and Vietnamese. This multilingual approach allows us to reach an even broader audience and make our discussions accessible to all space enthusiasts.

The central theme of my plenary speech will be the EcoSpace global program, which aims to reshape the existing world order through collective human efforts. Only by working together can we address the global challenges of our time. As the name suggests, this initiative is dedicated to the development and widespread implementation of innovative biospheric (i.e., biosphere-friendly) engineering technologies – solutions designed to reduce the technological burden on our beautiful Blue Planet and preserve Earth for future generations.

The program offers the world a new path for the development of Earth's human civilization, with a key element being the General Planetary Vehicle (GPV) – a geocosmic complex designed as a self-sustaining spacecraft encircling Earth along the equator. The GPV can transport up to 10 mln tons of cargo and up to 10 mln passengers to space and back in a single trip. Importantly, this drastically reduces the cost of geocosmic logistics by at least a thousand times compared to rocket transportation while maintaining biospheric ecology, as the GPV operates solely on electrical energy.

The GPV can help humanity become a spacefaring civilization and enable large-scale development of near-Earth space. This would allow us to relocate all industries harmful to our planet, such as those that pollute the air and water and destroy flora and fauna, off-world. Through the GPV, we can establish space settlements and industries where millions of people can live and work in natural climatic conditions similar to Earth's subtropical regions.

“

**In ancient times,
prophets warned people
of impending cataclysms.
Those who listened were saved;
the rest perished.
I am not a prophet –
I am an engineer.
All my forecasts
are based on calculations
and observations of processes
occurring on our planet,
which we did not inherit
from our ancestors
but borrowed
from our descendants.**

Thus, by implementing this program, humanity will not only gain access to new technological advancements but also align with the biosphere on a path toward engineering transformation of the global economy.

The transition from Earth-based industry to space-based industry and its placement close to the future consumer – Earth's humanity – is not merely about moving production beyond the planet into near space. It is also about creating comfortable and environmentally friendly housing for all inhabitants in their home – the Earth's biosphere, freed from the burden of the technosphere. It promises dignified work, organic food, clean air, spring water, healthy recreation and morally enriching entertainment.

The foundation of the EcoSpace program is built on my scientific work as a design engineer, inventor and visionary. It compiles the results of scientific analysis, experiments, design and engineering work that I have developed over 50 years of academic and engineering research.

In ancient times, prophets warned people of impending cataclysms. Those who listened were saved; the rest perished. I am not a prophet – I am an engineer. All my forecasts are based on calculations and observations of processes occurring on our planet, which we did not inherit from our ancestors but borrowed from our descendants.

Welcome Speech by Igor Kozhin,

Head of the UNIDO Centre for International Industrial Cooperation in the Russian Federation

If we do not come to our senses and make the fateful decisions necessary to save our shared home – the Earth's biosphere, then no more than two generations remain before the point of no return for civilization.

The growing interest in the EcoSpace program proves that more and more people concerned about the fate of our planet are listening to us. As I mentioned earlier, the EcoSpace project aims to unite regions and continents, peoples and nationalities. I want to emphasize that each year, our projects and ideas receive increasing support. For example, in 2024, we presented our solutions at the BRICS platform.

The biospheric technologies of the Unitsky Group of Companies have received numerous positive responses and have generated significant interest among prominent government officials, business representatives, scientists and the media. This confirms the importance and relevance of our initiatives as well as their potential. Therefore, we are on the right path! We can give the Blue Planet a second breath, preserving the biosphere and rebooting the technocratic civilization with new technologies that are friendly to Live Nature and humanity technologies whose effectiveness has already been proven in practice.

We are showcasing the first ecohouses, harvesting environmentally clean crops and creating human-friendly transportation. Each of you can see this at the Aquarelle EcoPark and the neighboring EcoTechnoPark in Maryina Gorka. EcoSpace is being created right here and now!

I am glad that this forum has brought together all those who, despite emerging difficulties and obstacles, are ready to move forward with me, advancing toward the pinnacle of success with ever-growing inspiration.

The VII Global Conference on Near Space Industrialization is officially open!

On behalf of the UNIDO Centre for International Industrial Cooperation in the Russian Federation, I would like to welcome the participants, organizers and guests of the VII Global Conference on Near Space Industrialization.

This is the second time that I have personally attended a scientific forum hosted by Anatoli Unitsky, and I find the topics and issues raised during this event be highly relevant and significant.

The main objective of UNIDO as an organization in the UN system is to promote effective industrial development in the context of achieving the Sustainable Development Goals proclaimed by the UN General Assembly. Our Centre, which is a direct division of UNIDO in Moscow, is designed to enhance international economic, technological, industrial, scientific and technical cooperation, thereby contributing to the global efforts of the UN.

At the moment, our organization's priorities, according to the updated strategy of the Director General of UNIDO, Mr. Gerd Müller, are: promoting stable industrialization; transition to clean energy and expanding the use of renewable energy sources; introducing digital technologies and vocational training; harnessing the potential of a circular economy; reducing waste, plastic and wastewater emissions; eradicating hunger through investments in sustainable agriculture and new technologies; and ensuring resilience to climate change.

As you can see, the activities of our Centre coincide with the topics of this conference in many ways. In 2022, we signed a cooperation Agreement within the framework of the EcoSpace program. In 2023, it was decided to develop cooperation with Astroengineering Technologies LLC and other organizations of the Unitsky Group of Companies; currently, the possibility of launching joint projects is under consideration, including the use of uTerra soil elixir to combat desertification and address world hunger. We hope that our interaction will be continued with new promising initiatives and activities to achieve international economic, social and environmental integration based on engineering and technical innovations.

I am confident that the VII Global Conference on Near Space Industrialization will contribute to further strengthening cooperation for the benefit of universal and sustainable industrial development.

I wish all participants, organizers and guests of the forum fruitful communication, mutually beneficial exchange of experience and professional success!

Welcome Speech by Pyotr Vityaz,

**Academician
of the National Academy
of Sciences of Belarus,
Doctor of Engineering Sciences,
Professor, Honored Scientist,
Head of the Aerospace Activities
Department of the National Academy
of Sciences of Belarus, Deputy Head
of the Space Research Agency
of the National Academy
of Sciences of Belarus**

Dear Anatoli Eduardovich, Nadezhda Gennadievna, distinguished participants of the VII Global Conference on Near Space Industrialization and honored guests,

On behalf of the researchers at the National Academy of Sciences of Belarus, I extend our sincere best wishes for your continued success in advancing outer space exploration for the benefit of humanity.

It is universally acknowledged that all things have a beginning, exist in state of motion and ultimately reach an end. Recognizing this truth compels us to consider about the future and the preservation of life for generations to come. Everything that unfolds on Earth is linked to the processes occurring within our planet's depth, in near and distant space, and – undoubtedly – influencing the number of natural disasters, including the destructive activities of humans. The topics under discussion at this conference may seem fantastical, but they are not only intriguing – they are also valuable at current stage. We must unite our efforts to build a society of individuals who are committed and resolute in addressing the pressing challenges of our civilization. Together, we can forge a sustainable future with comfortable life while preserving and protecting our home planet.

Dear participants, I would like to highlight that 2024 has been a landmark year for Belarus in the development and application of space technologies. This year marks the 90th anniversary of Yuri Gagarin's birth, the first cosmonaut who opened the door to space for humanity. We take pride in the fact that our compatriots, alongside Russian and other peoples of the former USSR, actively participated in the scientific and technological breakthroughs achieved through the dedication of thousands of Soviet scientists, designers, test pilots and cosmonauts. Prominent figures in Belarusian science made invaluable contributions to overcoming the forces of gravity, including Kazimierz Siemienowicz, Yakov Zeldovich, Semyon Kosberg, Zhores Alferov and many others. We hold deep respect for our Belarusian cosmonauts – twice Heroes of the Soviet Union, Pyotr Klimuk and Vladimir Kovalyonok as well as Hero of the Russian Federation, Oleg Novitsky, who completed his fourth mission in 2024 as commander of the 21st expedition to the International Space Station, alongside Marina Vasilevskaya. The first Belarusian female cosmonaut, not only completed a short space flight but also conducted seven experiments, five of which were scientific and two focused on public education. For her bravery and significant personal contributions to the exploration of near-Earth space, Marina Vasilevskaya was awarded the highest state honor – the title of Hero of Belarus.

Currently, the National Academy of Sciences of Belarus, in collaboration with Belarusian and Russian organizations and the Roscosmos State Corporation, is developing a Belarusian-Russian remote Earth sensing satellite with a resolution of 0.35 m. As part of the Kompleks-SG joint program, a group of three nanosatellites is being manufactured, one of which belongs to the National Academy of Sciences of Belarus and is designated for studying the ionosphere and conducting joint research. The Belarusian space system for Earth remote sensing, established in 2013, continues to be effectively utilized for the benefit of various ministries and departments.

In closing my welcoming speech, I would like to express my gratitude to the conference organizers, managers and specialists from Astroengineering Technologies LLC for this impressive exhibition of innovative developments.

I wish everyone success, good health, and ongoing cooperation as we continue our space exploration for the benefit of future generations.

**The topics under discussion
at this conference may seem fantastical,
but they are not only intriguing –
they are also valuable at current stage.
We must unite our efforts to build a society
of individuals who are committed
and resolute in addressing the pressing
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Together, we can forge a sustainable future
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Welcome Speech by Valery Klyushnikov,

**Academician
of the Russian Academy of Cosmonautics
named after K.E. Tsiolkovsky,
Doctor of Engineering Sciences,
Chief Scientific Officer of TsNIImash JSC**

Dear colleagues and friends,
I am firmly convinced that the development of industrial infrastructure in near-Earth space should become the primary paradigm for its long-term utilization and exploration.

We often quote K. Tsiolkovsky: "Earth is the cradle of humanity, but one cannot live in a cradle forever." Yet, we have not provided a clear answer to the question, "Why do we need space?" The era of enthusiastic romantics ended with the launch of the first satellite and the first human spaceflight. Now is the time for pragmatism. Near-Earth space industrialization is the most effective way to address contemporary challenges and makes humanity's quest for space more meaningful. By gradually relocating energy-intensive and polluting industries off our planet and developing extraterrestrial resources, we can prevent the degradation of its biosphere, ensure sustainable progress for our civilization and transform Earth into a thriving garden.

The methods and pace of near space industrialization may vary, but eventually, we will confront the challenge of overcoming "the curse of gravity" and facilitating the efficient cargo transportation to and from near space in quantities of hundreds and thousands of tons. We can confidently assert that among the known methods for achieving non-rocket access to space, the General Planetary Vehicle proposed by Anatoli Unitsky is likely the most well-developed.

A geoengineering project of this scale will require the collective effort of many countries and nations, engaging specialists from various fields. However, first, the concept of near-Earth space industrialization must resonate with the public. I believe this is the primary objective of the conference.

I wish the participants of the forum and, Anatoli Unitsky in particular, unwavering determination in achieving their goals as well as bold and innovative ideas, a constructive spirit and support from government authorities, industrial enterprises and educational institutions!

Near-Earth space industrialization is the most effective way to address contemporary challenges and makes humanity's quest for space more meaningful.

Welcome Speech by Mikhail Sverdlov,

**Director of the IMBRICS Plus
Business Communications Foundation**

Dear colleagues and Mr. Anatoli Unitsky,
I appreciate being invited to such an important conference!

I am confident that from this year onwards, the members of BRICS+ and Astroengineering Technologies LLC will initiate the implementation of ideas that are certainly important for humanity. The significance of thinking about future generations is spreading across the globe, not just in our country. Moving forward is impossible without such reflections. We will ensure that your ideas reach the final recipients, and hopefully what we talk about at this conference will come to life quickly.

In 2024, Anatoli Unitsky presented his projects within the framework of the VI International Municipal BRICS Forum in Moscow. The largest event was attended by more than 6,000 people, of whom 600 were heads of major municipalities. In my opinion, these are the people who will be the main active supporters of the idea of near space industrialization. Their contribution will help achieve the goals and objectives of humanity.

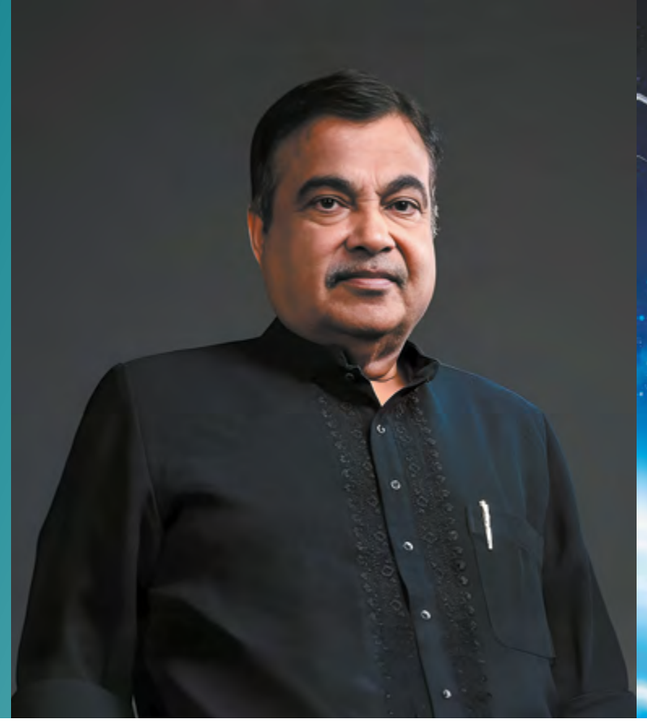
Herewith, I hope that we, along with Astroengineering Technologies LLC, will sign a declaration on further cooperation within the framework of the VII Global Conference on Near Space Industrialization.

Wish all the participants of the forum a fruitful work! Dreams must come true!

The significance of thinking about future generations is spreading across the globe, not just in our country. Moving forward is impossible without such reflections.

Welcome Speech by Nitin Gadkari,

**Doctor of Sciences in Philology,
Master of Commerce,
Minister of Road Transport and Highways
in the Government of India**



Greetings dear guests, friends, ladies and gentlemen.

I am honored to participate in the VII Global Conference on Near Space Industrialization. This forum brings together some of the most talented minds, experts, scientists and industrialists, who will share their technical experience and discuss solutions for environmentally friendly and safe exploration of near-Earth space.

The event will become a platform for discussing new ideas, challenges and opportunities in this area. In the international space race, non-rocket exploration of near-Earth space could be an alternative way for human economic expansion into space.

In our country, the space program is being implemented under the leadership of the Indian Space Research Organization (ISRO), which is engaged in scientific and engineering developments and technologies aimed at maximizing the benefits of near space exploration for India and all mankind. From the launch of the Aryabhata satellite in 1975 to the Mangalyaan Mars Orbiter Mission in 2014 and a number of successful flights of Chandrayaan to the Moon, ISRO has been constantly expanding the boundaries of its space exploration capabilities.

The focus of this conference is on developing green technologies. It should be noted that when I met Mr. Unitsky few years ago, I liked his idea of protecting the environment for future generations, as it can be carried out efficiently and over a long period of time through effective solutions. I remember visiting the string road in Sharjah (UAE), which was implemented by uSky Transport, and how I enjoyed the test drive. I saw how safe it was. I am confident that the proposed concept has the potential to completely transform the passenger and cargo transportation system.

As the Minister of Road Transport and Highways, I pay special attention to the development of reliable transport infrastructure through various initiatives, including the use of plastic and municipal waste as well as steel slag in road construction. We have introduced the use of bamboo emergency barriers, the reprocessing of road surfaces and application of modified polymer bitumen and fiberglass reinforced steel in our construction projects. India aims to reach zero emissions by 2070.

In addition, one of our tasks is to transform the country's energy landscape so that farmers become producers not only of crops but also of energy. We support the use of alternative fuels such as ethanol, methanol, liquefied natural gas, electricity, hydrogen and biodiesel to power construction equipment in order to protect the environment.

Environmentally friendly aviation fuel is already being produced from forage crops such as sugar and starch. In the future, all plants can be used as raw material for it.

At this forum, I would like to propose the idea of exploring the use of alternative biofuels for the space program. It us a long way to go, which will eventually lead to environmental safety and stability.

I express my gratitude to Mr. Unitsky and Astroengineering Technologies LLC for organizing the conference. Anatoli Unitsky is a pioneer in the non-rocket space exploration, he is a game-changer in the transport industry.

In conclusion, I would like to wish all participants of the event every success, new discoveries and achievements. Work together, with understanding and determination! Build a future where people and nature will harmoniously coexist!

> **In the international space race, non-rocket exploration of near-Earth space could be an alternative way for human economic expansion into space.**

Welcome Speech by Yuri Pleskachevsky,

Corresponding Member of the National Academy of Sciences of Belarus, Doctor of Engineering Sciences, Professor, Honored Scientist of the Republic of Belarus

Allow me to begin this welcome speech by addressing Anatoli Unitsky, the organizer of this forum. I also extend my greetings to Nadezhda Kosareva – his friend, wife and, as I know, a person of utmost importance in his life, inspiring him to realize ideas of civilizational significance! I greet all attendees of the conference and wish that your expectations related to this event are fulfilled and that the set goals are achieved.

Despite the global scale of this conference and the uniqueness of Anatoli Unitsky as an engineer, inventor, scientist, thinker, philosopher and truly planetary figure, I want to highlight three aspects that make this event particularly significant for me personally.

The first aspect relates to our joint work with Anatoli Unitsky back in 1988. At that time, I was the Deputy Director for Science, overseeing patent and licensing activities, while he headed the Patent and Licensing Department. Over the years, our paths have occasionally diverged, but we have always maintained contact. In every position I have held, whether as the Director of an Institute, Vice President of the Academy of Sciences of our country or Chairman of the State Committee on Science and Technology of the Republic of Belarus, I have consistently, within my capabilities, supported Anatoli Unitsky and his great ideas.

The second personal aspect: surely, among those present in this hall, only two people have participated in all seven conferences – Anatoli Unitsky and yours truly. I had the honor of attending the first conference in 1988, which took place in Gomel. Even then, the event attracted public attention with its groundbreaking ideas, bringing together specialists from various fields, including cosmonauts.

The third aspect: I have reviewed all the collections published following the conferences, meaning I have thoroughly studied every scientific work presented by Anatoli Unitsky and his disciples.

This signifies that I fully support everything expressed here. From an engineering (physical) perspective, everything is feasible. From the standpoint of materials science, the challenges related to creating the General Planetary Vehicle are also solvable. At the same time, I would like to highlight two problems that must be overcome to achieve the intended goals.

The first obstacle to overcome is the political will of leaders. If two conferences ago there was no light at the end of the tunnel, now I see that a match is burning at its end. Today, representatives of UNIDO, the Skolkovo Foundation and key figures from BRICS are present here, organizations that forward-thinking individuals associate with their future and the future of humanity. Recently, it was announced that 34 additional countries, including Belarus, are interested in joining the five core BRICS nations – Brazil, Russia, India, China and South Africa. This indicates that such organizations and global projects have universal human significance. Consequently, the prospects are beginning to take shape. However, of course, many challenges and questions remain. Our civilization is akin to a runaway Titanic, whose crew is currently engaged in conflicts without realizing that such reckless movement will inevitably lead to a collision at some point. Organizations like BRICS have the potential to unite the global team and steer this ship called "Human Civilization" in the right direction.

The second most important problem that must be solved is ensuring safety. Transport is inherently high-risk from a legal standpoint. The greater the speed, the higher we fly, the deeper we go underwater, and the more passengers involved (we are talking about millions), the greater the risk. It is essential to devise ways to safeguard both technology and people at every stage of space exploration. First and foremost, an anti-meteorite defense system must be established. There is a need for global stations that track approaching cosmic objects, including those coming from the direction of the Sun, which are difficult to detect. This issue must be resolved, as it largely determines the future success of this global project.

In conclusion, I would like to share one more observation. The conference discusses various areas of activity, from string transport to environmental technologies. These are the fields that are in demand today and shape the image of your companies. They form the foundation that will ensure the advancement of such a global project as the General Planetary Vehicle.

Wishing success, health and good fortune to all of us. Special congratulations to Anatoli Unitsky, who celebrated his 75th anniversary in 2024. The first 75 years are difficult, but the next ones will be easier! We wish you a long and fruitful creative journey, and we will always be by your side!

If two conferences ago there was no light at the end of the tunnel, now I see that a match is burning at its end.

Welcome Speech by Yuri Khakhanov,

**Ph.D. in Economic Sciences,
Head of Acceleration,
Head of Urban & Smart City Technologies Unit
at the Skolkovo Foundation**

Mr. Anatoli Unitsky, esteemed colleagues,
I am delighted to welcome you all today!
Traditionally, space initiatives have been viewed solely in the context of their implementation in space, while terrestrial initiatives have been focused exclusively on Earth. However, for the first time, these realms are brought together through the proposals of the Unitsky Group of Companies presented at this conference. Mr. Unitsky has consolidated space industrialization and the concept of linear cities of the future into one comprehensive global project.

The chosen strategy for developing and promoting this idea appears promising, as the industrialization of space is, among other things, closely linked to how we will live on our Blue Planet. Therefore, the Earth initiatives presented – such as ecotechnoparks, ecocities and the overall concept of ecological balance – represent progressive directions.

The Skolkovo Foundation actively supports over 100 ecological innovations in the course of its activities. We welcome other ambitious projects and are prepared to assist in their implementation.

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Welcome Speech by Arseny Mitko,

**Corresponding Member
of the Russian Academy
of Natural Sciences,
Ph.D. in Engineering Sciences,
Associate Professor,
President of the Arctic Public
Academy of Sciences**

Dear colleagues, friends and conference participants,
On behalf of the Arctic Public Academy of Sciences and myself, I welcome you to this pivotal international forum dedicated to the industrialization of near space. It is a great honor to stand among such esteemed specialists and like-minded visionaries. Together, we are united by our desire to expand the boundaries of human capabilities and implement ambitious ideas.

This is not my first time attending this conference, and I am increasingly impressed by the scale of its organization and the significance of the topics discussed. Today, we are not just exploring new horizons; we are creating a future where near-Earth space exploration becomes the foundation for sustainable development of our civilization. What was once considered fantastic is now a reality. Space represents a new frontier, and we are faced with significant challenges. However, I am confident that through collaboration, we can overcome these obstacles.

I extend my gratitude to the organizers for this impressive event and to each participant for your contributions to shaping the future. May our collective efforts propel humanity forward in the exploration of near space. Wishing everyone good luck, success and prosperity!

Today, we are not just exploring new horizons; we are creating a future where near-Earth space exploration becomes the foundation for sustainable development of our civilization.

UDC 008.2+504.06+629.78

EcoSpace Program

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Humans chose the technological path of civilizational development about 2 mln years ago when they created the first engineering technologies, lit the first fire and started cooking food over an open flame. Primitive people were dying of lung cancer at the age of 20, until they guessed to take fire and other simple industrial technologies out of the cave, their home, into the environment – the big biosphere house Earth.

Today, we fully feel the result of subsequent technological development and the creation of a global industry (technosphere) – the biosphere of our planet is filled with technological smog, threatening not only humankind but all life on Earth. However, we are now farther than ever from solving global ecological and socioeconomic problems. The United Nations' concept of sustainable development has not led to a fundamental shift in the world economy towards a biospheric path of civilizational development. Moreover, anthropogenic pressure on the biosphere continues to worsen.

There is only one solution. Joint efforts are required to separate the biosphere and the technosphere in space and to provide the latter with an ecological niche outside the biosphere. Such a civilizational vector of progressive technological development will ensure the preservation and development of life on our planet according to the laws and directions formed during billions of years of evolution. It will also create conditions for the harmonious interaction of the human community – human civilization on Earth – with the biosphere.

The biosphere was not created by humans but by a set of billions of species of living organisms, in which *Homo sapiens* as a biological object has never been the dominant species. Therefore, it should not dominate in the future, otherwise, it can break the historically established planetary biosphere genetic code that has been transmitted from generation to generation trillions of times for the simplest unicellular organisms and billions of times for multicellular organisms, each species of which consists of millions, billions and even trillions of trillions of individuals.

There is no safe ecological niche for the technosphere on Earth, where it would be separated from the biosphere, but there is one in near space, at an altitude of 300 km and more, where there are ideal conditions for most technological processes created by *Homo sapiens*: weightlessness, deep vacuum, ultrahigh and cryogenic temperatures, unlimited raw materials, energy and space resources, etc. At the same time, the optimal place to deploy a lifeless technosphere should not be outer space in general, where there may be extraterrestrial life with its specific ecology, but the dead (non-living) near space, where life – whether terrestrial or extraterrestrial origin – does not exist.

Keywords:
civilization, EcoCosmoHouse (ECH), Equatorial Linear City (ELC), General Planetary Vehicle (GPV), Industrial Space Necklace "Orbit" (ISN "Orbit"), new urbanism, panspermia, space Ark, space industrial waste, space industrialization.

Thus, we conclude that near space industrialization is necessary, as exemplified by the central concept of the EcoSpace program "Earth – for Life. Space – for Industry." However, this will only be possible with the presence of an energy-efficient, environmentally friendly and safe geocosmic transport and infrastructure complex capable of facilitating industrial-scale cargo and passenger transport to and from near space (amounting to millions of tons of cargo and millions of passengers per year) while reducing transportation costs compared to launch vehicles by at least 1,000 times.

The rocket and space industry does not meet any of these requirements. The overall energy efficiency factor of a launch vehicle (considering all preflight and flight costs and energy losses) powered by solid or liquid fuel is about 1 %. Geocosmic transportation by rockets will always remain extremely environmentally hazardous, and its cost will exceed 1 mln USD for each ton of cargo delivered into space (or back). And, most importantly, the ozone that protects our planet from harsh cosmic radiation (ultraviolet) is eliminated in colossal volumes – millions of tons per one launch of a heavy rocket.

Other innovative solutions proposed by engineers are also inefficient, for example, the technology of a space elevator on a stretched steel cable, with a length of more than 50,000 km and a declared capacity of up to 10,000 tons of cargo per year (less than 1 g per inhabitant of the planet). At the same time, the necessary superstrong and ultralightweight structural materials for this technology are lacking, as well as the capability to deliver millions of tons of structural components for the elevator to the orbit with the height of 35,786 km (geostationary orbit), since such an elevator can only be assembled from space – toward Earth and in the opposite direction (to secure a counterweight with a mass of more than 10 mln tons).

The geocosmic transport system optimal for the industrialization of space must meet the fundamental laws of nature. These include four physical conservation laws: energy, momentum, angular momentum and motion of the system's center of mass. At the same time, the design and principle of the cosmic transport system operation should be integrated into the environment with a minimal impact on the biosphere, harmoniously fit into the natural landscape and avoid interfering with local and global biospheric processes. Only one engineering solution meets the specified requirements and several additional geocosmic transport and logistics assignments subject to the space industrialization – this is the General Planetary Vehicle (GPV) introduced to the world community in 1982 by Soviet engineer Anatoli Unitsky.

The GPV is a reusable geocosmic transport and infrastructure complex powered by electric energy for non-rocket industrial exploration of near space, made in the form of an aircraft encircling Earth in the equatorial plane. The GPV is equipped with two longitudinal belt flywheels set inside the body in vacuum channels and held on magnetic suspensions. Once accelerated by linear motors, the flywheels can rotate for years inside the vacuum channels and, consequently, around the planet, since neither the magnetic cushion on permanent magnets nor the vacuum will create significant resistance when traveling at cosmic velocities. Energy costs for a fully loaded round trip will be only due to internal energy losses estimated at no more than 3 % (theoretically it is possible to reduce them to 0.5–1 %). The GPV efficiency factor using the superconductivity effect can be close to the theoretically possible limit of 100 %.

The accelerated flywheels will transfer their kinetic energy and impulse to the GPV body and its cargo as they ascend from Earth into space, and will receive energy back from the spacecraft body and its cargo as they descend to Earth. Once the space industry is established, when the return cargo flow from space exceeds the direct cargo flow from Earth, the GPV will begin to generate electricity, like a giant equatorial power plant with a capacity of more than 100 mln kW: the excess cargo delivered to Earth, like falling water in a hydroelectric plant, will give its kinetic and potential energy to the belt flywheels and those to the Earth's power system.

In terms of energy efficiency, the delivery of each tone of space cargo to the Earth's surface by the GPV would be roughly equivalent to the energy contained in one tone of oil. Therefore, available space minerals, such as those found in the main asteroid belt, with a total mass of more than 10^{18} tons (billions of billion tons), can be considered from Earth's perspective as an oil field of the same mass – this energy will be sufficient to power Earth's civilization for millions of years to come.

The future cosmotechnogenic terrestrial civilization, coping with global environmental, resource and sociopolitical challenges on the home planet will be based on three components designed to provide the whole necessary set of conditions for sustainable development of terrestrial humanity which has become cosmic and retained its technological (industrial) civilizational foundation:

1) BioSpace – the restored and naturally evolving biosphere of Earth which is free from anthropogenic impact;

2) TechnoSpace – an energy- and resource-efficient technosphere transformed on Earth and newly created in space, which does not have an anthropogenic oppressive impact on the Earth's biosphere;

3) HomoSpace – an improved global sociopolitical structure, having both terrestrial and cosmic (extraterrestrial) components.

The most important element of the updated technosphere of Earth will be the Equatorial Linear City (ELC) – the terrestrial component of the geocosmic transport and communication complex, hosting the GPV takeoff and landing overpass with all the infrastructure necessary for carrying out GPV flights and servicing global geocosmic cargo and passenger flows. The ELC consists of cluster-type settlements harmoniously integrated into the natural environment of terrestrial and oceanic areas of the planet, located on a strip along the equator and interconnected by rapid (up to 150 km/h), high-speed (up to 360 km/h), ultrahigh-speed (up to 600 km/h) and hypervelocity (over 600 km/h) routes of Unitsky String Transport (uST).

The first launch of the GPV into space will give start to the creation of the Industrial Space Necklace "Orbit" (ISN "Orbit") – a transport and infrastructure, industrial and residential complex acting as a functional analogue of the ELC located in near space on the equatorial circular orbit. The ISN "Orbit" will also serve as a base for the planet's protection against cosmic threats (including the meteoric ones) and a platform for future expansion of the Earth's civilization into space.

The transition to industrial space exploration does not mean a complete rejection of industrial development on Earth, it implies the evolution of the existing terrestrial industry to more efficient, eco- and biosphere-friendly technologies that will demonstrate better quality features:

1) production of natural (organic) food products, i.e., preindustrial analogues that existed when agriculture did not use chemical fertilizers, pesticides and GMOs;

2) production of waste-free green electricity that causes no damage to the planet's biosphere and global economy;

3) construction of eco-friendly residential, industrial and other buildings and structures that do not consume land;

4) creation of transport, energy and informational eco-oriented infrastructure above the earth's surface at the so-called second level.

The conditions for these transformations will be provided by technological platforms designed to preserve the ecological balance on the planet:

- uGreen – preindustrial organic farming;
- uEnergy – green energy mainly represented by relict solar bioenergy (RSBE);
- Unitsky String Technologies (uST);
- EcoHouse – eco-oriented construction of residential, industrial and other buildings and structures on Earth.

The EcoSpace program implies changing the existing world order by universal human efforts. Only together, collectively, we can change the nature of human development. Our technogenic civilization, which puts all the success of its own development on engineering technologies, in no way should abandon industry and its technological foundation. Deindustrialization is fatal to the civilization that we know and that we all, the whole humanity, belong to.

This project involves consolidation and civilizational patriotism on a planetary scale. In this case, traditional investment, technological and social risks lose their significance when compared to the main one, namely the loss of time necessary to understand that the cosmic vector of industrial development is the only correct inevitable solution that can be implemented under the current conditions and at the present development stage of our Earth's technogenic civilization, its technologies and science.

Every day of delay brings us closer to the global ecological (technical and biospheric) catastrophe that cannot be avoided: no more than two generations separate us from the point of civilizational no return. However, humanity still has a choice: either to continue spending decades on hot and cold wars, on inflating financial bubbles and creating global crises, on developing a quasi-culture of unrestrained consumption and lack of spirituality leading to a digital concentration camp or to already choose an alternative way of building a new civilizational future and preserving our common home, namely the biosphere of planet Earth.

The author of the EcoSpace program, engineer Anatoli Unitsky, offers well-founded and economically profitable engineering and technical solutions designed not only to save the biosphere and humanity from degradation, extinction and death but also to ensure rapid economic growth and industrial progress of the Earth's civilization, which may be the only intelligent one in our vast Universe. We clearly cannot abandon the technological path of development, otherwise, we will turn into a purely biological civilization that of an anthill, a swarm of bees or a flock of dolphins having neither engineering technologies nor other disciplines generated by them, such as economics, science, art, culture, philosophy and other social manifestations of the human population once again stipulated by the technological (read industrial) vector of human development.

The organizational plan for the EcoSpace program implementation involves three stages.

1. Preparatory stage.
Implementation period: 20–25 years (from 2025 to 2050).
Goals and objectives: conducting the entire complex of research, development and technological work (R&D), basic construction of the ELC (including an equatorial takeoff and landing overpass), production of the cargo and passenger GPV, organizational preparation and logistics support of the GPV's geocosmic flights.

2. Basic space industrialization.
Implementation period: 10–15 years (from 2050 to 2065).
Goals and objectives: creation and rapid capacity expansion of the basic space industrial branches, which will allow the competitive displacement and smooth, industry by industry, reconstruction of the existing environmentally dirty part of the Earth's technosphere.
In parallel, it is planned to carry out the installation of the transport and infrastructure component of the ISN "Orbit" along with the construction of the first residential and industrial orbital clusters using materials of terrestrial origin mainly as well as the Earth's industrialized technologies.
Further, mass industrial development of equatorial orbits using space materials and technologies is planned.

3. Large-scale space industrialization.
Indefinite, starting from 2065.
Goals and objectives: expanding the range of high-quality consumer and industrial cosmic goods and services, setting up a competitive geocosmic market.

It is necessary that the general world community as well as political, scientific and business elites deeply realize the inevitability of the cosmic vector of industrial development which should be applied to our entire technocratic civilization, not just a single country or group of countries. Only then it will become possible to establish an international consortium with sufficient participation of the states belonging to the planet's equatorial belt and as many participating countries with high economic, scientific and technological potential as possible. A new cosmoindustrial technological order with a new economic paradigm of inexhaustible space resources and opportunities, based on the unification of universal human efforts to create a progressive geocosmic civilization model, will lead to a new united sociopolitical structure of the world.

Earth – for Life.
Space – for Industry.

Introduction

We, the EcoSpace scientific school and engineer Anatoli Unitsky, assert the undeniable: the current generation has not inherited our planet from our ancestors, but rather borrowed it from our descendants. This debt must be repaid; otherwise, we risk depriving ourselves of a future – human civilization will simply cease to exist.

We are not waiting for change; we are creating the EcoSpace right now. The implementation of our technologies and each of their components accelerates the achievement of our goals and strengthens confidence in our success. We have already constructed the first string rail roads, inhabited the first ecohouses and harvested ecologically clean crops. We are resolutely moving toward our goal – overcoming demographic, food, transport, energy, infrastructure, ecological and other critical challenges for humanity's survival. By progressing in this direction, we are opening boundless horizons for our entire terrestrial human civilization.

Today, as we stand on the brink of a civilizational catastrophe – with wars raging in Europe, the Middle East, Africa, and famine looming – nations are ramping up arms production, engaging in a struggle for global dominance. The threats of nuclear weapon use from the "global elites" are becoming increasingly frequent and severe. In this context, as World War III is closer than ever, and ecological disasters strike humanity across all continents like a plague, we, the EcoSpace scientific school and engineer Anatoli Unitsky, hereby proclaim the fundamental principles of the EcoSpace program.

1. The current pace and direction of development, along with modern industrial technologies, have led human engineering civilization into a state of systemic socioecological crisis. This fact is widely recognized.

2. The systemic crisis of civilization is linked to its technogenic nature and the relentless pursuit of increasing production and consumption volumes, despite the limited spatial, energy and raw material resources of Earth. It is also rooted in the inherent antagonism between the anthropogenic technosphere and the naturally occurring biosphere.

3. An attempt to resolve the crisis through measures aimed at artificially restraining the pace of industrial growth and reducing the Earth's population does not address the existing problems and contradicts the essence of our technogenic civilization which has been developed over millennia, ultimately leading to its inevitable degradation and collapse.

4. Humanity has a genuine opportunity to overcome the systemic crisis while maintaining a technogenic (engineering) trajectory of its development and rejecting measures aimed at artificially restraining the pace of industrial growth.

5. The antagonism between the technosphere and the biosphere can be fundamentally resolved by spatially separating them – relocating the environmentally harmful aspects of industry beyond the living shell of Earth into the near space.

6. The path to solving global problems lies in the creation and implementation of new engineering technologies across key sectors of the global economy: transport, residential and industrial infrastructure, agriculture and energy.

7. Solving global challenges and overcoming the systemic crisis of civilization requires a transformation of the prevailing socioeconomic model and a shift from the dominance of consumption values to the dominance of creation values.

8. The role of national states and large transnational capital in the global economy should be limited to avoid conflicts and wars over resources and dominance. The objective of states should be to enhance the capacity for the existence of national societies and civilization as a whole without state involvement, much like the primary task of parents is to teach their children to live independently.

9. The foundation of the global socioeconomic transformation essential for solving the problems of survival and development of civilization is a new model of human settlement and lifestyle that ensures the maximum possible autonomy of each individual home and residential community while maintaining harmonious and effective connection with other similar autonomous social units, rationally distributed across the Earth's terrestrial and aquatic surface.

10. Ensuring access to unlimited cosmic resources – spatial, energy, raw materials and technological (such as microgravity and deep vacuum) – will open boundless opportunities for humanity's further civilizational development while maintaining its identity as a fully realized geocosmic engineering civilization.

11. Nowhere in the vast Universe can there be more suitable conditions for life for earthlings than on our beautiful Blue Planet. Therefore, humanity should remain living in its native home – on Earth that birthed it, specifically, in its delicate envelope – the planet's biosphere, in its primordial state as it was before the emergence of the earthly industry which stands in opposition to all living things.

12. All spheres of human activity located in its cradle – on planet Earth – such as agriculture, transport, energy, residential and industrial infrastructure, should be organized with the logic of minimizing negative impacts on the surrounding biosphere environment. The harmful aspects of the industry should be relocated to near space. The foundational civilizational formula should be: "Earth – for Life. Space – for Industry."

The EcoSpace program is designed to address a number of important tasks.

1. The implementation and scaling of transport and infrastructure complexes of Unitsky String Transport (uST) across all continents and countries, characterized as the safest, most energy-efficient and environmentally friendly, with the lowest resource intensity (including mineral, energy and land resources) and the lowest transportation costs among all known transport and communication technologies.

2. The widespread adoption of waste-free and environmentally friendly technologies in relict solar bioenergy, which rely on the use of fossil fuels such as brown coal, oil shale, peat, dead organic matter and other, all of which have absorbed the mineral composition of relict soils and the energy of the ancient Sun.

3. The widespread implementation of technologies for the production and use of organic fertilizers in agriculture, which contain a high concentration of associations of thousands of species of agronomically valuable aerobic and anaerobic microorganisms, fondly collected from all continents and stored in the world Bank of soils (established on the territory of Unitsky's Farm Enterprise, Maryina Gorka, Belarus).

4. The transformation of human settlement patterns, initially at the level of individual development projects, and subsequently on the scale of states and the planet as a whole. This involves a shift towards linear pedestrian cities with elevated uST transport systems – featuring the second-level infrastructure – as the primary form of organizing residential areas and facilitating labor and cultural migration.

5. The implementation of Anatoli Unitsky's General Planetary Vehicle (GPV) project, including the creation of all necessary infrastructure for the full GPV operation.

6. The establishment of a space industry for the extraction of non-terrestrial raw materials, the obtaining of extraterrestrial energy and the production of goods to meet the needs of earthlings, which by that time would be about 10 bln people.

We are doers, not dreamers. An increasing number of individuals worldwide are supporting us. We see the problems, we know the solutions, and we act.

Global Challenges: Anthropogenic Oppression of Biosphere and Lack of Terrestrial Resources

Since the second half of the last century, global problems associated with anthropogenic oppression of the biosphere and depletion of natural resources have clearly been felt on Earth. In case of maintaining the current growth and development rates of the technosphere created by our technocratic civilization inside its biosphere home, it is predicted that just in two generations the pollution and destruction of the biosphere as well as depletion of certain types of resources will reach such a level, that our planet may become unsuitable for the life of terrestrial humanity.

Degradation of natural ecosystems is primarily associated with the depletion and destruction of living fertile soils, which are considered the immune system and the basis of the Earth's biosphere health. It is the soil that determines the correct course of natural biogenic processes, being the initial and final element of the enclosed food chains of all plant and animal organisms, in particular protozoa, in which human is also included.

One of the first factors of land depletion and destruction was the rural way of life. As a result, the fertile soil layer was repeatedly, over the centuries, cultivated with unilateral removal of irreplaceable micro- and ultramicroelement nutrients (almost the entire periodic table) along with the harvest. This accelerated the degradation of soils, their water and wind erosion, which cannot be compensated by natural restoration processes.

Further development of intensive farming technologies using chemical fertilizers and pesticides has led to direct contamination of lands with life-threatening chemicals and compounds. Additional pollution was caused by the harmful emissions of hydrocarbon combustion products into the atmosphere (mainly by automobile and aviation transport and thermal power plants), incomplete processing of nuclear waste and rocks (including during stripping operations),

as well as carcinogenic dust released as a result of the wear of automobile tires and asphalt.

More than 50 % of the world's population lives in cities today. The habitual urban lifestyle of modern humans not only destroys fertile lands within the boundaries of megacities but also, together with the harvest, irrevocably takes a proportional (i.e., over 50 % of all food products) part of humus and useful nutrients (more than 80 chemical elements of the periodic table in the form of thousands of complex organic compounds) to the cities from the normal biogenic agricultural turnover. In turn, agricultural products, after being used by the urban population as food, do not return to cultivated lands, since all the biogenic results of their processing settle in urban dumps and sewage drains.

Not so long ago additional and an even more dangerous aspect of environmental pollution emerged, namely the practice of technogenic substitution of biological processes. This refers to a wide range of transgenic organisms, food and medicines developed on the basis of nano-, bio-, genetic and information technologies. Their use has reached significant proportions and has strongly entered human routine, becoming an integral part of biological life. This irreversibly changes the course of development of the entire biosphere and undermines its ability to self-regulating, which has been created and finely polished for billions of evolutionary years since the birth of life on our planet.

Another consequence of anthropogenic pollution of the atmospheric biosphere part is the intensive destruction of the ozone layer, including that by rocket launches and stratospheric aviation.

The rapid expansion of the technosphere leads not only to pollution of soils, atmosphere and water resources but also to their exhaustion: today the lack of fertile soils, clean air and drinking water is considered the acutest problem in many parts of the world already. According to experts, the reserves of oil, gas, copper ores and other minerals will be completely used up over the next 50–100 years. Despite such disappointing forecasts, the field of extraction and processing notes a forced increase in the costs of energy consumption, transport and cleaning measures due to a growing share of extracted minerals being obtained from poor and hard-to-reach deposits.

The riches and achievements of modern civilization, of which we are so proud, are illusory. A huge part of the planet's inhabitants suffers from poverty and hunger, lack of education and access to healthcare, or is simply on the verge of survival. One of the main reasons for such social inequality is the unfair structure of the modern world, in which economically developed states predatorily exploit the human, natural and mineral resources of economically underdeveloped countries, forgetting that Earth (or rather, its biosphere) is our only and common space home for all billions of species of living beings (not just humans), and we do not have another such home and will not have it in the foreseeable future in the vast Universe.

Prerequisites for New Cosmic Vector of Industrialization

According to modern ideas, life originated on Earth about 4 bln years ago. Developing and adapting to the conditions existing on the planet, living organisms began to transform the environment. This is how the biosphere, with its billions of species of living organisms, and the planet, transformed by them over billions of years, came to be – a biosphere complex of ecosystems, where all elements (living and mineral ones – soil, water and air) are perfectly balanced with each other.

Then along came humans who, thanks to their intelligence, began to strengthen the power of their muscles, senses and intellect, started to create equipment and master technological processes. It was then that humanity chose the industrial path of development and experienced the conflict between the human-made technosphere and the natural biosphere. Our ancestors fully felt the destructive impact of smog and technological waste when cooking on a fire, tanning skins and using other primitive industrial technologies in their cave house: at the age of 20, they were dying of lung cancer. People were forced to make a decision that turned out to be the only right and possible one – they survived, having guessed to take their simplest production facilities into the environment, i.e., the biosphere. Since then, the Earth's biosphere has become a new big home for the emerging technogenic civilization and global industrial technologies.

The modern industrial power of humankind is a natural result of the development of our civilization for thousands of years. Formerly cave *Homo sapiens*, who existed in local communities with primitive tools, turned into modern urban *Homo technocraticus*, the creator of a planetary civilization with developed industry. Naturally, the large biospheric home of the planet Earth turned out to be too small for the technosphere that has grown in size and power. The issue of anthropogenic threat to civilization has once again appeared on the agenda since technogenic smog now engulfs the big home as well.

Plants, factories, power plants, machine tools, cars, roads, power lines and other engineering structures and equipment in the technosphere can be compared to the biosphere's living organisms [1]. They also exchange energy, information and matter with the environment. At the same time, despite the ecologists' aspirations, it is basically impossible to create closed and absolutely green engineering technological cycles in the technosphere in order to similarly solve all environmental problems on the planet caused by industry.

This conclusion can be illustrated by the following analogy. In the biosphere, biological and technological chains have closed upon themselves countless species of microorganisms – one can see them as peculiar microscopic machines, workshops and factories that utilize the waste products of all living organisms without exception and turn them into biohumus, i.e., nutrition for plants and hence into raw materials for other living organisms. These so-called factories are present in any part of the biosphere reaching up to a trillion specimens in each kilogram of biospheric substance – thousands, millions and billions in air, water and soil, respectively. It is impossible to create something similar in the technosphere, namely millions of microscopic factories processing technogenic wastes of some production units into raw materials for other production units in any cubic centimeter of biospheric space basically accommodating modern industry. Not just factories but super-complex autonomous automated production facilities can reproduce independently and provide themselves with energy and raw materials without building roads, power plants, or power transmission lines.

Even the global Earth–Biosphere system cannot be considered enclosed, since solar energy, cosmic radiation, space dust and meteoritic matter keep flowing into it, while outer space receives technogenic light at night and radio waves around the clock. Hence, the technosphere, being an open system just like the biosphere, also inevitably transforms the environment, i.e., the planet Earth and its nature. If we ask ourselves how, the answer will be this: obviously, by destroying the biosphere, since dead technogenic technologies are antagonists of the biological ones, in other words, the metabolism of living organisms.

Here are some important facts to be emphasized. The entire biosphere of Earth is essentially a billion-year-old cumulative waste of all billions, if not trillions, of species of living organisms that have existed in the past and exist today. Ozone is the result of chemical reactions of oxygen conversion which in turn continuously enters the upper layers of the Earth's atmosphere in the form of waste from photosynthetic activity of plants and some types of bacteria. Humus, whose content in the soil determines its fertility, was formed by processing in the digestive system of an earthworm (night crawler) and due to the activity of thousands of species of agronomically valuable aerobic and anaerobic soil microorganisms. Therefore, healthy fertile soil, such as chernozem, contains up to a trillion microorganisms per kilogram and functions like the immune system of the entire terrestrial biosphere. This is where the food chain for most living organisms on the planet begins, and this is where all living things end their lives.

The living fertile humus of the Earth's soils is not only the main biosphere resource but also the key component of the global immune system: it feeds, waters and cures the biosphere and, accordingly, humans, including through healthy food grown on this soil. The health of living fertile soils being almost universally destroyed by plowing, chemical fertilizers, pesticides and industrial pollution is what the health of flora, fauna and, of course, humanity depends on. In particular, it is the weakened immune system of the biosphere, and hence of humans, that causes the emergence and spread of epidemics and pandemics [2].

The global aggravation of environmental problems is primarily because the fact that the technosphere has come very close to the biosphere through volumes of environmental transformations. For example, the biosphere during photosynthesis currently reproduces about 250 bln tons of dry organic matter per year [3], which in terms of fuel is only an order of magnitude more than the annual energy consumption of all equipment available to the Earth's civilization. And the volume of soil, coal, ore and other mineral raw materials moved and processed by machinery has already exceeded the volume of organic matter produced by the biosphere.

A drastic way out of the developed situation is the same as it was hundreds of thousands of years ago, back in the prehistoric era. In order to ensure the preservation and development of the Earth's biosphere suitable for human civilization, the ecologically dangerous part of the Earth's industry must be taken outside our common big home. We are talking about creating an industry in the cosmos, where there is not only inexhaustible space, energy and resources but also fundamentally new technological conditions, such as weightlessness, deep vacuum, technological purity, etc. At the same time, the multibillion humanity should continue to live, as before, in their biospheric home named Planet Earth.

From a biological point of view, humans themselves do not pose any danger to the planetary ecology. They are one of the species of living beings with a total biomass of about 500 mln tons, and their mass share in the Earth's biosphere is minuscule – less than 0.02 %. For example, the total mass of termites and ants on the planet is significantly higher. In addition, they emit CO_2 and methane in the process of life activity: during respiration and digestion, and in a much larger relative volume than humans, because their metabolism is more active due to their small size.

The human body was formed as a result of evolution under terrestrial conditions and is perfectly suited only to them, such as the Earth's gravity, the Earth's magnetic and electric field, the Earth's air saturated with phytoncides from blooming plants, the Earth's spring water containing dozens of microelements important to earthlings, food grown on the Earth's living fertile soil, and so much more earthly things we have no clue about, but won't be able to exist without not only today but also in the foreseeable future.

It is pointless to try to defeat nature, on which we are so dependent, in its own home, thus it is necessary to take out dead engineering technologies outside the planet. The current technogenic Earth's civilization requires a reboot to the cosmic vector of industrial development, namely:

- Earth should remain a place for the biosphere, humanity and eco-oriented technologies necessary for the Earth's technogenic civilization;
- outer space should be used for all environmentally harmful, energy- and resource-intensive industrial technologies.

The first step towards the implementation of this program should be the creation of an efficient geocosmic transport and infrastructure system on the Earth–Space–Earth route.

Mechanism of Competitive Elimination of Anthropogenic Oppression of the Biosphere

Due to the inexhaustibility of resources and the uniqueness of the space technological environment, the space industry and its products have absolute competitive superiority in cost and quality over the current Earth's technosphere. However, this advantage will manifest itself only if there is an efficient geocosmic transport system that provides a level of transport expenses no more than those borne by industries and enterprises of the modern planet's technosphere. Such a solution is the GPV by engineer Unitsky [1], which is distinguished by unique indicators of energy efficiency, passenger and cargo capacity, technical and economic advantages of electric traction, as well as environmental cleanliness.

The II International Scientific and Technical Conference "Non-Rocket Space Industrialization: Problems, Ideas, Projects" [4] put forward a hypothesis for the consistent competitive removal of the current Earth's technosphere and the harmful anthropogenic oppression of the biosphere associated with it. The created space industry should logically and efficiently support the global transition of Earth's technogenic civilization toward industrialization of space.

According to the laws of the competitive market, if one of its participants manages to introduce an innovative, more efficient technology, then the rest of the participants in this market, to withstand competition, also need to master this or another, no less efficient technology [5]. As soon as one or another product of the current Earth's technosphere is displaced from the market by products of the space industry that are superior in cost and quality, then industries and enterprises that have not withstood such competition will be forced to stop their production, and either declare bankruptcy or integrate into a new cosmic vector of industrialization and launch a program of their cosmoindustrial re-equipment.

The cosmic vector of industrialization, which ensures an effective competitive and investment attractiveness of the EcoSpace program and fully meets the goals of relocating the most environmentally harmful industries and enterprises of the Earth's technosphere as soon as possible, assumes that, as for any economy, the capacities of the basic branches of the space industry are should be created first and increased rapidly. We are talking about space solar and hydrogen energy, space transport on hydrogen rocket fuel, extraction and processing of mineral raw materials of asteroids and other space bodies, production of structural materials and composites, industrial elements, assemblies and equipment from these raw materials, construction of industrial and residential biospheric clusters on the equatorial orbits of Earth, etc.

It is the basic branches of the space industry that should be the first to enter into a competitive battle in the markets of energy, raw materials and transport services in order to get the upper hand over their terrestrial industrial counterparts being the main sources of anthropogenic

oppression of the biosphere. In addition, the use of space resources at competitive rates will ensure market superiority for all other branches of the space industry to be formed at subsequent stages.

Inexhaustible Resources of Space as the Basis of Cost Competitiveness

As noted above, the cost and quality competitive advantages of the space industry can be explained by the easily accessible and inexhaustible nature of space resources as well as a number of physical specific features of the cosmic technological environment.

Thus, the high economic efficiency and competitive cost of solar electricity generated in space is determined by the high specific power of the solar flux available around the clock in space – 1.37 kW/m^2, while on the Earth's surface the solar flux power is approximately 0.1 kW/m^2, since more than 50 % of solar energy is reflected and delayed by the atmosphere, and the rest of it is inaccessible at night, with cloudy sky and at dust storms, fog, rain, snow, etc. [6]. At the same time, space solar power plants (SSPP) do not assume expenses on fuel (extraction, transportation and waste disposal), reaching 50–70 % of the net cost of electricity, compared, for example, with thermal and nuclear power plants.

The absence of fuel and its combustion products will exclude the expenses for cleaning and disposal of harmful emissions as well as dumping of radioactive waste and life-expired contaminated equipment. The simplicity of the technology and the low specific material consumption of space film solar batteries will significantly reduce the specific capital costs and, as a result, proportionally minimize the expenses for depreciation and repair. The possibility of directing an energy-intensive beam from space to Earth directly to the consumer will allow to avoid the expenses for main-line transportation of electricity across Earth, which is especially important for remote and hard-to-reach territories (with strict observance of environmental and other safety of such energy transmission).

At the same time, the main consumer of space solar energy, not necessarily converted into electricity, will be the most energy-intensive orbital industries, such as metallurgical and chemical plants that will be integrated into power plants, which, for example, will exclude the need for high-capacity power transmission lines. In addition, weightlessness will significantly reduce the material consumption and cost of creating orbital workshops and factories with weightless structures and equipment that do not bear gravitational loads, as on Earth.

The high efficiency and competitive price of asteroid minerals extracted in space are determined, among other things, by a significant level of concentration of a useful mineral in them, up to the pure state, which means a multiple reduction in the costs of extraction, transportation and enrichment of such ore raw materials. In addition, inexpensive hydrogen-oxygen rocket fuel produced in space from water using cheap space electricity will be used to deliver industrial expeditions to the extraction site. The inexpensive electric energy received here, in space, will be used to power the mining equipment. Moreover, the resource-producing industries won't require funds for cleaning or disposal of harmful emissions, return of waste rock to the quarry and its reclamation, while the mining equipment, due to weightlessness, will also be characterized by low specific material consumption and, accordingly, lower capital and operating costs and depreciation charges.

The consumption of space energy (including electricity), raw and other materials together with the provision of geocosmic and cosmic transport services at rates that are significantly lower than those on Earth synergistically enhance the cost-competitive advantage not only for all basic industries but also for the space industry as a whole. Thus, taking into account the strategic importance of the basic industries and the need to pursue a certain tariff policy in space, it is extremely important that management control is established over these basic space industries by the international operator of the EcoSpace program.

One of the key requirements of a dead cosmic environment that is aggressive to humans is automation and robotization of production processes. Given the current development of these technologies, we expect a substantial reduction in operating costs. The absence of personnel and the human factor, while excluding any nature protection and environmental restrictions in a qualitatively new technological environment, such as weightlessness and vacuum, will significantly expand technological schemes and processes, including those through the use of more efficient substances that would be toxic and hazardous for Live Nature. In addition to the direct reduction of payroll costs, the costs of ensuring work safety conditions and supporting social infrastructure for employees and their families will also be minimized.

An example of a truly cosmic technology will be 3D printing. It will allow to fully automate and robotize the production of almost any product, obtain unique composites from materials of different densities, create structures of the required spatial shape with precise dimensions and surface finishing quality, reduce the number of technological process stages of raw materials to one operation, quickly change and expand the product line due to remote readjustment of production programs without the imperative manufacturing of new rigging and promptly make any adjustments to the technological process. The 3D printing technology in weightlessness and vacuum provides an opportunity to unify the form-factors of raw materials used in space, limiting them to technological fluid, plastic, wire, or powder, which will significantly reduce the range of raw materials and optimize cosmic logistics. 3D printing will almost completely exclude technological waste, and if any appears, the costs of its disposal under space conditions will be minimal.

The non-cosmic factors of the cost-competitive advantage of the space industry can be associated with the constant tightening of environmental requirements on the planet, which will lead to additional expenses for enterprises of the current Earth's technosphere. Environmental regulations on Earth will not affect the space industry in any way. Given the global environmental goals and objectives of the EcoSpace program, it is also quite expected that its participants will receive support in the form of various international tax and trade preferences.

Conditions of Cosmic Environment as the Basis of Quality Competitiveness

In addition to cost advantages, the branches of the space industry will have qualitative and competitive advantages determined by the specific conditions of the cosmic environment, such as:

- absence of gravity (weightlessness);
- deep vacuum;
- purity of the technological environment (absence of gases, dust, microorganisms and other contaminants);
- cryogenic and high temperatures;
- other conditions the recreation of which on Earth is limited and extremely costly or impossible at all.

The advantages of outer space as a place for the deployment of the industrial technosphere are primarily associated with the specifics of the environment, favorably differing from terrestrial one.

On Earth, most solid materials undergo a softening or melting stage during their creation or processing. When there's gravity, plastic or liquid material is being held, and its volume and surface are being formed by the walls of the technological mold, which is the cause of many technological flaws. In space, due to the absence of gravity, secondary forces prevail (for example, surface tension), and any molten or liquid material automatically takes the shape of a sphere. It can be changed without contact and with the help of a slight influence of external forces acting in an acoustic, electromagnetic, or electrostatic field.

The main advantage of composite materials is that they are obtained from hardened substances whose physicochemical, mechanical and other properties complement each other, and therefore their quality depends on the structural uniformity. Under the Earth's gravity, there's an inevitable stratification of liquids of different densities leading to heterogeneity of the structure of terrestrial composites. In space, in conditions of microgravity or weightlessness, the obtained composite is isotropic, having no volumetric structural defects. This means that its physical and mechanical features will be significantly better. Among such materials can be, for example, foams made of metals – steel, aluminum and copper alloys, titanium, tungsten and others that cannot be created on Earth.

Other strong points of the space technological environment used for production are technological purity and deep vacuum. The conditions created by modern vacuum chambers while being distinguished by high technological value (the cost of obtaining 1 m^3 of deep vacuum on Earth is comparable to that of 1 ton of oil) are much worse compared to the conditions of outer space. Even having achieved satisfactory purity in a vacuum chamber, it will not be possible to keep it because of the inevitable contamination from the walls of the chamber and equipment. But the purity of materials is one of the most important requirements for the uniformity of a structure as well as for the quality of materials and products made with their use.

An additional productive aspect of space conditions is the possibility of ultrafast cooling to ultralow temperatures. Combined with other features of the cosmic environment it gives the technologists of various industries new ways to control the phase composition of manufactured materials, the degree of their homogeneity as well as the nature and density of crystal lattice defects.

It is easy to create high temperatures in space, for example, using the concentration of solar radiation. That is why

many metallurgical technologies involving the melting of raw materials can become more effective since they will be used in weightlessness with zero contact and in an absolutely clean environment in the best of heat insulators that is vacuum.

The specific features of the cosmic environment open up the widest technological prospects not only for materials science and metallurgy but also for the production of nonmetallic materials, substances and components, including drugs, organic and biologically active substances, which expands prospects for pharmaceuticals and bioengineering. In turn, the discovery of new materials with unique properties is a technological breakthrough in related industries.

Impossibility of Using Launch Vehicles and a Space Elevator for Space Industrialization

Space industrialization means the emergence of a global cargo flow on geocosmic routes, namely between cosmic production facilities and terrestrial humanity serving as a collective consumer of products manufactured in near space.

With an Earth population of about 10 bln people and an annual production (expenditure) of space products at the level of 10 kg per inhabitant of the planet, which is not much at all, the geocosmic transport system should ensure a bilateral cargo flow that is fantastic by modern standards, namely about 100 mln t/year. That is why the key element of future space industrialization will be geocosmic transport on the Earth–Space–Earth route.

The cost of launching a ton of payload into low Earth orbit using a rocket engine running on liquid or solid fuel is currently about 10 mln USD, and the return delivery of each ton of cargo costs twice as much reaching a 20 mln USD. The cost of cargo transportation to higher orbits, including the geostationary one, increases manifold. If we rely on modern rocket and cosmic transport, the annual budget for the implementation of the immense near space industrialization program will significantly exceed 100 tln USD/year which is an unjustified and simply insane amount, way surpassing the current global GDP figure.

We should separately mention the harm that rockets cause to the environment, since the rocket vector of space industrialization, including the exploration of the Moon and Mars, is currently considered of the highest priority.

The destruction of the ozone layer and the formation of ozone holes coincide in time with the beginning of spacecraft flights. According to environmentalists, the launches of space launch vehicles and stratospheric aircraft along with the use of freons have depleted the ozone layer by 8–9 % in less than 70 years [7].

If we conduct an honest assessment of the damage caused by the destruction of the planet's ozone layer by calculating the expenses for its restoration not by natural (which are supposedly "free") but by technogenic methods, then, obtaining a ton of ozone will cost more than 1,000 USD[1]. Accordingly, in order to restore more than 10 mln tons of ozone after the launch of each heavy launch vehicle, the electric energy alone must be spent in the amount of about 10 bln USD. If each heavy rocket delivers at least 100 tons of cargo into orbit, which is still unattainable, then each ton of payload will cost us at least 100 mln USD in terms of environmental damage. Consequently, environmental tax on the development of near-Earth space using launch vehicles should be at least the specified 100 mln USD of environmental damage for each ton of cargo delivered into orbit. And no prospective cost-cutting of rocket launches will be able to reduce the price of putting a ton of cargo into orbit below this mark. Moreover, the sensitivity of the biosphere to environmental damage with each new launch of launch vehicles will be higher and higher.

Throughout the entire history of rocket cosmonautics, no more than 300–400 tons of cargo were put into orbit on average annually. The same transportation work – moving up to 400 tons of cargo per year over a distance of 300 km – can be performed on the planet by one horse harnessed to a single cart. However, just as one cart will not be able to service the transportation needs of almost 8 bln people today, so in the future, the entire global rocket sector, in transport terms equivalent to that very single cart, will not be able to meet the requirements of the space industry, tied to the needs of 10 bln of earthlings. And here we don't even take the financial component into account, as the delivery of a ton of cargo into orbit by launch vehicles now costs on average 10 mln USD, and the total expenses for space exploration over 60 years of the cosmic era have already exceeded 2 tln USD.

[1] The main factor contributing to the cost of ozone production is the consumption of electricity. The best industrial ozonators consume about 10 kW·h of energy to produce 1 kg of ozone [7]. With an average global cost of electricity at about 0.1 USD/kW·h, the cost of electricity needed to produce 1 ton of ozone will be approximately 1,000 USD. In fact, these investments will be much higher, taking into account the cost of equipment and overhead expenses.

The technology of a space elevator on a stretched cable, often mentioned in the press, is not an alternative to rockets. It was proposed back in 1959 and scientifically worked out in 1975 by the Soviet engineer Yu. Artsutanov. Firstly, at present, humanity still doesn't know how to produce a material of sufficiently high strength and low density that could be outstretched from the Earth's surface beyond the geostationary orbit covering a distance of almost 100,000 km. Secondly, the space elevator construction should be carried out from top to bottom – from a geosynchronous orbit towards the Earth's surface, and in the opposite direction as well (to balance the elevator structure), therefore, existing rocket and space technologies, even for thousands of years, will not cope with the task of launching millions of tons of structures into such a high orbit.

And that's not all the points where the space elevator technology is inconsistent for near space industrialization. The performance of such a structure is thousands of times less than is required (up to 10,000 t/year) with a construction cost of at least 10 tln USD, that's why such a geocosmic transport system will be even more unprofitable than a rocket one. Moreover, the movement of an electric elevator cabin up along a cable to the geosynchronous orbit (at an altitude of 35,786 km above sea level), the speed of which cannot exceed 150–200 km/h due to the unfavorable dynamics of such an ultralong flexible thread (because of the Coriolis forces), will take more than a week, i.e., the journey into space will be longer than, for example, today's trip on the Trans-Siberian railway from Moscow to Vladivostok.

General Planetary Transport System by Engineer Anatoli Unitsky

It is difficult to predict how technology, including space technology, will evolve in the future. The only thing we can say with certainty is that whatever form this technology takes, it will still adhere to the fundamental laws of physics that govern our world. These natural laws, repeatedly confirmed through practical application, will remain valid for all time. In the field of mechanics, this includes the four conservation laws, to which all other specific conservation laws can be reduced: energy, momentum, angular momentum and the motion of the system's center of mass. All modern modes of transport, whether carts, bicycles, cars, trains, ships, airplanes, helicopters, or rockets, are designed according to these laws. Cosmic transport will be no exception [8–11].

In addition to fundamental laws of physics, the geocosmic transport system must meet several conditions and requirements:

- it must be designed not as a stationary structure but as an aircraft with ultra-large payload capacity – at least 1 mln tons;
- it should rely solely on the internal forces of the system, minimizing any interaction with the environment and eliminating the need for linear support on the Earth's surface;
- its efficiency factor should approach 100 %, with a productivity rate of millions of tons per year (and potentially billions in the future);
- when returning to Earth, it should recuperate the potential and kinetic energy of space cargo and its own structure with near-perfect efficiency factor (otherwise, excessive heat generation would destroy the system);
- it must consume electrical energy, and the power requirements per ton of cargo should be minimal – around 100 kW – similar to that a car shows (for comparison, the specific power of a launch vehicle is 10,000 times higher, at 1 mln kW/t);
- acceleration and deceleration during geocosmic transportation must be comfortable for passengers and suitable for cargo (not exceeding 1 m/s^2), and the time to reach orbit and accelerate to the first cosmic velocity should be measured in hours, not days.

From a physics standpoint, the most environmentally friendly geocosmic aircraft that uses only its internal forces to reach space has a single design option: a self-supporting structure encircling the planet along the equatorial plane, with its center of mass aligned with the center of the planet.

Only one engineering solution satisfies all the above conditions and requirements – the GPV, developed by engineer Anatoli Unitsky. The GPV is a toroidal structure with a cross section of several meters, encircling the planet at the equator, with ribbon flywheels located in vacuum channels at its core. These flywheels, accelerated to cosmic velocities (around 10 km/s) by linear electric motors, generate the necessary lifting force through centrifugal forces. By shifting thrust from one flywheel to another, the structure rotates around the planet until it achieves the first cosmic velocity in a circular equatorial orbit. At every 100 km above Earth's surface, the diameter of the GPV ring symmetrically increases by 1.57 % in all directions, relative to the center. However, the GPV's center of mass remains unchanged, always coinciding with the planet's center of mass.

The GPV project was developed about 50 years ago and during this time has been repeatedly investigated and verified by calculation methods, which are described in detail in the author's popular scientific publications[2] and in his monographs[3].

The GPV is the only technological solution in which a transportation system – more precisely, a self-supporting spacecraft – can launch cargo into various circular equatorial orbits without the use of jet engines. It operates solely using the internal forces of the system, without any energetic, mechanical, chemical or other interactions with the environment, including the atmosphere and the ozone layer. As such, the GPV is the ultimate environmentally friendly solution for geocosmic logistics on any planet, including Earth.

In a single flight, the GPV can transport approximately 10 mln tons of cargo and 10 mln passengers into orbit, supporting the creation and operation of the near-Earth space industry.

The GPV will be capable of launching into space up to 100 times per year. Furthermore, the cost of delivering each ton of payload to orbit will be thousands of times lower than that of modern launch vehicles, amounting to less than 1,000 USD/t. This means the cost of a passenger ticket to orbit could be as low as 100 USD, with travel comfort exceeding that of a modern train.

Feasibility Study of Large-Scale Geocosmic Transportation

The cost of geocosmic transportation by the GPV consists of three main components:

1) electrical energy costs;

2) personnel salaries (including taxes and deductions);

3) depreciation costs for the GPV and the equatorial uST transport and infrastructure complex, including the takeoff and landing overpass servicing it.

The total energy reserve required to lift a 40-million-ton GPV (approximately 1 t/lin m) into near space, including a payload of about 10 mln tons (250 kg/m) delivered into orbit, and return it to Earth (without the payload), is approximately 4.2×10^{11} kW·h.

To supply the GPV with start-up electrical energy, it is advisable to have dedicated power plants. This would allow energy distribution within the geocosmic system at a cost of approximately 0.05 USD/kW·h. Additionally, extra energy can be sourced from the electrical grids of countries along the equatorial belt, through which the GPV launch overpass will pass. It is most cost-effective to draw this energy at night, as nighttime rates are 2 to 2.5 times lower than daytime tariffs.

The approximate cost of the total energy E_0 required for the first launch of the GPV will be as follows:

420 bln kW·h × 0.05 USD/kW·h = 21 bln USD,

and the unit cost for a total payload mass of 10 mln tons will be 2,100 USD/t. In this case, once the flywheels are accelerated, they will be able to rotate inside the vacuum channels for years, as the magnetic cushion on permanent magnets and the vacuum will not create resistance when moving at cosmic velocities.

This means that the energy inputs for the second and subsequent flights of the GPV will be limited to the portion of total energy proportional to the transported cargo, along with internal energy losses, estimated at no more than 10 %. However, theoretically, these losses could be reduced to 5 % or even as low as 1–2 %. When the GPV ascends, it will transfer energy to the Earth cargo, and during descent, similar to the falling water in a hydroelectric plant, the cargo from space will transfer its potential and kinetic energy back to the GPV. Given that, after the establishment of the space industry in equatorial circular orbits, the main cargo flow will be from space to Earth, the GPV will begin generating electrical power, functioning as a giant dynamo with a total capacity of about 100 mln kW.

This implies that the primary specific energy component of the production cost of lifting a ton of cargo will be:

E_1 = 2,100 USD/t × (25 % of GPV gross weight +
+ 10 % of GPV efficiency factor losses) = 735 USD/t.

[2] Unitsky, A. Peresadochnaya, kosmicheskaya, kol'tsevaya [Interchange, Cosmic, Circular] / A. Unitsky // Izobretatel' i ratsionalizator. – 1982. – No. 4; Unitsky, A. V kosmos... na kolese [Into Space... by Wheel] / A. Unitsky // Tekhnika – molodozhi. – 1982. – No. 6; Unitsky, A. Spasatel'nyy krug planety [Planet's Life Ring] / A. Unitsky // Vek XX i mir. – 1987. – No. 5; etc.

[3] Unitsky, A.E. Strunnyye transportnyye sistemy: na Zemle i v Kosmose [String Transport Systems: On Earth and in Space] / A.E. Unitsky. – Gomel: Infotribo, 1995. – 337 p.: ill.; Unitsky, A.E. Strunnyye transportnyye sistemy: na Zemle i v Kosmose [String Transport Systems: On Earth and in Space] / A.E. Unitsky. – Minsk: Bielaruskaja navuka, 2017. – 342 p.: ill.; Unitsky, A.E. Strunnyye transportnyye sistemy: na Zemle i v Kosmose [String Transport Systems: On Earth and in Space] / A.E. Unitsky. – Silakrogs: PNB Print, 2019. – 576 p.; Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.; etc.

The main specific energy component of the cost of launching a ton of cargo will be negative (i.e., the GPV will become a source rather than a consumer of energy):

E_2 = 2,100 USD/t × (–25 % of GPV gross weight + + 10 % of GPV efficiency factor losses) = –315 USD/t,

since the descent cargo does not expend but transfers its cosmic potential and kinetic energy to the GPV.

The main specific energy component of the cost of a round-trip full-load flight:

E_3 = 2,100 USD/t × 10 % of GPV efficiency factor losses / two cargo transportations = 105 USD/t.

The GPV and the equatorial takeoff and landing complex (ETLC) will operate automatically. Nevertheless, their operation will require the creation of at least 200,000 jobs[4] with an average salary with taxes at the level of 50,000 USD/year and annual total salary costs of 10 bln USD. Then the unit cost component (UCC) in terms of salaries for 50 flights per year with a full load of 10 mln tons of cargo along the Earth–Space route will be approximately:

UCC = 10 bln USD/year / 50 flights/year / 10 mln t/flight = = 20 USD/t.

In terms of complexity of equipment and composition of components, the GPV is generally equivalent to an electric car (for example, the Tesla brand costs 50,000–75,000 USD and weighs 2–3 tons), and the cost per ton of its construction does not exceed 25,000 USD. Since the mass of a loaded GPV (without payload) will be about 30 mln tons, the capital costs for its creation (design and construction) will be equal:

30 mln tons × 25,000 USD/t = 750 bln USD.

Once the space industry reaches full capacity and the development of asteroids and the Moon as sources of raw materials begins, the demand for equipment and materials delivered from Earth will significantly decrease. Simultaneously, the reverse flow of cargo from orbit to Earth will greatly surpass the upward flow, as the majority of industrial products for Earth will be sourced from space. The GPV will carry less payload into orbit (the estimated load for an ascending flight will be only 20 %) and will primarily ascend to space to retrieve products manufactured there.

[4] In order to maintain 1 km of the GPV it is necessary to employ about five specialists.

Therefore, under average long-term operating conditions for the GPV (e.g., 50 years of operation with 50 flights per year, a payload capacity of 10 mln tons, 20 % loading on the upward route and 100 % on the downward route), the total volume of cargo transported in both directions over the entire operational period (depreciation) will be approximately 30 bln tons. Consequently, the estimated depreciation costs per ton of cargo, based on capital investments in the GPV, under these assumptions will be:

C_{GPV} = 750 bln USD / 30 bln tons = 25 USD/t.

The length of the equatorial takeoff and landing overpass complex, including uST for ground transportation, will be 40,076 km, with 20 % of its length consisting of land areas and 80 % of maritime areas. Since the GPV is not only designed for going into space but primarily for launching cargo and passengers into orbit, there will be uST 5-in-1 transport and infrastructure communicators along the equator on the planet and along the equatorial orbit in space. They will include ground and orbital complexes of urban (rapid), high-speed, ultrahigh-speed and hypervelocity transport, along with energy and information links and communication lines. Power plants, cargo and passenger logistics hubs, industrial and residential clusters will also be built, united in the Equatorial Linear City (ELC), where about 100 mln people (about 1 % of the Earth's population) will live and work.

The cost of such a complex (including the uST) built on the planet Earth can be estimated at 1,320 bln USD, based on the fact that on average it will be 25 mln USD/km on land areas and 35 mln USD/km on maritime areas. Taking into account the total volume of cargoes transported by the GPV over its full life cycle, the depreciation charges per ton of cargo from capital investments in the transport and communication part of the ground ETLC will be equal to:

C_{ETLC} = 1,320 bln USD / 30 bln tons = 44 USD/t.

Thus, the full depreciation charge is made up of the cost of restoring the GPV and ETLC:

$C_{depr} = C_{GPV} + C_{ETLC}$ = 25 USD/t + 44 USD/t = 69 USD/t.

The analysis of the data in Table 1 leads to the following conclusions: the highest cost of geocosmic transportation in the first year of operation is primarily due to the upward flow of cargo and passengers. This is largely caused by the lack of compensatory income from downstream power generation and the relatively low volume of transported cargo and passengers, which results in a high unit cost of labor. Nevertheless, these figures are still over 1,000 times lower than those projected for launch vehicles, even in the most optimistic scenarios. As the volume of both outbound and return transportation increases, the costs will decrease.

In the tenth year of operation, when the cargo flow from orbit to the planet significantly exceeds the cargo flow from the planet to orbit (500 mln t/year compared to 100 mln t/year, respectively), the unit cost of transportation will be negative (–81 USD/t). This indicates that the GPV geocosmic complex will generate profit not only as a transport system but also as a giant linear kinetic power plant, stretching over 40,000 km and equipped with ribbon flywheels totaling approximately 20 mln tons. These flywheels will be capable of converting excess potential and kinetic energy from space cargo into electrical energy.

The following conclusions can be drawn from the data in the Table 1:

1) the cost of geocosmic transportation decreases as the total annual productivity increases, meaning that as the combined forward and return cargo flow rises. The largest share of unit costs occurs during the transfer of energy to the cargo when it is placed into orbit during the first six years of operation;

Table 1 – Volume and cost of geocosmic transportation by the GPV in the first 20 years of operation (an optimal variant of geocosmic logistics)

Year (from the beginning of the GPV operation)	Annual transportation volume, mln tons		Unit cost components for geocosmic transportation of a ton of cargo, USD/t					Unit cost of transportation, USD/t, (–) – profit
	To orbit	To Earth	Cargo energy	Loss energy	Salary	Depreciation	Other	
1	100	10	430	191	91	69	8	789
2	200	50	315	168	40	69	8	600
3	300	100	263	158	25	69	8	523
4	400	150	239	153	18	69	8	487
5	500	200	225	150	14	69	8	466
6	500	250	175	140	13	69	8	405
7	400	300	75	120	14	69	8	286
8	300	350	–40	113	15	69	8	165
9	200	400	–175	140	17	69	8	59
10	100	500	–350	175	17	69	8	–81
11	100	500	–350	175	17	69	8	–81
12	100	500	–350	175	17	69	8	–81
13	100	500	–350	175	17	69	8	–81
14	100	500	–350	175	17	69	8	–81
15	100	500	–350	175	17	69	8	–81
16	100	500	–350	175	17	69	8	–81
17	100	500	–350	175	17	69	8	–81
18	100	500	–350	175	17	69	8	–81
19	100	500	–350	175	17	69	8	–81
20	100	500	–350	175	17	69	8	–81
Total	4,000	7,310						

2) as the reverse cargo flow increases, it plays an increasingly significant role in reducing geocosmic transportation costs. The GPV is projected to cease consuming energy by the eighth year of operation and will begin functioning in the Earth–Space–Earth cycle as a giant kinetic energy storage power plant;

3) after the seventh year of operation, the dominant factor influencing the unit cost of geocosmic transportation will be the compensation for energy losses. These losses can be mitigated by increasing the overall efficiency factor of the GPV. For example, if efficiency factor is improved from 90 to 95 % (as accepted in these calculations), energy losses will be halved – from 10 to 5 %. Moreover, if efficiency factor reaches 99 %, losses will decrease tenfold;

4) the impact of service personnel salaries on the unit cost of transportation will be minimal (projected at 17 USD/t after the eighth year). For instance, even a fivefold increase in salaries during the tenth year of operation (raising the annual salary fund from 10 bln USD to 50 bln USD) will not significantly affect the cost of geocosmic transportation. In this scenario, the cost will remain negative, resulting in a unit profit of 13 USD/t for the delivery of cargo from Earth to space and back;

5) the depreciation costs of the GPV (69 USD/t) also have a negligible effect on the unit cost of geocosmic transportation. This implies that even if the total cost of creating the geocosmic transportation and infrastructure complex (2.07 tln USD, which includes 0.75 tln USD for the GPV and 1.32 tln USD for the ETLC) is higher – potentially double that amount, exceeding 4 tln USD – the cost of geocosmic transportation will still be negative. In this case, delivering of cargo to space and back to Earth would yield a unit profit of 12 USD/t.

The above analysis demonstrates that the GPV boasts unprecedented technical and economic performance. Even if the cost of travel is zero (i.e., passenger travel and the transportation of 1 ton of cargo along the Earth–Space–Earth route are free), the construction of this geocosmic transport and infrastructure complex will remain profitable. After the ninth year of operation, it is projected to generate a profit exceeding 48 bln USD annually. Moreover, for every 100 USD charged per ton of cargo transportation, an additional annual profit of 60 bln USD will be realized. For instance, if the cost of cargo delivery is set at 1,000 USD/t for consumers of geocosmic logistics (compared to the current 10 mln USD/t for launch vehicles), the operating organization's annual profit could reach 600 bln USD.

Components of Future Cosmic Technogenic Civilization

The GPV is not merely a geocosmic transport system aimed at reducing the costs of geocosmic logistics and technospheric impacts or solving global environmental issues on Earth. The world around us was built by engineers whose boldest ideas, materialized through technology, have served humanity and paved the way for discoveries. These innovations are meant to help us address the global environmental, resource and social challenges of our time and save future generations from impending catastrophe. The string technologies, developed by engineer Anatoli Unitsky, the deployment of the GPV and the relocation of the Earth's technosphere into near space, enabled by the GPV, will serve as tools for creating a new EcoSpace.

EcoSpace represents a more perfect world, defined by the trinity of BioSpace, TechnoSpace and HomoSpace. Together, they form a set of optimal conditions for the sustainable growth and further development of Earth's technogenic civilization in the space direction.

BioSpace is a restored and balanced planetary biospheric ecosystem, open to space, that includes terrestrial humanity. It no longer experiences the anthropogenic pressures of the technosphere and continues to evolve by the laws of Earth's Live Nature. The components of BioSpace include:

- natural and cultural (organic farming) ecosystems on land as well as aquatic ecosystems (lakes, rivers, etc.);
- oceanic, marine and atmospheric ecosystems with the possibility of environmentally friendly management of weather, climate and other planetary systems through natural methods;
- the flora and fauna of terrestrial and aquatic ecosystems (including microflora and microfauna), with biodiversity preserved;
- Earth's humanity, where every individual is healthy and happy.

TechnoSpace refers to newly created industrial components, including:

- Earth-based industry, developed with eco-oriented technologies and limited to only those industries necessary for humans within the Earth's biosphere;
- space industry, encompassing energy-consuming, resource-intensive and ecologically harmful sectors, which, in the cosmic environment, achieve absolute competitive advantages in price and quality over previous terrestrial industry;
- the GPV geocosmic transport and infrastructure complex, which provides environmentally friendly transport and logistical connections between Earth and space components of industrial TechnoSpace, facilitating the movement of cargo, energy, information and passengers on a planetary industrial scale;
- artificial intelligence, which manages all the above components under the multi-level supervision of HomoSpace.

HomoSpace represents an enhanced global sociopolitical system founded on the unification of the international community of biological humans (but not digitized convergent biorobots) around a centralized authority. This center will consolidate the territorial, financial, economic, scientific, human, military and political resources of all nations involved in the EcoSpace program.

This will unlock access to the vast and sustainable resources of space. On the basis of a space-oriented economy, it will create new sociopolitical and economic conditions that enable the fullest realization of sustainable development goals for humanity, including social justice, equality, freedom, harmonious growth as well as the right of every planet dweller to a dignified, long and fulfilling life.

HomoSpace is developed and guided by humans, with artificial intelligence serving as an assistant and advisor, not as a leader. The central value of HomoSpace lies in the humanity of individuals and their spirituality as sociobiological beings, created by the Universe (God) through billions of years of life's evolution on our space home named Planet Earth.

Planet Earth Will Forever Be Home to Humanity

Nowhere in the vast Universe is there, nor can there be even in the distant future, a more suitable environment for humanity than our home planet. However, humans need at least four eco-oriented industries alongside themselves within the biospheric home on Earth:

1) production of natural, organic foods;

2) generation of green electricity, heat (in cold climates) and cooling (in hot climates) without compromising the biosphere's ecology;

3) construction of eco-comfortable housing, production buildings and facilities;

4) functioning of eco-oriented transport, energy and information infrastructure.

None of these or other industries of the Earth's technosphere should have an anthropogenic, oppressive impact on the surrounding terrestrial biosphere. They should be characterized by high efficiency, low energy and resource consumption, and demonstrate high quality indicators. Only eco-oriented technological platforms will provide these conditions.

The **uGreen** technological platform represents organic farming in a new framework, focused on recreating and intensifying natural biospheric processes by directly borrowing and utilizing natural soil ecosystems, including their microflora, microfauna and biogeocenosis. This approach involves a complete rejection of synthetic chemicals (such as fertilizers, plant protection products, etc.), gene modification technologies and other elements of traditional intensive farming. The principle of organic farming based on natural biohumus arises from the fact that evolutionary biosphere ecosystems and the processes within them are so complex that it is impossible to fully study or accurately replicate them using bioengineering methods and nature-like technologies. However, certain processes can be improved and cultivated to enhance soil organic fertility and combat desertification. This eco-oriented approach to organic farming entirely excludes any harmful anthropogenic impact on Earth's biosphere, which has evolved over approximately 4 bln years.

The **uEnergy** technological platform focuses on the generation of green electric and thermal energy through:

- specially equipped thermal power plants that burn brown coal, oil shale, peat and other organic materials in an environmentally friendly manner, to produce fertile living humus from combustion waste;
- renewable energy sources, including solar energy harnessed both on Earth and in space as well as energy from wind and ocean currents;
- hydrogen–oxygen pairs as fuel accumulators, addressing challenges in optimizing the planet's energy systems and supporting cosmic transportation.

The **EcoHouse** technological platform focuses on eco-oriented construction of residential and industrial buildings on Earth, integrating homes with the external natural (biospheric) environment. These structures are designed to incorporate both natural and cultural (organic farming) ecosystems, allowing for the regulation of atmospheric, soil and water parameters by Earth's natural processes. During construction, the soil excavated from beneath the buildings is transferred to roofs and floors, where it is enriched

with living humus. This greening process operates on the principle that every construction project contributes to increasing the area of fertile soil and enhancing its fertility. In cases where the planet's external environment is characterized by ecological pollution or extreme climatic conditions, such as in Antarctica, when there may be a need to utilize underwater or underground spaces, or to address research tasks related to human life support in space, the EcoHouse structure can be transformed into an EcoCosmoHouse on planet Earth (ECH-Earth).

The **ECH-Earth** is a terrestrial structure designed for the autonomous and unlimited long-term residence of a human settlement, accommodating a specified number of inhabitants. Within its enclosed inner space, conditions are maintained to support the development of natural ecosystems. The ECH-Earth replicates the essential properties of Earth's biosphere while also modeling additional technological processes to ensure that human needs for a decent living, such as atmospheric and habitat parameters as well as food resources, are met. This structure serves as an Earth-based biosphere model of engineer Unitsky's space house project, focusing on the creation and organization of internal spaces and all relevant components (biosphere, technologies, interconnections of processes, etc.) within a closed cycle of matter (both living and mineral), energy and information.

The **Unitsky String Technologies (uST)** technological platform involves the construction of transport, infrastructure and energy information networks, known as uNet, along pedestrian linear cities of a cluster type, based on prestressed (string) Unitsky structures. This platform is designed to provide all necessary communication links between objects on Earth, between entities in near space moving along circular equatorial orbits and between terrestrial objects and those positioned in near space.

Equatorial Linear City and EcoHouse: A New Urbanism

The most important terrestrial component of the geocosmic transport and infrastructure complex is the **Equatorial Linear City (ELC)**. Its territory hosts the GPV takeoff and landing overpass, along with all the necessary infrastructure for facilitating flights and servicing global geocosmic cargo and passenger flows. The ELC is harmoniously integrated into the planet's natural environment, both land and water areas, in the form of cluster-type settlements. These settlements, situated in the equatorial zone, are connected by the second level transport systems – routes of **Unitsky String Transport (uST)**.

The ELC represents a special case of the new linear urbanistic concept from the EcoSpace program, known as linear city (uCity). This involves the development of residential, administrative and industrial clusters using the EcoHouse and ECH-Earth eco-oriented technologies, such as:

- **uEnergy**: supplying settlements with green electricity and heat;
- **uGreen**: providing natural (organic) food products;
- **uNet**: forming transport, energy and information communication networks using eco-oriented string technologies.

The main elements of the ELC structure, distributed according to the general functional scheme, include:

- the GPV takeoff and landing overpass with engineering and communication networks;
- complexes for communication, astronavigation and automated control of the GPV and geocosmic industrial technosphere;
- clusters for the production of components for the Earth-based part of the geocosmic technosphere, as well as the assembly, maintenance and repair of GPV units;
- energy clusters that supply power to all parts of the geocosmic complex, including the processes of GPV takeoff and landing;
- sections of the global ground transport and communication network uNet, along with regional and intracity transport networks within the ELC zone;
- logistic geocosmic centers, cargo terminals, passenger stations and railway stations;
- cluster-type residential complexes;
- clusters for scientific, educational, cultural, health, sports and other institutions;
- preserved and eco-developed natural areas.

Like the rest of the terrestrial technosphere essential for humanity within the biospheric home Earth, linear cities are characterized by their lack of oppressive anthropogenic impact on the planet's biosphere. They also offer highly efficient urban management and ensure a high standard of living and working conditions for all residents without exception.

The development of clusters and the linear ELC elements will comply with national legislation and specific infrastructure requirements.

The planning and organization of the ELC residential clusters will follow a model of integrated development, which includes:

- residential areas with sufficient social infrastructure;
- pedestrian streets and community centers;
- elements of the natural-ecological framework, such as parks, squares, boulevards and other public spaces.

The residential development of the ELC consists of self-sufficient, harmoniously designed units, each distinguished by a high-quality living environment. Air, water, soil and the surrounding flora and fauna are free from oppressive or destructive impacts. Over 90 % of the territory is preserved for Live Nature, including green areas on rooftops.

The residential cluster of the linear city is anchored by a dominant structure, the interchange hub, housing stations for uST transport of the second level, integrated with shopping centers, hotels and other sociocultural facilities. Surrounding this hub, within walking distance over an area of 100–200 ha, will be single-story and low-rise residential buildings accommodating 2,000–5,000 or more residents. They will have access to everything essential, including food, water, energy and a full range of modern services, along with spaces for work and recreation. Such an integrated approach will allow each settlement to remain self-sufficient, even during pandemics, temporary isolation or natural disasters.

Industrial clusters in the linear city will be positioned away from residential zones. Movement within these complexes will be primarily on foot or by bicycle, with each settlement designed to be easily crossed in 15–20 min. Transport access between clusters will be provided by various elevated electric unpiloted uST transport: urban (up to 150 km/h), high-speed (up to 360 km/h), ultrahigh-speed (up to 600 km/h) and hypervelocity (over 600 km/h) for cluster, continental and intercontinental travel, including routes across seas and oceans.

Residential apartment buildings will be integrated into single functional complexes, resembling a multi-apartment "horizontal skyscraper" up to 400–500 m or more in length. The roofs will feature glazed greenhouses, while the ends of these buildings will house technical rooms and cargo elevators.

Biotechnologies developed under the guidance of engineer Anatoli Unitsky enable waste-free food production and consumption processes. At the end of the agricultural cycle, instead of producing waste, biohumus is generated and returned to the soil as organic fertilizer, continuing the natural cycle. Each cluster will have its power generation capacities, integrated into the unified energy system [9–11].

Scientific experiments in eco-oriented technologies related to EcoHouse and uEnergy are being successfully implemented at EcoTechnoPark and Aquarelle EcoPark (Maryina Gorka, Belarus). Several types of innovative buildings and structures have already been constructed and are operational there, including some with subtropical greenhouse and indoor garden, designed as autonomous enclosed natural ecosystem.

This principle naturally adapts buildings to various geographical and climatic conditions, including mountainous regions within the equatorial zone. Rows of interconnected houses are placed on organized terraces, conforming to the terrain. The second level transport complexes overcome the limitations of mountainous landscapes, such as elevation differences, while ensuring access to facilities. Engineering corridors are straightened, reducing the length of key utilities and making previously inaccessible areas attractive and habitable.

By the time the ELC is created, along with the construction of the GPV and the geocosmic infrastructure, and the start of practical industrialization of near space, the Earth's population will have reached approximately 10 bln people. Simultaneously, the total length of the network of newly constructed linear cities across the planet will extend to about 10 mln km, covering a notional area of approximately 10 mln km^2, or 1/15 of the Earth's landmass. This is considered "notional" because roads and buildings will not take land away from nature but, on the contrary, will contribute to adding fertile soil to the roofs of structures. As a result, 14/15 of the planet's terrestrial surface can be designated as nature reserves and protected areas by that time.

Restored BioSpace of Earth and "Rehabilitation Therapy"

Elimination of the anthropogenic oppressive impact on the biosphere by taking environmentally harmful industries and enterprises into space to near-Earth orbits, as well as the transformation of the technosphere necessary for humans with the help of eco-oriented technologies is the basis for the restoration of the Earth's BioSpace. However, given that the health of the biosphere – soil fertility, aquatic ecosystems and the atmosphere – has suffered almost irreparable damage, and natural processes are quite slow, rapid recovery will require intensive "rehabilitation therapy," which can be carried out using elements of the EcoSpace program.

In order to restore soil cover, the eco-oriented uGreen technologies have already been created and are being tested within the framework of the EcoSpace program, allowing to produce biohumus based on brown coal, shale, peat and waste from their combustion at specially equipped thermal power plants. Brown coal, oil shale and peat are former plants that lived about 100 mln years ago and took minerals for their life (more than 80 chemical elements) from the relict soil, so all this mineral composition (100 % of combustion products) must be returned to the soil, transforming it into biohumus. Consequently, the waste of such a power plant is living humus, 1.5–2 % of which is enough to significantly increase soil fertility and make even degraded lands (including desert sand) fertile again. With biohumus it is possible to transform the most desolate and lifeless areas of the planet into blooming gardens. For instance, this uGreen technology has already been used for planting a desert area at the uSky Test and Certification Center (Sharjah, UAE). Another example – planted orchards and vineyards at the former tank range (Maryina Gorka, Belarus), which had been soaked in gunpowder and diesel fuel.

The most crucial task in saving the Earth's biosphere is conserving its biodiversity, especially protecting plant species with socioeconomic value for humanity, such as fruit and berry crops, cereals, vegetables, textiles, spices, aromatic plants, medicinal species and more [12]. Since a significant amount of plant raw materials is currently imported from tropical countries, the eco-oriented technological platforms EcoCosmoHouse and uGreen aim to model environments as close as possible to tropical and subtropical zones [8–11]. This approach will allow multiple harvests per year, ensuring a supply of healthy food and providing comfortable living and working conditions for employees in space industry enterprises. It is well known that one method for preserving and restoring rare plant species is through the creation of botanical gardens. The ECH-Earth could become a new and much more effective tool for preserving plant, water, microbiological and other forms of biodiversity on our planet.

The GPV geocosmic transport and infrastructure complex should carry thousands of tons of ballast (water and liquid oxygen) on each flight in the additional loading mode, which will help restore and regulate the total levels of ozone, oxygen and moisture in the upper atmosphere, including their concentration in specific regions of the atmosphere. This, in turn, will allow for weather and climate control on a global and local scale, using natural rather than anthropogenic methods. In particular, ozone makes up only one ten-millionth of the atmospheric mass, yet it absorbs about 3 % of the solar energy that reaches Earth. The capacity of this "thermal blanket" is approximately 6 tln kW [13], which, for comparison, is 3,000 times greater than the capacity of all the power plants on the planet.

Accordingly, by altering the composition of the ozone layer, it is possible to effectively and rapidly influence the following components of the Earth's biosphere:

1) atmosphere (wind speed and direction, precipitation, humidity, temperature, etc.);

2) terrestrial land (restoring forests, improving soil fertility, eliminating soil erosion and human-made deserts, etc.);

3) the World Ocean (mariculture, adjusting the ecological balance, managing sea currents, etc.);

4) weather and climate both regionally and globally;

5) ionosphere, geomagnetic field, etc.

All of this will help maintain the Earth's biosphere in a state of ecological balance. By coordinating light, heat and other agronomic factors, it will be possible to drastically increase the productivity of organic agriculture on the planet. It is crucial that such intervention in the weather "cuisine" is environmentally friendly, as ozone is a natural component of the atmosphere and its ozone layer.

Thus, the reorientation (reboot) of the Earth's industry towards the cosmic vector of civilization's development, using the aforementioned and newly developed eco-oriented technologies, will ensure that the EcoSpace program advances towards its goals and objectives even at the earliest stages of preparation for near-space industrialization.

Industrial Space Necklace "Orbit" and EcoCosmoHouse

The future space industry should be positioned as close as possible to its end users – the billions of people living on Earth – and, therefore, near the planet's surface. This proximity will simplify, speed up and reduce the cost of geocosmic logistics. Since the space industry will comprise a vast number of components (factories, workshops, laboratories, technological platforms, power plants, residential modules, etc.), several industrial equatorial orbits that do not overlap are planned for development. Additionally, provisions for vertical transitions between adjacent orbits should be made, meaning all orbits must be located within the same equatorial plane. Developing these orbits is energetically favorable, as they will harness the planet's rotational speed, which is fastest at the equator (1,674 km/h).

The practical industrialization of near-Earth space will begin with the first launch of the GPV. Initially, the Industrial **Space Necklace "Orbit" (ISN "Orbit")** will be established – a multifunctional transport, infrastructure, industrial and residential orbital complex designed to serve Earth's population. This cluster-type ring will encircle the Earth in the equatorial plane, orbiting at a low altitude of about 400 km. The total length of the ISN "Orbit" will be 42,520 km.

Despite the extensive automation and robotization employed in space, the industry will still need human workers, for whom it is being created. As the Earth's population grows and space-based production expands, the number of jobs in orbit will increase. Additionally, space offers the potential for recreational complexes with unique characteristics, attracting a separate category of orbital inhabitants: tourists and vacationers. To accommodate this, it will be necessary to build **EcoCosmoHouses (ECH)** – a new type of residential settlement where millions of people can live, work, rest and undergo therapy. The ECH, designed for several thousand inhabitants, will replicate gravity and recreate the most favorable aspects of Earth's subtropical biosphere, incorporating all essential natural elements: atmosphere, diverse landscapes, living organisms, soils, biogeocenoses, aquatic ecosystems and more.

The EcoCosmoHouse technological platform will serve as the foundation for constructing these space-based settlements. Each ECH will feature an enclosed ecosystem similar to Earth's, with artificial gravity, fertile soil, flora and fauna (including microflora and microfauna) and an atmosphere regulated for temperature, humidity and other parameters. This ecosystem will support long-term, autonomous, eco-friendly living and activities for both individuals and communities. Thousands of such settlements will be built in equatorial orbits around the planet as well as in deeper regions of near and far space.

The atmosphere inside the space house will be carefully regulated to match Earth's natural conditions in terms of pressure, composition, humidity and temperature. Since humans, as well as animals and plants, absorb moisture from both food and the air, the humidity level must remain optimal throughout the year (between 55–60 %). The air temperature will be maintained within a comfortable range of 21–25 °C. If needed, all atmospheric parameters in the space house can be adjusted according to both daily and seasonal variations.

In space, the concepts of a day and a year take on different meanings, as the ECH completes one orbit around the Earth every 1.5 h, or 16 times a day. This makes artificial lighting necessary, and the lengths of day and year can be modified rather than adhering to the traditional 24-hour day or 365-day year. For optimal plant growth, light intensity should exceed 1,000 lx. The lighting system should be:

- qualitative. Different phases of plant growth require specific light spectra. Bluish light supports the development of green mass; yellow and red hues are important for root system growth and preparation for flowering; greenish light stimulates photosynthesis in plants with denser leaf structures;
- long-lasting. Many plants thrive and bloom only when exposed to daylight for at least 14 h, similar to summer conditions on Earth;
- localized. It is beneficial for each plant to receive light for a specific duration during the flowering. For some plants, this duration may be as short as 8–10 h/day;
- intense. Insufficient lighting can be harmful to plants, especially light-loving species that require up to 100,000 lx, equivalent to direct sunlight.

The primary source of illumination in the space house will be the Sun, utilizing special mirrors and lenses or through solar energy conversion into electricity.

Creating a comfortable environment for humans in space can only be achieved by thoroughly replicating Earth's biosphere, including a diverse array of flora and fauna, as well as soil biogeocenosis with thousands of species of microorganisms [9–11, 14]. Healthy fertile soil is critical, as it acts as the immune system of the biosphere. Without it, creating safe and comfortable living conditions would be impossible.

The biosphere complex of the space house must continuously produce oxygen for the humans and animals living there, generate healthy food and convert all organic waste into humus.

The structural part of the residential cluster "EcoCosmoHouse" can take the form of a hollow sphere, cylinder, torus or a combination of these shapes, with diameters ranging from 200 to 500 m. These structures will rotate around their axis to simulate gravity. Large space settlements will be paired along a single axis, allowing for their initial spin-up and rotation in opposite directions via electric motors.

Space settlements, particularly those in Earth's orbit, face meteorite and radiation hazards. The most effective protection against these threats includes thick multilayered barriers, which may consist of foam materials within the structure, multi-meter layers of soil and protective layers of air and water, either on the ground or in surface water bodies. The outer shell of the space house, made from high-strength materials such as composites, will have a load-bearing wall thickness of approximately 5 mm, making it the least material-intensive part of the ECH.

Living and office spaces can be housed in gondolas – the GPV containers that transport passengers or cargo to orbit. These gondolas are hermetically sealed, equipped with life support systems, designed to handle overpressure and fitted with a hatch (door). Their full autonomy ensures the safety of inhabitants, even in the event of depressurization caused by a meteorite impact.

On the inner side of the shell, above the porous anti-meteorite and anti-radiation protection, a layer of living, fertile soil of at least 1–2 m thickness will be laid. This soil will support forests, gardens, meadows and their respective biogeocenoses. Additionally, ecosystems for both freshwater and saltwater reservoirs will be created. The sloped sections of soil, closer to the axis of rotation, will feature mountain landscapes with streams, waterfalls and foothill ecosystems. The air within the space house will be enriched with the fragrances of flowers and beneficial phytoncides, whose positive effects on human health surpass those of any medicine. There will be no noise pollution; only the sound of birdsong and the gentle rustling of leaves in the breeze will be heard.

Space Industry Waste Disposal

Any industry, including the space industry, follows a similar technological model: raw materials and energy enter as inputs, while products (or services) and industrial waste are produced as outputs. This waste results from isolating the desired product (or service) from raw materials. Eliminating waste from processes that reduce entropy (in opposition to the second law of thermodynamics) is fundamentally impossible. Even the ecologically advanced life that emerged on Earth around 4 bln years ago could not overcome this.

Living organisms adapted their complex biotechnological processes (metabolism) to manage biogenic waste, including waste produced at the end of their life cycles – after death. As a result, all waste, without exception, became part of the food (biotechnological) chain. This adaptation led to the creation of the biosphere – a shared home for billions of species, entirely supported by the by-products of their life activities, such as atmospheric oxygen, the protective ozone layer, biohumus that ensures soil fertility and more.

Just as life on Earth built the biosphere from biogenic waste, space-based industry will inevitably create a similarly scaled technosphere built from technological waste. In this context, recycling waste from industry located in space will become essential following the deployment of the GPV – a self-supporting spacecraft capable of providing extensive geocosmic logistics.

Lagrange Points and Space Industry

Each star system, including the Solar System, has Lagrange points (L-points), or libration points (from Latin *librātiō* – oscillation). These are regions in a two-body system where a third object of smaller mass, influenced only by the gravitational forces of the two larger bodies, can remain stationary relative to them [15].

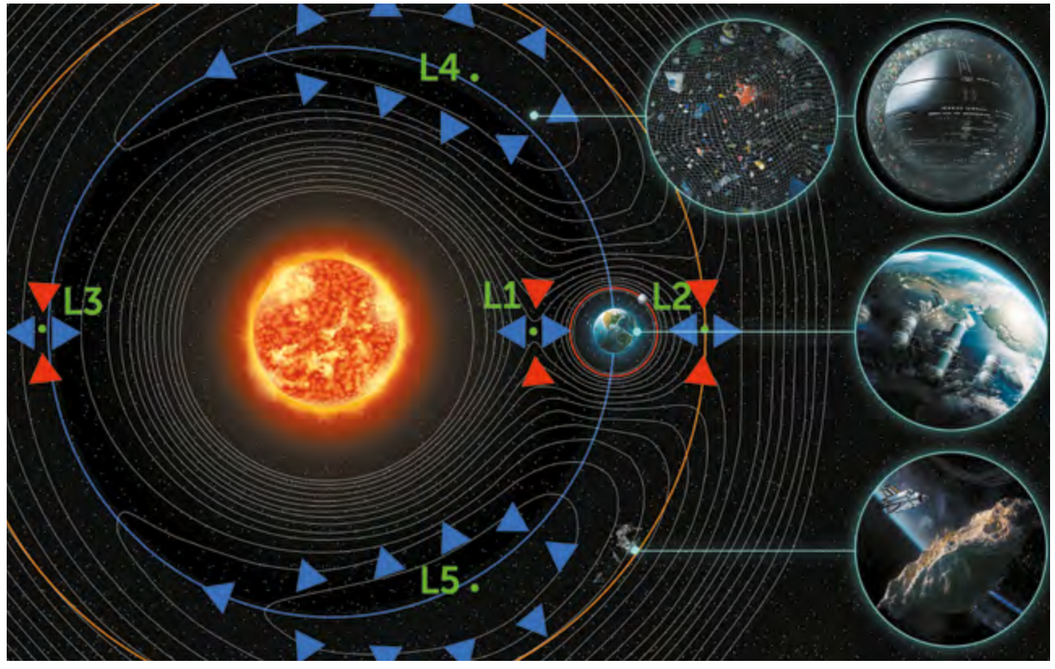
At Lagrange points, gravity is virtually absent. Any cosmic bodies placed there will remain balanced in a gravity well with extremely gentle slopes. Objects displaced from this position by some external force will "roll" back to the center of this gravity well due to microgravity.

Science fiction writers, who have long taken an interest in Lagrange points, have imagined various objects placed there: alien artifacts (Larry Niven's Protector), space debris dumps (Charles Sheffield's Summertide and Andrey Balabukha's Neptune's Harp) and even entire planets (Poul Anderson's Planet of No Return). Isaac Asimov suggested placing radioactive waste in Lagrange points (View from a Height) [15].

Lagrange Points and First Technological Process Stage

The production of space goods, regardless of its location in space, must be conducted not for its own sake but for the benefit of its creators and consumers – Earth's inhabitants (in the future, there will be around 10 bln people living on their home planet) [16]. Displacing humans from Earth to other planets, asteroids, or into space – people who bear a billion-year evolutionary history encoded in hereditary units in the genes located within nuclear chromosomes and organelle DNA – is inhumane. In our view, there is no better place in the Universe for terrestrial humans to live and work, now or in the distant future, than their cradle – the Earth's biosphere.

It is the alien industry (the technosphere), created by humans, that must be removed from Earth's biosphere and relocated to a more suitable technological environment – where there is weightlessness and deep vacuum, conditions absent on Earth, as well as almost unlimited access to solar energy and mineral resources, such as those in the main asteroid belt between Mars and Jupiter. This shift would elevate all existing industrial technologies on Earth to a fundamentally new level of engineering and economy. For instance, the all-metal asteroid 16 Psyche contains trillions of tons of native metals (it might once have been the core of a destroyed planet) – iron, nickel, gold, platinum – whose value is estimated at over 10,000 quadrillion USD [17].



The first technological process stage for the production of space-based semi-finished goods is proposed for placement at the Lagrange points of the Sun–Earth system. Factories and facilities can be built here to process raw materials, delivered, for example, from the asteroid Psyche, into semi-finished goods. Additionally, powerful energy system drawing on inexpensive solar power will be established here to support the energy-intensive primary-stage space industry, referred to as the Lagrange industry due to its location. In the absence of gravity, industrial waste can also be stored within zones enclosed by films and/or fine mesh. These zones can be solid or hollow, such as a hollow sphere or cylinder, a design easily achievable in zero gravity. Such space-based storage would serve as a meteoroid barrier for the space production sites inside. A 10-meter-thick wall, formed from mineral waste in a particular way, could withstand the impact of a meteorite weighing up to 1 ton and traveling at 10 km/s, while a 50-meter-thick wall could withstand up to 10 tons.

If the volume of primary-stage production in the future exceeds 10 bln t/year of space semi-finished goods (far surpassing today's equivalent production on Earth), the amount of industrial waste would be approximately double – around 20 bln t/year. A hollow sphere with a diameter of 100 km and a wall thickness of 1 km would require (to form its walls) about 30,000 km^3 (approximately 50 tln tons) of industrial waste. The Lagrange industry would produce this volume of waste over 2,500 years. Additionally, a wall of 1 km thickness would protect the inner space of the hollow sphere, formed from waste, from meteorite impacts of up to 1,000 tons. This protective barrier should be built in stages, beginning with the direction of the most likely meteorite arrivals.

Thousands of similar 100-kilometer-diameter production spheres could be freely positioned within the Lagrange zones of the Sun–Earth system, enabling the first process stage space industry to operate for millions of years. Initially, such production could be localized in smaller volumes, starting with a sphere diameter of 100 m and a protective shell thickness of 1 m.

It is essential to note not only the environmental friendliness of industrial waste disposal at Lagrange points but also the extremely high energy efficiency. Thus, alternative waste disposal methods, such as depositing waste on the Sun, the Moon, or in deep space (e.g., in the asteroid belt), would be extremely energy-intensive – requiring energy equivalent to over a ton of gasoline for every ton of industrial waste. By contrast, moving the same ton of waste across the bottom of the gravity well in weightlessness (for example, from the center of a 100-kilometer hollow sphere to its wall) would require the energy contained in only 1 g of gasoline.

Moreover, disposing of industrial waste on the Sun or Moon at the first cosmic velocity would negatively affect the surfaces of these celestial bodies causing solar or lunar quakes and creating additional scars on the Moon. Not all waste would even reach the Sun's surface without evaporating (depending on the mass and size of the waste).

ISN "Orbit" and Cosmic Logistics

A semi-finished product is not yet a complete thing, which is better produced closer to its consumer (humanity on Earth) and specifically in the ISN "Orbit," located at an altitude of 400–500 km. This is also an ideal location for the production of final space products, including chemically pure, high-strength and specialized structural materials and composites, pharmaceuticals, electronics, machinery and other equipment.

Logistics between Lagrange production sites and the ISN "Orbit," performed in zero gravity along Earth's orbit around the Sun, will require minimal energy. Only non-orbital logistics, such as flights to and from the asteroid belt, will be energy-intensive, demanding powerful rocket engines. Depending on mission requirements, these engines may vary widely – chemical, ion, electric, kinetic, nuclear, solar sail and more.

In the ISN "Orbit" zone (due to its proximity to Earth's biosphere), engines must meet environmental standards as understood by Earth's inhabitants. For example, water is safe for Earth's biosphere and life, while every living organism composed of about 75 % water. Therefore, launches from Earth's orbit into space should use rockets with hydrogen-oxygen jet engines, where the combustion product is H_2O. Water delivered from Earth to orbit, stored in the GPV ballast system, can be split with solar energy into H_2 and O_2 to refuel the fuel tanks of space tugs assembled directly in the ISN "Orbit." This approach allows interplanetary travel to harness solar energy beyond Earth, ensuring that this logistical system will not impact the planet's ecology or its biosphere.

Industrial Waste as Construction Material and Energy Source for Earth

Most mineral industrial wastes are chemically inert and environmentally safe. After additional thermal treatment in a vacuum, such as by sintering with concentrated solar radiation easily achievable in outer space, these materials are planned to be used on Earth as durable and lightweight

(foamed) construction elements such as bricks, blocks, cladding tiles, panels, etc. Some of these wastes can be processed (again, using solar energy, weightlessness and deep vacuum) into binding agents – cement and its stronger analogs. In this case, such orbital construction products possess high energy, both potential and kinetic, relative to the planet's surface, which can be recovered in the GPV as electrical energy during its landing on Earth.

A feature of the GPV operation is that its mass with cargo should be roughly the same during both takeoff and landing. Otherwise, flight modes would be suboptimal: either with excessive acceleration or with a significant loss of energy, which would need to be discarded into the environment as heat. Therefore, a ballast system is required. Water is a sensible ballast during takeoff into space, which can then be transferred in orbit to produce hydrogen-oxygen fuel for the space tugs. As reverse ballast for the GPV, with a certain excess, construction materials made in space from industrial waste should be used.

Each excess ton of cargo delivered to Earth will provide the GPV with energy roughly equivalent to the amount contained in one ton of oil. So, if the annual reverse cargo flow from space to Earth exceeds the direct cargo flow, for example, by 1 bln tons, this would be energetically equivalent to extracting 1 bln tons of oil on Earth. In this case, industrial waste will become a 2-in-1 ecotechnology: it will serve not only as a building material but also as an extraterrestrial source of green energy.

Thus, it is anticipated that in the future, oil extraction and the production of mineral construction materials on Earth will cease – no need for oil wells or quarries to obtain construction materials. Only the production of organic construction materials, substances and fuel will remain on Earth, for example, wood processing and production of alcohol from plant materials and wood as an environmentally clean fuel, since alcohol is more eco-friendly than natural gas, which is universally considered to be the greenest fuel.

New Production Capabilities and New Right of Property

Modern humanity has all the necessary resources to meet its growing needs and accomplish the items of the EcoSpace program, providing access to the rich resources of space. However, this requires an alliance of states and businesses, while the current system of property rights prevents the elimination of social inequality, which makes disunity and armed, informational and economic conflicts inevitable.

According to the UN, in 2023, in 59 countries, more than 20 % of the population (one in five people) faced severe food shortage [18]. The number of people affected by sharp hunger is estimated at 281 mln. At the same time, if during most of history, the resources were extracted and distributed more or less evenly throughout the inhabited part of the land, now economic inequality is increasing every year. In 1820, the income ratio between 20 % of the richest and 20 % of the poorest population was 3 : 1 [19]. In 1991, it rose to 86 : 1. Based on the report of the UN University World Institute for Development Economics Research, in 2000, 1 % of the richest people owned 40 % of the world's assets [20]. This situation is exacerbating. The World Inequality Report 2022 published by the Paris School of Economics as a result of a four-year research shows that the world is characterized by very high levels of income inequality and extreme level of wealth and that "contemporary global inequalities are close to early 20th century levels, at the peak of Western imperialism" [21].

Almost 50 % of the world's population accounts for only 2 % of the world's wealth, and 10 % of people own 76 % of all known values [21]. Thus, the significant increase in the productive capacity of civilization and the number of values in the world, which began in the 20th century, did not bring about universal prosperity, but due to the concentration of super-wealth in the hands of states and large private businesses has increased economic inequality between people and countries by an order of magnitude, thereby contributing to the growth of tension on the planet, as well as exacerbating global crisis processes. The tool for solving this contradiction should be a technological platform, the implementation of which will change the structure of property and entail the need to revise the system of law in order to eliminate inequality. Such a technological platform is proposed in the EcoSpace program within the framework of uCities projects.

A high degree of automation in residential and industrial clusters of uCities will minimize the amount of physical and administrative resources required for their maintenance. Highly efficient mobility will become a tool for developing remote areas, reducing the artificially created difference in land costs. By adhering to the new logic and obtaining everything necessary for life in abundance within the framework of their settlement, the individuals will achieve the highest degree of autonomy, so that the role of states and corporations will inevitably diminish. Human will no longer be forced to labor, which traditionally acted as a system-forming factor in the formation of property rights, since any property is based on labor or, at least, acquires value only thanks to labor. A change in the labor system will stipulate a change in the property right.

The establishment of the institution of labor-based property rights will eventually make it impossible for large capital entities in the form of states and corporations to emerge. This will lead to the elimination of the key reasons for social inequality and the resulting confrontations. By curbing the sphere of economic subjectivity, states will be compelled to focus not on ensuring their sovereignty and ramping up economic power, but on the implementation of globally significant projects, including the GPV.

Thus, within the framework of the EcoSpace program, the role of initial cells or centers of formation of a new socioeconomic system will be played by clusters of uCities. The logic of mass transition to this form of community life space organization will not be fundamentally different from the logic that set the specifics of spatial dispersal of people in previous eras. It is determined by a number of factors, among which the most important are the efficiency of the system's inherent production method and transport accessibility of territories.

Linear cities imply spatial and sectoral decentralization of production facilities. In this logic, the agricultural and energy sectors should be placed under community-type management, which will create prerequisites for reorganization in services and heavy and light industries. The only sphere of the world economy that should continue to develop and be managed centrally is transport, since it is the only one that requires coordination over a large space, while everything else, including energy, with the appropriate adjustment of regulatory and legal tools, can effectively exist in centers, spatially arranged in territorial units of cluster type.

The development of a high-speed (up to 360 km/h) transportation network will entail the construction of efficient service chains, supplies of raw materials and components as well as product sales, which will extend for hundreds of kilometers. In the most suitable locations of transport networks, it is planned to place clusters of different specialization – raw materials, industrial, scientific, cultural and educational, etc. A person will be able to choose a place of residence close to the place of work, and if it is exceptionally impossible for some reason, the distance of comfortable transport accessibility will still extend not for tens (as in modern megacities), but for hundreds of kilometers.

The way and environment of life in the clusters are fundamentally different from urban areas and more reminiscent of the village way of life. Each person will be able to live in a natural and most suitable for him environment upon that due to inexpensive, safe and environmentally friendly high-speed transport while having access to all the benefits of modern civilization – education, culture, entertainment, recreation, etc. This opportunity will certainly become in demand, so that the prospect of mass deurbanization on the planet, where about 60 % of the world's population will live in cities soon, turns out to be not only real but also technologically justified as part of the EcoSpace program.

The transition to new forms of spatial-regulatory and, in the long-term perspective, to the legal organization of society can be carried out in two main ways: through government programs and the implementation of individual development projects at the expense of investments of future residents of the linear cities' clusters under construction. In a second way, the main incentive to purchase a new type of real estate will be, for example, the opportunity for a person to have a year-round supply of healthy agricultural products, as well as to receive a kind of passive income through the sale of a surplus of these products. If the average cost of housing in uCity is less than 1,000 USD/m^2, such passive income for each house in the cluster will be more than 10,000 USD/year. This means that a buyer will be able to fully compensate for the cost of purchasing a home over 10 years and make it a long-term source of income in the years afterward.

Perfect HomoSpace as Consolidation of Human Efforts and Inexhaustibility of Cosmic Resources

A unified sociopolitical consciousness, a common space vector of industrialization for all, a planetary geocosmic transport system, the ELC, the ISN "Orbit," as well as the implementation of the EcoSpace program by the joint efforts of all humankind – all this will inevitably lead not only to a new cosmoindustrial technological order with a new economic paradigm of inexhaustible space resources and opportunities but also to a new integrated sociopolitical structure of the world.

The newly created space industry is designed to reorient the technosphere of Earth in the following way: harmful industries will be taken out into space, and the remaining industries will be reduced. Their place will be taken

by environmentally friendly industry. First of all, the following sectors will fall under the reduction:

• traditional hydrocarbon power engineering (the minimum required amount of energy on Earth will be represented mainly by relict solar bioenergy, which mineral waste will become the basis for biohumus production and for solving the interrelated global problems of our time – food, hunger and desertification;

• mining, metallurgy, chemical and engineering sectors;

• other environmentally harmful, energy- and resource-intensive sectors.

All of the above are the basic sectors of the modern world economy, most of which belong to the developed countries of the world.

The implementation of the EcoSpace program will inevitably lead all countries, especially the developed ones, to replacing a significant part of their national economies with participation shares in the new highly efficient global geocosmic economy. At the same time, the political weight of countries will depend on their contribution to the newly formed global economy based on accessible and inexhaustible cosmic resources.

Economic stability, guaranteed by the inexhaustible potential of outer space, will allow to establish a new society living under comfortable conditions in harmony with the Earth's nature, strengthen the development of science, creativity and art as well as release resources for the aesthetic development of earthlings, the upbringing of children, the formation and propagation of the principles of humanism, ethics and constructive cooperation.

Organizational Aspects of Preparation and Establishment of Space Industry

In order to consolidate all humanity within the framework of full-scale implementation of the EcoSpace program, it is necessary for the broad world community, political, scientific and business elites to deeply realize the inevitability of the space vector of industrial development of the Earth's technogenic civilization as well as to estimate the advantages and material benefits of this project – the most global and economically promising in the history of humankind.

For this purpose, it is important to conduct a series of international activities to promote the EcoSpace program among scientific, sociopolitical, environmental and other organizations. World opinion leaders, major international blocks and corporations, national industries related to the space industry, and others who can contribute to the early implementation of the EcoSpace program should be involved in joint efforts to develop the program.

The key element determining the success of the EcoSpace program will be the EcoSpace scientific school, the setting up of which is already underway by the author of the program, engineer Anatoli Unitsky. This refers to both reeducation of already qualified scientists and specialists and education of young personnel – schoolchildren, undergraduates and postgraduate students – in a wide range of scientific disciplines and specialties. As part of the targeted selection of promising personnel, given the long-term nature of the EcoSpace program, it is crucial to search for and attract talented young people.

The organizational plan of the EcoSpace program implementation implies three main stages.

1. Preparatory stage.

Implementation period: 20–25 years (from 2025 to 2045–2050).

Goals and objectives:

1) carrying out a set of research, development and technological work (R&D) in the following areas:

• 5-in-1 equatorial takeoff and landing overpass combined with the uST transport and infrastructure complex;

• infrastructure, primarily equatorial – transport, logistic, industrial, residential, energetic and informational;

• GPV;

• ISN "Orbit" – transport, infrastructure and industrial complex in orbit, including new space industries: industrial, energetic, informational and residential;

2) solving the relevant issues of biological, ecological and engineering nature in the creation of the ECH as an enclosed autonomous biospheric ecosystem for the preservation of biodiversity of the planet Earth and as a model of future human settlement in outer space; other environment-oriented ecotechnologies for their immediate application on our planet;

3) preparation and creation (construction) on Earth of a 5-in-1 GPV equatorial launch overpass, combined with the uST transport and infrastructure complex as well as buildings, structures, infrastructure (industrial and residential complexes, power plants, including relict solar bioelectric power plants, control and communication systems, power lines, etc.);

4) fabrication and assembly of the GPV (40,076 km long; total payload-free weight is about 30 mln tons in one of the available versions of implementation), starting-up and adjustment operations;

5) construction of the ELC as a transport and logistics complex of the geocosmic transportation system, deployment of the equatorial linear industry as a terrestrial component of the space industry within its urban boundaries. Commencement of harmonization of the technosphere and the rest of the Earth's territory with the biosphere by reducing the technosphere to the volumes required by humankind and its re-equipment based on eco-oriented technologies;

6) organizational preparation of geocosmic flights, in particular coordination with civil and military aerospace agencies worldwide. Collection of orbital space debris that jeopardizes the GPV and the emerging space industry. Adjustment of regulations and international legislation in the field of air and maritime law. Other related activities.

It is worthwhile noting that today a serious international engineering team is already working under Anatoli Unitsky's leadership, which conducts research and development of key components of the GPV and other elements of the EcoSpace program regularly. Every year international scientific and technical conferences on non-rocket near space industrialization are arranged, where the recent achievements in all areas of the EcoSpace program development are demonstrated, as well as discussions and debates on problematic aspects and further plans are held. The representatives of scientific circles from different countries of the world, such as Belarus, Russia, Kazakhstan, Ukraine, Great Britain, Canada, Germany, UAE, USA, etc., show great interest in this research.

2. Basic space industrialization.

Implementation period: 10–15 years (from 2050 to 2060–2065).

The following should be done during the initial 5–10 years of the basic near space industrialization:

1) establishment of construction and installation sites along low equatorial orbits, raising and mounting the load-bearing (supporting), transport and communication components of the ISN "Orbit," which will complete the construction of this supporting structure and the entire cosmic transport and energy-informational infrastructure for 2–3 years of the GPV flights;

2) parallel deployment of solar power plants in orbit and, within the first three years, achievement of net capacities exceeding those of the Earth's power industry to meet the needs of the emerging space industry and facilitate entry into the wholesale electricity markets;

3) starting the arrangement of several installations in orbit for the production of hydrogen and oxygen, for example, by the method of electrolysis of saline solution (ballast sea water) as well as facilities for liquefaction and storage of hydrogen and oxygen obtained along the way;

4) sending mining expeditions prepared in advance on Earth to the nearest asteroids rich in valuable raw materials after the GPV is launched for the first time. For example, the asteroid Psyche is estimated by some experts to contain more than 100 bln tons of gold and platinum group metals valued at a minimum cost of 10^{18} (million trillions) USD, while the iron and nickel content is much higher, reaching a value of 10^{19} USD (at current prices);

5) establishment of geocosmic transportation services to support breakthrough space projects. Launch space services for collecting space debris, servicing existing satellites and restoring the ozone layer, etc.

The following should be done during the second five-year period of the basic near space industrialization:

1) maintaining the current growth rates of the net capacities in solar-hydrogen power engineering until the net capacity exceeds that of the terrestrial industry by at least twofold. This includes all power units across every type of ground transport along with cars and electric vehicles. Following this, all transport on the planet will transition exclusively to electric type;

2) starting the construction of the first several thousand space industrial clusters on supported and infrastructured equatorial orbit, utilizing materials delivered from Earth from the outset. Creation on their basis of a space construction and industrial complex that produces structural materials using raw materials sourced from space. This approach will enable the mass construction of industrial clusters – projected to reach at least 40,000, spaced approximately every kilometer along the orbit – for the subsequent large-scale industrialization of space;

3) immediate acquisition of dominance in the energy and raw materials markets of the planet. Begin the reduction of the Earth's technosphere volume to an environmentally safe level that does not impact the biosphere in a detrimental anthropogenic way.

3. Large-scale space industrialization.

Indefinite from 2065.

Goals and objectives:

1) expansion of the range of high-quality consumer and industrial space goods and services. Formation of a competitive space market;

2) preparation for the expansion of the Earth's civilization into deep space.

Obstacles Threatening EcoSpace Program, Risks and Their Prevention

The peculiarity of the EcoSpace program lies in the fact that it is a global project in terms of scale and geographic coverage and civilizational one in depth and significance of its transformations. The program implementation is possible only through the joint efforts of all countries with the participation of major government and corporate investments. At the same time, its goals and objectives meet the interests not only of the participants-investors but also of all humankind. Considering these factors, as well as the overall support from international government institutions, the EcoSpace program is practically not subject to risks associated with the level of development and state of the economy, tax and finance policy, legislative and legal framework and investment environment, market situation and other business conditions in a particular state. However, the EcoSpace program has already encountered many obstacles on its 40-year path and will have to overcome no less obstacles in the future.

The main difficulties that the EcoSpace program faced at the initial stage and continues to face up to this day are tied to the society not understanding the inevitability of an environmental catastrophe if pursuing a passive variant of civilizational development, as well as to the unwillingness of scientific circles to perceive large-scale civilization-wide innovative technologies. At present, these are only the so-called "scientific elites" who, for subjective reasons, do not want to recognize the uniqueness of a whole series of eco-oriented technological platforms proposed by engineer Unitsky, a researcher and pioneer in many branches of science and technology.

In the future, it is likely that the EcoSpace program will likely have to withstand the onslaught of "political elites": they will certainly not want to delegate their authority in favor of a single high-tech and humanistic vector of anthropic development. This may be the rocket and other industrial lobbies, fearing a competitive confrontation with a new space industry. All of the above "elites" are interested in momentary success, so they are unlikely to support the EcoSpace program, the success of which will be felt not by themselves but by the whole of humanity just after one or two generations.

The elimination of these obstacles will be orientation to the broad world community, as well as reliance on opinion leaders from science, engineering, culture, art and other spheres, whose human and professional interests practically do not depend on the upcoming transformations in the technosphere and completely coincide with the life-affirming goals and objectives of the EcoSpace program. And only after winning the sympathy and support of a large number of the world's population can we count on the fact that the "elites," still driven only by disingenuous motives, even if not supporting the program itself will be faced with the choice of their followers on whom they depend. Only then they would be able to perceive the content of the EcoSpace program and, having tried all the benefits on themselves, begin its active implementation.

As for scientific risks, Anatoli Unitsky and the team of scientists, engineers and other specialists organized by him have answers to almost all these questions. The scientific and technical justification of the design and technological solutions for the geocosmic transport system is beyond doubt. Speaking about the GPV, we can safely assert that the main basic aspects of the technology have been well studied and confirmed by the positive conclusions of various authoritative experts.

The possibility of a design embodiment also does not need any special additional arguments – currently, there are not only the abovementioned design developments but also many components of the geocosmic transport ecosystem that have already been implemented in industrial samples and are being used on Earth. The correctness of further engineering calculations and the operational reliability of the equipment produced in the future are issues of a proper arrangement of R&D and quality control of manufactured products, which are well-developed by the aerospace industry. Considering the scale of consolidation of international forces, the degree of risks of this kind will be much less than now.

If we talk about flight safety, then considering the global nature of the unification of forces, including the potential of special services and armies of the participating countries, the arrangement of security can also be provided at a much higher level than it is possible to do within individual states. The absence of negative environmental consequences is guaranteed by the essence of the EcoSpace program since all the proposed transformations are subject to a single logic of eco-orientation. The amount of resources of the existing technosphere is estimated: there are enough of them, even if only one of the top five most developed countries of the world will undertake the implementation of the EcoSpace program.

Another obstacle at the initial stages of the EcoSpace program implementation may be the refusal of one, several or all countries of the Earth's equatorial strip to participate in it, as well as claiming by these states demands on excessively inflated compensation payments for the use of zones of the equatorial strip belonging to them. The next reason for avoiding participation in the program is the fear that the GPV would collapse on their territory. To prevent this risk, it is necessary to inform the management and the public (not only in the equatorial regions) about the really low probability of an emergency and measures to limit possible catastrophic consequences as well as to provide insurance for such risks.

As for the overestimation of price requirements, this issue does not seem critical, because we are talking about the most expensive land in the era of cosmotechnocratic civilization. Accordingly, the risk prevention measures can be the establishment of uniform standards for the purchase of territories of the equatorial strip, as well as a mandatory condition of a package agreement simultaneously with all equatorial countries, the vast majority of which are economically underdeveloped. For them, participation in the EcoSpace program is a unique chance to raise their economy to the level of the most highly developed countries in the world. Thus, any attempts of any equatorial power to put forward inflated price demands backed by the threat of boycotting the further implementation of the EcoSpace program will result in isolation for it not only from the partner countries in the equatorial strip but also from other states.

If we talk about other, more traditional risks, there is a huge number of them. There is no doubt that the universal scale of the EcoSpace program, with the support of international authorities, will allow not only to carry out efficient risk prevention using standard methods and means for investment projects but also to avoid most of their parts.

The biggest risk for humanity associated with the EcoSpace program is the loss of precious time and what little is left of it to fully realize the inevitability of the cosmic vector of further industrial development of Earth's engineering civilization, to have time to consolidate the efforts of all countries and to begin as soon as possible a full-scale implementation of the EcoSpace program designed not only to save the world but also to make it better in every civilizational sense [22].

Commonality and Differences Between EcoSpace Program and UN Concept of Sustainable Development

In 1972, at the UN conference held in Stockholm, the international community acknowledged the reality of environmental and resource disasters. In 1987, the UN General Assembly stated that ensuring the sustainable development of humankind was the most significant problem facing the world community. In the same year, the World Commission on Environment and Development for the first time formulated the definition of sustainable development as meeting the needs of the present without compromising the ability of future generations to meet their own needs. At the UN Conference on Environment and Development, held in Rio de Janeiro in 1992, the concept of sustainable development was adopted as a result of the combination of three directions, namely:

1) economic direction. Economic efficiency should be assessed based on long-term prospects which also consider environmental consequences;

2) ecological direction. The main goal in the field of ecology should be the stability of physical and ecological systems. Activities that lead to environmental degradation endanger the existence of all humankind;

3) social direction. It is important to be aware of social problems and the need to preserve cultural and social stability, as well as to reduce the number of conflicts that cause destruction.

For many decades of its existence, the concept of sustainable development has been constantly improved. In July 2014, the UN General Assembly Open Working Group on Sustainable Development Goals approved a document containing 17 Goals aimed at achieving sustainable development, namely [23]:

1) end poverty in all its forms everywhere;

2) end hunger, achieve food security and improved nutrition and promote sustainable agriculture;

3) ensure healthy lives and promote well-being for all at all ages;

4) ensure inclusive and equitable quality education and promote lifelong learning opportunities for all;

5) achieve gender equality and empower all women and girls;

6) ensure availability and sustainable management of water and sanitation for all;

7) ensure access to affordable, reliable, sustainable and modern energy for all;

8) promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all;

9) build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation;

10) reduce inequality within and among countries;

11) make cities and human settlements inclusive, safe, resilient and sustainable;

12) ensure sustainable consumption and production patterns;

13) take urgent action to combat climate change and its impacts;

14) conserve and sustainably use the oceans, seas and marine resources for sustainable development;

15) protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss;

16) promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels;

17) strengthen the means of implementation and revitalize the global partnership for sustainable development.

"Human dignity will be the core of my work," said UN Secretary-General António Guterres. He is convinced that this unique international organization is capable of solving the challenges facing the world and contributing to success in transforming the society. Like his predecessor Ban Ki-Moon, Mr. Guterres considers the achievement of the 17 Sustainable Development Goals a priority task to create a better world for the benefit of the whole humanity [24].

The UN Secretary-General's statement expresses concern that the concept of sustainable development, which is advisory, has not been able to radically transform the world for the better for many decades, and the main problem of anthropogenic oppression of the biosphere has not only been solved but has become even more acute and continues to aggravate the ecological situation on the planet.

Unfortunately, as the events of recent years have shown, the concept of sustainable development, with all its noble intentions, proposes to restrain further economic growth and technological development as well as incur additional costs for the creation and implementation of environmentally friendly and resource-saving technologies. It is obvious that such measures lead to an increase in the cost of living, and this is an objective economic obstacle to their voluntary widespread use.

Unlike other earth biological species, *Homo sapiens* find the meaning of life in the freedom of self-expression, personal growth and development, including the material one. Forcible restriction of the achieved living standard is perceived as an infringement of personal rights and freedoms. Thus, quarantine measures related to the COVID-19 pandemic, which temporarily reduced economic activity, caused a public protest.

Moreover, artificial containment of growth and reduction of consumption simply cannot solve the problem of pollution of the Earth's biosphere space and the shortage of mineral, energy and other resources contained in this space. Even if it is possible to limit or significantly reduce consumption, the short-term reduction achieved will still be offset by the subsequent growth of the human population and the technosphere. It is known that in the enclosed ecosystem of a Petri dish, the mold population, having absorbed all available resources and filling a limited space with its waste products, inevitably dies. This is almost an exact copy of what is happening to our human technocratic civilization in the biosphere house Earth and what we are moving towards with increasing speed.

Civilizational Expansion: Objectives and Imperatives

The main goal of living organisms, laid down genetically, is not consumption but the creation and processing of simple non-living (dead) substances into complex organic matter. Therefore, once life has emerged, it should not disappear, which is laid down at the level of genes in the main instinct of any living organism – in procreation.

Life – DNA molecules, living cells, tissues, organs and systems of any living organism – is the highest form of engineering, in which the Creator used all natural laws and knowledge of physics (quantum and relativistic) and chemistry (inorganic and organic), energy and material science, design and engineering (in the range from nanometers to tens of meters, i.e., in sizes from protein and DNA molecules to dinosaur and whale), mathematics and our other real (not digital virtual) micro- and macroworlds.

The biochemical metabolism of any living cell of any living organism in the living terrestrial biosphere can be taken as an example. In each cell, thousands of complex biochemical reactions with thousands of different organic substances, including the synthesis of DNA molecules, occur simultaneously. Thus, in a launch vehicle, which is a symbol of the perfection of modern engineering, there is only one simple chemical reaction – the combustion of fuel. Upon that, a rocket cannot replicate itself or at least some of its parts, such as the jet engine, fuel tank or control system. However, a living cell can. That is why not even a cell but only its small structural element – DNA molecule (it counts tens and even hundreds of billions of "parts," i.e., atoms arranged into the most sophisticated spatial construction) – is more complicated and perfect than any rocket in millions of ways, and thousand times more complex than the whole Earth industry created by countless generations of engineers.

More than 80 chemical elements of the periodic table are involved in the vital activity of the cell. It has its roads, bridges, power plants, workshops, factories, machine tools, slipways, technological lines, intelligent control systems, etc. So, the Earth's life is an engineering project, and its Creator (no matter what it is or who it is – Nothing, Random, Highly Developed Civilization or God) is certainly an outstanding Cosmic Engineer.

During the singularity and the subsequent Big Bang, a fine-tuning of the physical laws of the Universe – the "physical genes" of its further programmed development – was carried out. The purpose of such tuning is the birth of Intelligent Life which regardless of the place of its randomly predetermined appearance will spread to the rest of the non-living material world of the Universe. Therefore, the goal of a civilization that can go beyond its planet will not be the ever-increasing consumption of energy and resources but the expansion of the Civilization Area first to neighboring star systems, then to the home galaxy and further to neighboring galaxies and their clusters.

The implementation of the EcoSpace program in all its aspects will make it possible to create technical conditions for long-distance flights of the representatives of the *Homo sapiens* species to distant planets where new settlements can be established.

During interstellar flights, the physical laws of preservation, such as mass, energy, momentum, angular momentum and motion of the center of mass, programmed in the Big Bang, must be observed. For example, an interstellar space Ark with a weight of 200,000 tons, accelerated to a speed of 100 km/s, will have extremely powerful (according to modern Earth concepts) energy:

- kinetic energy: 10^{18} J (for comparison: the same energy will be released by 21 mln tons of gasoline when burned in 71 mln tons of oxidizer (oxygen), i.e., in 93 mln tons of chemical fuel);
- impulse: 2×10^{13} kg·m/s (for comparison: a train of 800-million-ton weight running at 90 km/h has the same impulse).

Both kinetic energy and impulse should be supplied to the ship during the flight twice: at the launch (during acceleration within our Solar System) and at the end of the flight (during deceleration within the star system whose exoplanet will be the final target of the Earth's expansion).

It is more reasonable to launch from the Earth's orbit – from the Lagrange points in the Sun–Earth system [15], where the space component of the Earth industry and its resource and energy base will be created. To arrive – also to the Lagrange points in the Star–Exoplanet system, where the engineering crew of the Ark should create an industrial, resource and energy base for colonization of the exoplanet, which should become a second home for the Earth's life (and for a human being among others). Otherwise, why should the space Columbians fly to such a distance? The size of Lagrange points (more precisely, zones) is pretty vast – they extend for millions of kilometers, so thousands of astroengineering objects of various purposes as big as a planet can be placed there.

While equipping a space mission, it is necessary to solve many problems, both engineering (design, technological, energy, resource, flight safety: space radiation and dust, meteorite hazard, etc.) and sociobiological. How many species of living organisms out of billions existing on Earth should be flown and in what quantity ("two of every kind" will not be enough)? What should be the enclosed ecosystem of biosphere type on the ship? How many people and what specialties should the crew have, which will be replaced several hundred times from generation to generation, considering that the mission does not end with just a multi-millennial flight – the goal is not just a flight but colonization of the exoplanet? How should we organize a closed society, orders of magnitude more complex than, for example, the tribes of Amazon Indians, so that not just not to be degraded for thousands of years of flight but also to get development and progress, which will be realized during the colonization of the exoplanet?

The Ark is not just a spaceship but the greatest engineering structure, a kind of biosphere safe deposit, capable of storing Earth's life, including humans, and then transferring it safely to exoplanets, to which even light takes many years to reach. This is possible only in an ECH – an enclosed ecosystem of biosphere type [25].

The **ECH-Ark** will not only represent the Earth's biosphere in miniature but will also be the most sophisticated flying vehicle autonomously existing for thousands of years with its energy, engines, fuel reserves and exhaustible resources (not participating in the biospheric cycle), engineering communications, repair base, housing and production facilities, farming equipment, crop species and aquaculture, flora, fauna and fertile soil, as well as a society with kindergarten, school and university, medical institution, workplaces with hundreds of specialties, etc.

Let us consider the Ark, which is minimal in size and biospheric capacity. The hull of the ship is shaped like a rotating body – a spindle (Figure 1) with a length of 500–2,000 m and a diameter of 200–500 m for a crew of 1,000–10,000 people.

The Ark has three main zones.

Zone 1.1 – biospheric (natural) compartment where there are no people but only flora and fauna, both terrestrial and aquatic, untouched by humans. There, in particular, basic oxygen for biosphere needs should be produced and excess carbon dioxide absorbed. For example, the annual demand of 1,000 people (including children) for oxygen for breathing in the Ark will be about 180 tons.

Zone 2.1 – living compartment and agricultural zone – a place for human habitation, organic food cultivation and economic activities of the Ark crew.

Zone 3.1 – production compartment, where there is microgravity, weightlessness (along the Ark's rotation axis) and, if necessary, deep vacuum, for which it will be enough to connect the technological vacuum chamber with the surrounding space. Production and repair shops, robotized machinery, power, scientific and other equipment are located here.

Approximate composition of the loaded Ark with a total weight of 200,000 tons, or 200 t/person (without fuel and considering the working mass to generate the braking jet impulse) is as follows:

1) air volume: 12 mln m^3 (12,000 m^3/person); weight: 15,000 tons (15 t/person, of which oxygen 3 t/person);

2) water (reservoirs with fresh and sea water, ground water, service water) – 25,000 tons (25 t/person);

3) fertile soil (biohumus) and living organisms (including flora, fauna and people) – 45,000 tons (45 t/person);

4) supporting structure – 25,000 tons (25 t/person);

5) special protection (from space radiation and meteorites) – 35,000 tons (35 t/person);

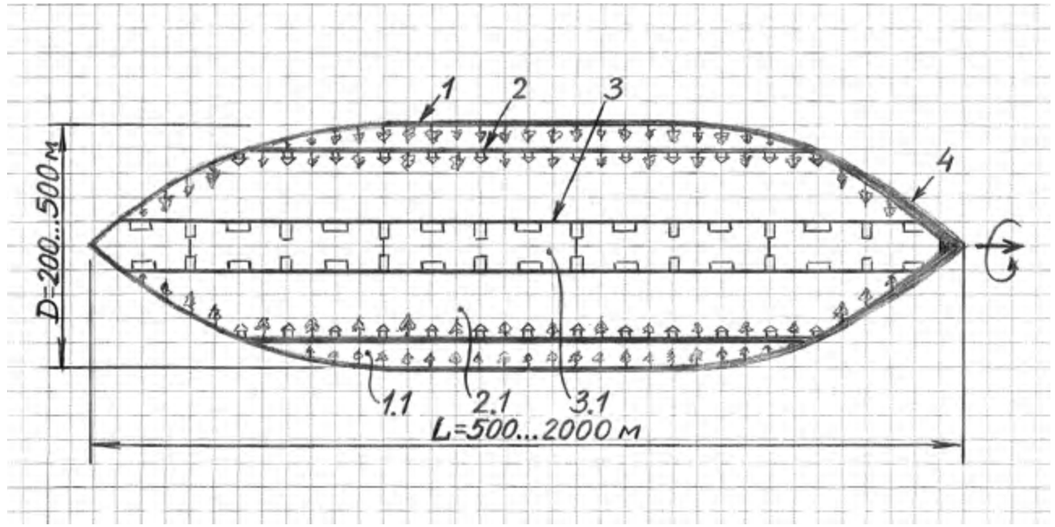


Figure 1 – Longitudinal section of the Ark (option):
1 – outer (protective) shell, 1.1 – biospheric (natural) compartment; 2 – living compartment shell ("floor"),
2.1 – living compartment and agricultural zone; 3 – production compartment shell ("floor"),
3.1 – production compartment; 4 – frontal armor protection

6) equipment (power, production, maintenance, utility networks, etc.) – 40,000 tons (40 t/person);

7) miscellaneous – 15,000 tons (15 t/person).

Besides, the Ark should have a reserve of nuclear fuel (several tens of tons in terms of plutonium-239) and several hundreds of thousands of tons of working mass to create a braking impulse at the exoplanet (see below).

To obtain the Earth's gravity level (acceleration of gravity is 9.8 m/s^2), the Ark's "spindle" should be spun around its longitudinal axis to a circumferential velocity of 31 m/s (one rotation in 20 s). A layer of fertile soil, sometimes 1 m deep, covering the inner surface of such ECH and required for planting gardens and forests, as well as for the placement of soil biota – biogeocenosis (the basis of the fertility of any terrestrial soil), will provide additional radiation and meteorite protection.

We will outline the most sensitive engineering problems and possible optimization of ways to solve them, which is especially important to ensure the safety of interstellar travel within the civilization panspermia mission.

The Ark's safety is not limited only to the safety of high-speed navigation in outer space which is full of dangers, it also includes protection against cosmic radiation, cosmic dust, meteorites, etc. It is equally important to prevent other threats, such as those that accompanied the earthly stage of human civilization development, such as riots, dictatorships, revolutions, wars, pandemics, consumerist (for the sake of pleasure and money) attitude towards oneself, society and the environment, as well as other global problems within an enclosed ecosystem, which can destroy not only the ecosystem itself but also the human society living in it – a civilization in miniature. In the Ark, this has to be excluded consciously and at the proper level: it is worth ensuring technological and social, energy and food, resource, information and other types of security for the engineering (not purely biological) type of civilization that has set out on a multi-millennial journey.

Physical Security

The main physical safety issue in such a long flight is radiation and meteorite protection. For example, a 100 kg meteorite flying at 20 km/s has a kinetic energy of 2×10^8 J, which is equivalent to the explosion energy of a 4,800 kg of TNT charge, and at 100 km/s – already 120 tons of TNT. An encounter with such a space traveler could be fatal for the entire expedition.

The probability of such a collision is not zero, but the space Ark has to have powerful armor made of minerals, several meters thick, especially in its bow. Since thickness rather than weight is important for protection, the ship's shell should be made with a lightweight porous structure. In addition, such armor will serve as a mineral storehouse, the need for which will arise repeatedly during such a long travel. The pores can be filled with water, which is necessary not only for the functioning of the Ark's biospheric complex but also for protection against radiation. Moreover, the substance of the armor will become a working mass for creating a braking impulse and decelerating the Ark's speed from interstellar to planetary orbital velocities at the end of the journey.

Consequently, the mineral waste of the Lagrange industry in the Earth's orbit (i.e., space industry located at the Lagrange points in the Sun–Earth system) is suggested to be immediately shaped (stored, packed) in the form of protective armor of a future interplanetary ship. For one year of work, such an industry can equip, if necessary, thousands of such space "Noah's" Arks for traveling to many corners of our Milky Way galaxy.

Energy Security

If at the launch it is possible to use the resources (energy and for the creation of the acceleration impulse) of the spaceport equipped at the Lagrange point of the Sun–Earth system, then for braking at the end of the journey such resources have to be on the Ark's board. Otherwise, the mission of space expansion will not be accomplished – the spaceship will continue its eternal wandering through the Universe until it is swallowed by some black hole.

Interstellar flights require a very high speed (by Earth standards) – even to the nearest star Proxima Centauri, 4.244 light-years away from us, you will have to fly for about 12,800 years at a speed of 100 km/s.

At the spaceport, it is necessary to use the resources of the Solar System to accelerate the Ark, including a special tugboat, for example, similar in function to the first stage of launch vehicles. When accelerating a spaceship weighing hundreds of thousands of tons, it is possible to use a gravitational maneuver around the giant planets Saturn and Jupiter, which will provide a significant total increase in speed – up to 50 km/s – without additional fuel consumption [26]. The same maneuver can also be performed at the end of the journey to reduce the speed, certainly, in the availability of giant planets at the destination point.

The energy component of the Ark should weight about 340,000 tons (with a total ship weight of 540,000 tons), basically, it is a working mass, as it is advisable to use water. It will become a reserve water for biospheric processes inside the Ark, it will be used for replenishment of sea and freshwater reservoirs, in engineering cooling and heating systems and also as an anti-meteorite and anti-radiation shield. Its optimal location is inside the armor pores of the spaceship, which has an average thickness of several meters. Water can be easily withdrawn and returned if required, so it can also participate in the biospheric cycle in the Ark.

The most promising technology for interstellar flights is the ion thruster, an electric rocket engine that generates jet thrust due to ionized gas accelerated in an electric field to speeds of 50–210 km/s [27].

There are 11 stars within a radius of 10 light-years from Earth, the journey to which at a speed of 200 km/s can take up to 15,000 years. The weight of the working mass in this flight will also be 340,000 tons, and the amount of nuclear fuel (in terms of plutonium-239) on board for braking at the exoplanet should be four times higher than for a speed of 100 km/s – 21 tons.

Since the power of the ion thruster and its thrust are extremely low, the Ark will have to accelerate and decelerate for several years (possibly decades).

The main daily energy consumption during millennial flights will be stable and sufficient in intensity and quality lighting of the Ark's internal surfaces, without which the metabolism of an enclosed biosphere-type ecosystem is impossible. Consequently, lighting, its stability and quality over time is one of the most critical onboard energy technologies.

The extractible reserves of nuclear fuel on Earth – uranium-238 (about 5 mln tons) and thorium-232 (2.7 times more) – have a total calorific value about 30 times higher than that of all fossil hydrocarbons (oil, coal, gas). Only this fuel will be enough to equip tens of thousands of Arks with a speed of 100 km/s or tens of Arks with a speed of 1,000 km/s into deep space, as energy costs for traveling at a speed of 1,000 km/s will be two orders of magnitude higher than at a speed of 100 km/s.

Technological Security

Humanity has no experience in creating materials, elements, units, devices and equipment with a service life exceeding a millennium. In the consumer society that currently exists on Earth, the opposite principle applies – the service life should be minimal, so that the consumer buys the same product, only slightly modified, and thus brings as much profit to the manufacturer as possible. Live Nature is organized quite differently: any mother, be it a bacterium or a human being, does not give birth to a child to make money on it. That is why it is necessary to realize biosphere-type engineering technologies in the Ark, which possess the functions of self-recovery ("treatment"), reproduction (division of technological "cells") and other characteristics, and with the potential in the direction of technological progress (not regression), same as in Live Nature, i.e., with the vector of development in the direction from simple to more complicated.

Engineering technologies can work in the dark, but life cannot exist without light: flora and fauna need it. So, there should be an analog of the Sun in the Ark. Note that there are no eternal lamps. If the lighting goes off, the Ark will plunge into darkness, and all living things, except protozoa, will perish. Consequently, the production (and repair) of failed power equipment, lighting devices on board and other devices belong to a critical technology, without the implementation of which the mission of panspermia will become impossible.

Upon arrival to the exoplanet star system (to the Lagrange points, not to the exoplanet itself), we will need landing modules capable of landing on the planet and returning, getting out of its gravity well, back to the Ark. Accordingly, such modules, as well as fuel and working mass reserve for them, are also required to be on board the Ark.

It is unlikely that the exoplanet will be ready for settlement by Earth organisms (in particular, its atmosphere, which should contain about 20 % oxygen and 80 % inert gases safe for metabolism). It may take millennia to adjust the atmospheric composition of the exoplanet, that is why the crew of the Ark coming from Earth should first of all deploy space industry from local raw materials and energy of the local star in the Lagrange points of the Star–Exoplanet system and only then begin the development of the exoplanet. Basic engineering technologies and equipment for the mission should also be brought from Earth aboard the Ark. In addition, the extraction of raw materials from the planets of the star system will be too energy-consuming, because the more massive the planet is, the more difficult it is to land on and then take off from it. So, mineral resources should be extracted from local asteroids and small celestial bodies.

Biospheric Security

Since the goal of interstellar flights is the expansion of humankind and the Earth's life into deep space, it is necessary to fly not in an ordinary spaceship but in the ECH-Ark. It will recreate the best part of the Earth's biosphere for several thousand inhabitants – a small society like a rural

settlement – with all the necessary natural conditions: atmosphere, variety of landscapes, living organisms, soils, biogeocenoses, aquatic ecosystems, etc. The most comfortable physical conditions will also be provided: optimal gravity (by means of centrifugal forces), illumination in the natural spectrum, air atmosphere (with optimal composition, temperature, pressure, humidity, oxygen content) and others.

Thus, the Ark crew for many thousands of years, from generation to generation, will be inside an enclosed ecosystem of the Earth's biosphere type, characterized by a natural cycle of substances and energy, as well as the optimal subtropical climate for human habitation. There will be a genetically diverse "population" – millions of species of the best representatives of living organisms, carefully selected from the billions (if not trillion [28]) of species existing on Earth, taken from all kingdoms of Live Nature: bacteria, viruses, fungi, plants and animals.

Consequently, in the space house it is necessary to simulate in miniature the biosphere of the planet Earth – the cradle of humans with the history of living evolution, numbering billions of years, including the one preceding *Homo sapiens* and recorded in his genes. It is worth presenting in all its diversity the flora and fauna of the Earth's climatic zones favorable for human life, from where we originate with our roots (for example, the ancient ocean roars in our blood – its mineral composition fully corresponds to the composition of marine water), as well as microflora and microfauna – soil biogeocenosis with thousands of species of associations of agronomically valuable aerobiotic and anaerobiotic microorganisms. Such soil will be more fertile than rich chernozem, while the "engineer of fertility," namely an earthworm of many species in the amount of at least 100 pcs/m^2, should work hard there as well.

Fertile soil in the Earth's biosphere is in essence its immune system and the key to the health of all living organisms, including humans. About a trillion microorganisms live in a kilogram of such soil. Without it, it will be impossible to create comfortable and safe conditions in the Ark for flora, fauna and also the crew, as well as for microflora and microfauna in soil and water environments.

The food chain of the biospheric living substance cycle begins and ends in the soil. For example, the basis of the human immune system is the microflora and microfauna of the intestine, which is considered to be soil-based. Tens of trillions of microorganisms of thousands of species live there. They work day and night – feed, drink and even treat us. For a definite reason, many experts call the contents of our intestines the second brain.

Mineral (except radioactive) and organic waste (including sewage) generated in the Ark is processed by microorganisms into biohumus, which is returned to the soil. Through the production of liquid and crumbly biohumus and its return to the soil, the Ark will ensure the circulation of all substances necessary for the life of its biosphere: water, oxygen, CO_2, food for flora and fauna (including humans), as well as the utilization of waste products of all organisms, including in the event of their death, etc.

In the biospheric section of the Ark (Figure 1, zone 1.1), optimal homeostasis should be established at all levels of the organization of communities of living organisms, with due regard for the regulation of abiotic and biotic factors, as well as optimal biosphere trophic chains and biological rhythms. Without this, it is unreal to achieve stability of cenoses in the Ark during the entire flight, which can last for thousands of years [29].

Before being sent into deep space, a fully equipped Ark should be quarantined for one generation (20–25 years) to fine-tune the enclosed biosphere-type ecosystem and the human society inside it in order to identify and correct imbalances, including time-delayed ones, which otherwise could not be avoided during the subsequent millennial journey.

Food Security

The annual need of a crew consisting of 1,000 people, comprising children, in organic food (cereals, bread, legumes, potatoes, vegetables and melons, fresh fruits and berries, meat products and fish, milk, eggs, etc.) is about 700 tons, or approximately 700 kg/person. Modern intensive agrotechnologies allow to cultivate annually in greenhouses agricultural products in the amount of 10–50 kg/m^2 (depending on crops), which will require on average up to 50 m^2/person of cultivated area.

Organic farming, including feeding plants with biohumus (crumbly and liquid) and animals with microgreens cultivated in vertical farms and chlorella grown in ponds, will require more fertile land (soils and ponds) in the ECH-Ark – about 100 m^2/person, and considering the food needs of farm animals and aquaculture – about 150 m^2/person. Another 50 m^2/person is needed for recreation areas, walking paths, playgrounds and other public spaces. Thus, the area of residential zone 2.1 in the Ark (Figure 1) should be approximately 200,000 m^2.

All horizontal surfaces in the residential zone, including the usable roofs of residential buildings and agricultural farms, should be occupied by fertile soil and participate in biospheric processes, comprising oxygen production and CO_2 absorption, as well as in the production of organic food. The multi-tiered arrangement of soils in vertical farms of the Ark will provide at least 500 m^2/person of producing soils, of which about 10 % is needed for oxygen production (considering the use of chlorella), 50 % – for growing plant food, 40 % – for animal food [29].

Resource Security

Inside the Ark a circulation of resources (substances) should be arranged, except for energy resources: they are irretrievably being lost and converted into heat energy, which is eventually radiated into space. Losses of substance, both inorganic and organic, should be minimized. For example, it is inexpedient to bury deceased people in space: irretrievable biosphere losses in organic substance for thousands of years of travel may amount in this case to tens of thousands of tons.

The living (biospheric) substance in the Ark is mostly fertile soil made of biohumus, i.e., insoluble salts of humic acids, with all the necessary set of macro-, micro- and ultramicroelements and associations of thousands of species of agronomically valuable soil aerobic and anaerobic microorganisms that enter into a complex symbiosis with the flora growing on this soil. Without them, as without earthworms, any most fertile soil becomes dead soil.

There should be a sufficient amount of biohumus in the Ark: based on a minimum calculation – at least 10 t/person. As in the Earth's biosphere, the amount of humus can be increased over time due to the conversion of part of the Ark's inorganic substance into organic substance. Biohumus is not only needed to ensure fertility; it will also provide additional protection against space radiation and meteorite threats by covering the inner surface of the Ark.

Materials and technological (dead) substances will be presented basically in the form of water, mainly as a working mass for obtaining braking impulses near the exoplanet. For example, in one of the versions, the weight of the working mass should be 340,000 tons with the initial curb weight of the Ark being 540,000 tons, i.e., the weight of the Ark after braking in the star system of the exoplanet will be 200,000 tons.

Additional stock of carbon (the main chemical element in the cells of living organisms), as well as macro-, micro- and ultramicroelements, will be concentrated (in addition to biohumus of soils) in thousands of tons of brown coal because it includes a balanced mineral component of ancient terrestrial living organisms (more than 80 chemical elements) that lived on Earth hundreds of millions of years ago, and the energy of the ancient Sun, which can be additionally used in the generation of energy on board the Ark.

Upon arrival to the exoplanet, the need for energy and mineral resources should be satisfied by the energy of the Star and resources of local asteroids and small celestial bodies, since such a space mining industry, created from scratch, will be less energy-consuming and more efficient than any similar planetary industry. Thus, the depth of the gravity well of a planet similar to Earth exceeds 6,000 km (with conditionally unchanged gravity, not with really decreasing gravity as you move away from the center of the planet), so it is inexpedient to extract resources in a "mine" of such depth and deliver them to the "surface" (in this case, to near space). It is easier to extract resources by the open pit mining on the surface, i.e., in near space on local asteroids for the panspermic space industry located there as well.

In this case, the main energy resource for the mission of space panspermia will be nuclear and thermonuclear materials of our Universe, and not, for example, stellar (solar) energy, as most researchers believe.

Social Security

What should the human society in the Ark be like? It is obvious that none of the known social arrangements – primitive communal, slave-holding, feudal, capitalist, socialist, or communist – is unsuitable for interstellar flights in a limited population in a limited in size and resources enclosed space (what is not a social Petri dish?).

All known social forms and patterns have in one way or another been built around various kinds of carnal consumption. The capitalist form of social structure, which dominates in today's earthly civilization, is especially dangerous for sustainable development. Capitalism in its pursuit of gains, maximization of consumption of everything and anything, and dominance in global governance inevitably leads to extremes: the destruction of the family, the individual and other fundamental universal values of life. The eight billionth earthly humanity is a civilizational achievement, not a tragic mistake, as the capitalist extreme globalists who preach the idea of a "golden billion" want to present to us, Terrans. It is the consumer society's perverted view of human physiology that leads to LGBT, gender reassignment and even cannibalism, which makes such a society unviable and causes its demise in the short term (by historical standards).

The space Ark not only needs the genetic diversity of millions of species of living organisms but also requires specialists of many professions of one intelligent species

that equipped such a complex in execution and functioning expedition – *Homo sapiens*.

The ECH-Ark represents the Earth's biosphere in miniature and is the most sophisticated flying vehicle autonomously existing for thousands of years with all civilization achievements: its energy, engines, fuel reserves and exhaustible resources (not participating in the biospheric cycle), utilities, repair base, housing and production facilities, farming equipment, agro- and aquaculture, kindergarten, school and university, medical and service institutions, etc. In other words, the Ark will need highly qualified specialists in at least 100 areas, not only during the launch but also after the journey of many millennia.

A stable society, such as small tribal nations and ethnic groups, which have carried their customs, traditions, culture, lifestyle and other national characteristics through millennia, has at least 1,000–2,000 people. In the Ark, unlike a tribe, where a chief, pagan priest, or shaman is enough to govern, all civilization achievements of modern humankind should be present: science (research laboratories and engineering design bureaus), education (preschool, school and higher education), art, sports, medicine, production (industrial, repair and restoration and agricultural), etc. The Ark society should be sustainable, capable of self-development and improvement, and at the same time not religious but reasonably engineering. Perhaps the best organizational form of the society is in the form of Russian communities or Jewish kibbutzim.

Such a society should have its charter (constitution, legislation), which should be followed for thousands of years of flight, where everything, absolutely everything, is well-thought-through, with surgical precision fine-tuning: physical, social, spiritual and moral. For example, with an average life expectancy of 100 years and a population of 1,000 inhabitants, 100,000 people will die in 10,000 years, however, the Ark should not turn into a continuous cemetery. This means that we need our customs, rituals and laws in the funeral business. In addition, the longevity of each person and their ability to take care of their health is important, so while building the crew of the Ark it is necessary to give preference to the people who are genetically, spiritually and morally predisposed to longevity.

The society is a special social organism, which is also to be optimized with the help of social engineering. It should not be transferred from the mother planet, but created in the Ark in the best form from scratch. Actually, all socioeconomic formations on Earth were built not by a reasonable man (engineer), but by a shaman, pagan priest, politician, military leader, official, or businessman – it is more important for them not to develop the society as itself but to use it to strengthen their power, personal wealth and prosperity.

Earthly social engineering – for example, the language of communication (information engineering), the Ten Commandments (social engineering), the twelve tenets of the Moral Code of the Builder of Communism (ideological engineering), etc. – is aimed at preserving society rather than developing it. And even this Code, which is based on religious commandments, is the construction of another prosperous "hive" or "anthill" but not the education of a socially oriented intelligent inhabitant of the space home named Planet Earth [16, 22].

It is necessary to maintain a balance in the Ark – the development of a closed society should not be directed against it (for example, there should be no crime, terrorism, drug addiction, etc.). What is "good" and what is "bad" for the society, in fact, has long been prescribed in religious commandments (probably by extraterrestrial intelligent civilizations visiting the Earth) – in the same Ten Commandments of Christianity [30], which can be reduced to certain postulates: through the Word of God and involvement in the services of the Church to arrange one's life: family, work, interests, hobbies, relationships with people, attitude to life in all its manifestations – everything is organized and settled through the commandments of God; struggle with sinful habits and passions; traditional family values [31].

Information Security

After the launch of the first Ark, after a certain period of time (e.g., a year) the second Ark will depart from Earth with the expectation that it will arrive at its destination at the same time as the first Ark, i.e., it should run at a slightly higher speed. At the same time, Ark-2 will eliminate the shortcomings of Ark-1, which became known in the process of radio exchange, and make important additions and improvements resulting from the progress of the Earth's humanity over the past year. Thus, a string of thousands of Arks will eventually fly to the exoplanet. This will ensure the success of the mission at the stage of an extra-long journey, as the constant radio exchange will provide up-to-date information and mutual assistance, and if required, a space shuttle will be launched from the nearest Ark (whether ahead or behind) to physically rescue a spaceship in distress (each Ark will be equipped with such a shuttle for landing on the exoplanet).

Consequently, all the Arks with a total population of millions of people, with Earth's technological power, without which colonization of the exoplanet is impossible, will reach their destination at the same time. The spaceships during the journey will be within radio visibility, comprising their home planet, so they will know any nuances of the technological, moral and spiritual development of the mother civilization. During the travel of the caravan, the Arks will have access to all relevant information necessary for the progress of the mission thanks to radio communication with each other and the Mother Earth's civilization.

Artificial Intelligence (AI) will be an important component of space panspermia and will be a servant, not a master of this mission. AI is just a machine for processing and generating information, which means that in the Ark society, it must fulfill the function that the subconscious mind performs in the human body. Our subconsciousness is responsible for controlling all systems, organs, tissues and cells of the human body (and there are about 50 tln of them!), because the consciousness is not able to process such an amount of information. And as the subconscious mind is controlled by consciousness, so the AI in the Ark should be controlled by the collective mind of the society made up of the personalities of the crew of the interstellar ship.

Prospects for Civilizational Panspermia

Several billion atoms (dozens of types of chemical elements with trillions of links between them) came together billions of years ago to form a sophisticated spatial structure, i.e., a DNA molecule (and those, in turn, into cells) – that's how life appeared. Tens of billions of neurons united into the brain and made trillions of connections – this is how the mind and intelligence appeared. Billions of people aggregated into a universal planetary society (with trillions of trillions of ties between them) – that's how engineering civilization appeared. And there is no need to artificially reduce the number of people living on the planet, it will be about the same "benefit" for a human being as reducing the number of nerve cells in their brain, for example, to that of a hamster's brain (approximately a thousand times less).

Accordingly, it is civilizational panspermia that is the vector of the civilizational development of extraterrestrial engineering civilizations. Having established on one of the planets, the Engineering Mind is simply obliged to spread itself to the whole available dead part of the Universe, making it alive. There is enough space and resources for trillions of intelligent beings, but not machines, including AI.

The EcoSpace program opens up prospects for civilizational panspermia to the inhabitants of the Earth: by solving formidable and distant tasks, it responds to the challenges that society is facing now. Step by step, implementing the technological and socioeconomic transformations suggested by the EcoSpace program, we are approaching prosperity much brighter and longer than all the dreams of humanity articulated so far.

Conclusion

We, the current generation of Earth's inhabitants, haven't inherited our planet from our ancestors but have borrowed it from our descendants. We must repay this debt, otherwise we will deprive ourselves of a future, as the terrestrial technogenic human civilization will simply disappear from the face of Earth.

No doubt implementing the EcoSpace program will require overcoming a significant number of challenges, not only of engineering and technical nature. However, all of these challenges pale in comparison to the problems and existential threats that will inevitably arise if humanity does not take urgent action now.

The author of the EcoSpace program, engineer Anatoli Unitsky, has created a unified coherent concept of the New World, filled with expansive ideas for rapid economic growth and industrial progress within the Earth's technogenic civilization.

The EcoSpace program describes cost-effective and comprehensively justified engineering, technical and socioeconomic solutions designed to save humanity from degradation, extinction and death.

Anatoli Unitsky with the representatives of his scientific school and his followers express their interest in the EcoSpace program becoming a universal heritage and leading to the creation of a more advanced world, thriving in an ecooriented principle: "Earth – for Life. Space – for Industry."

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Section

GEOCOSMIC AND GEOTECHNICAL SCIENCES, TECHNOLOGIES, MATERIALS AND RESOURCES

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Global Environmental Problems of Industrialization of Near-Earth Space

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Any anthropogenic activity is associated with negative consequences for the environment. As the human space expansion advances, the scale of such impact is expanding. The purpose of this study is to forecast and analyze the most significant environmental problems related primarily to the beginning of near-Earth space (NES) industrialization, including the presence of space debris, aerosol pollution of the atmosphere, electromagnetic pollution of NES, luminous pollution of the night sky as well as the impact of launch vehicles launches on terrestrial ecosystems in the process of deployment and maintenance of space industrial infrastructure. At the same time, NES is considered as a part of the global ecological system of planet Earth. In the proposed context, these problems are studied for the first time.

Keywords:
aerosol layer,
electromagnetic pollution,
environmental problems,
luminous pollution,
near-Earth space industrialization,
space debris.

Introduction

Near-Earth space (NES) is an integral part of the global ecological system of planet Earth. There are at least two grounds for such an assertion. Firstly, near space has actually already become a sphere of human activity. Secondly, the distribution of life is not restricted to the lower levels of the Earth's atmosphere. Microorganisms (spore forms of bacteria and micromycetes) retain their viability in outer space. This fact was proved by exposing the microorganisms–substrates systems on the outer shell of the International Space Station (ISS) for one and a half years [1].

In the future, the relocating of harmful, dangerous and energy-intensive industries to NES will turn Earth into a blooming garden. However, along the way, it is necessary to solve a number of environmental problems of a global nature. Their origins have already been identified: they are escalating in parallel with achievements in space exploration.

The environmental issues directly related to the NES industrialization should include:

- pollution of NES by industry-related fragments, i.e., space debris;
- aerosol pollution of the stratosphere and upper atmosphere;
- electromagnetic pollution of NES;
- luminous pollution of the night sky;
- the impact of launch vehicles on terrestrial ecosystems.

The abovementioned types of impacts on the global ecosystem are still occurring but on a significantly smaller scale compared to what might be expected in the future as space industrial development continues.

Pollution of Near-Earth Space by Industry-Related Fragments

Over the past 60 years, the amount of orbital debris has increased exponentially due to various factors. These include the expansion of the orbital grouping of active spacecraft due to the spent stages of launch vehicles and space tugs which ceased active operation and remained in orbit. Deliberate and accidental explosions and collisions between space objects have also contributed to this issue. With the further development of the space industrial infrastructure, additional sources of space debris will be added, including orbital factories and docks for the assembly of heavy spacecraft, refueling orbital stations, research laboratories, etc. The possibility of waste-free operation of such objects is highly questionable: for example, flakes of detached thermal insulation or condensed frozen particles of gas emissions should also be considered as dangerous space debris, not to mention abnormal emissions into space of various metal and plastic objects, and even more so of emergency products.

According to the United States Space Surveillance Network and ESA statistical modeling, today there are about 34,000 objects larger than 1 cm in near-Earth orbits, including about 8,300 active satellites, 900,000 objects from 1 mm to 1 cm and more than 128 mln objects less than 1 mm [2, 3].

The period of ballistic existence of low-orbit space debris varies and depends on the altitude of the orbit. Naturally, the closer to the atmosphere, the smaller it is, and vice versa. The lifetime of debris in orbits from 250 to 550 km ranges, depending on the midsection of a single fragment, from weeks and months to tens of years (Figure 1).

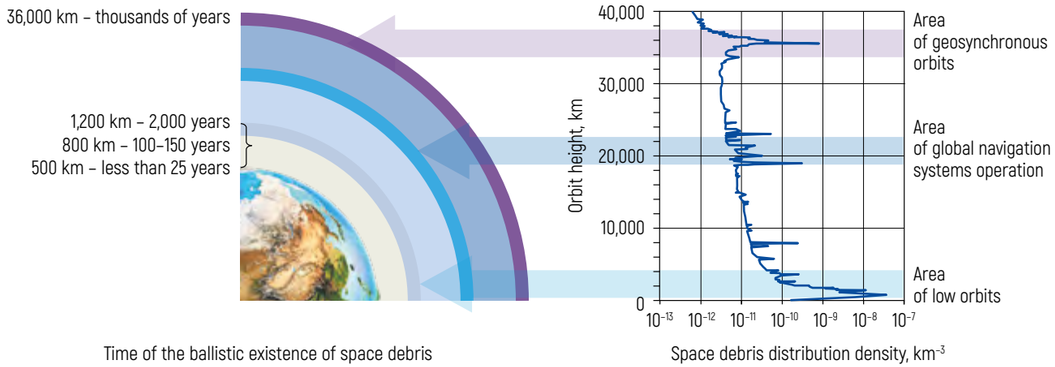


Figure 1 – Dependence of the ballistic existence time and flow density of the space debris on the orbit height

From an altitude of about 800 km, the resistance of the atmosphere weakens so much that space debris can remain there from 100–150 to 2,000 years or more (at an altitude of 1,200 km). The time of its ballistic existence in the area of global navigation systems operation (20,000–22,000 km) and in geostationary orbit (≈36,000 km) has been many thousands of years. However, the spatial density of pollution of these orbits is tens and hundreds of times less than that of low-Earth orbits.

For the large-sized spacecraft such as the ISS, the probability of a collision with a fragment larger than 1 cm capable of penetrating the shell of the station today is 10^{-2}–10^{-3} during a year of flight[1]. This is considered to be a high risk; therefore, special multilayer protective screens are used in the design of the ISS modules and evasive maneuvers are provided as well.

As for automatic spacecraft, it can be fatal for them to encounter even a millimeter-sized debris particle, not to mention larger fragments (the energy of an orbital collision with a 1 mm particle is 1 kJ, which is equivalent to the energy of a bowling ball thrown at a speed of 100 km/h).

In the future, it is possible that a chain reaction of self-replication of space debris population will make the use of NES impossible: any object launched into orbit will almost immediately collide with a fragment of debris.

The hypothesis of cascading self-propagation of space debris in mutual collisions of garbage was first put forward by NASA consultant D. Kessler in 1978 [5] and was named the Kessler syndrome (effect).

Information obtained during the modeling process conducted by NASA and seven other space agencies – members of the Inter-Agency Space Debris Coordination Committee – indicates that even if all space activities were to cease, the amount of debris in near-Earth orbits would continue to increase in the years to come [6].

Today, there are many attempts to determine the moment of onset of the Kessler syndrome based on various models and scenarios of space debris formation. The results of these forecasts range from denial of the possibility of a cascade effect, to the conclusion that it is already happening in some orbits, at least within a small unobservable fraction of space debris.

Extrapolation of the current growth rates of NES pollution leads to an unstable situation with exponentially increasing collision frequency (Figure 2).

[1] Possibility of non-breakdown means the parameter defining the possibility of breakdown of the containment square unit in a unit of time. According to NASA, its value is agreed as 10^{-5} $m^{-2} \cdot year^{-1}$ [4].

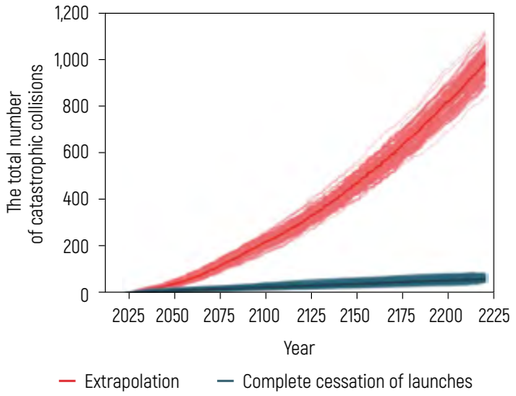


Figure 2 – Collision frequency forecast based on the LEOIADC model, taking into account accepted scenarios for the long-term development of space activities [7]

One of the basic principles of preventing space debris formation is the removal of decommissioned cosmic objects from the protected areas of NES, namely low-Earth and geostationary orbits, where there is no natural self-cleaning mechanism. However, 20–40 % of satellites that have completed their operation over the past decade are not able to independently descend from low-Earth orbits [7, 8]. In geostationary orbits, there are measures in place for such satellites to be removed from their current positions. At the same time, the success rate of these withdrawals is between 0.6 and 0.9 [7, 8].

There are polar opinions regarding the Kessler syndrome. The misconception of its inevitability rests on the assumption that all space debris fragments will stay in NES, where it risks colliding with satellites and other fragments. However, the kinetic energy of the colliding bodies is partly spent on destroying them and partly absorbed by each other, as a result of which the emersed swarm of fragments ends up in elliptical orbits with a perigee height located inside the Earth's atmosphere. Bodies in these orbits manage to slow down and burn up before they experience another collision.

At the same time, there is known experimental data of the near-zero impulse transfer during high-speed collisions of objects in space. Thus, the kinetic energy of colliding bodies does not actually decrease. And considering the fact that there is an explosive increase in the number of space objects in the low-orbit area, namely small spacecraft from multi-satellite groupings, and based on the likelihood of triggering effects that can significantly increase NES pollution, it is not possible to exclude the onset of the Kessler syndrome. The abovementioned trigger effects should include the fragmentation of large-sized spacecraft which for various reasons remain in their working orbits for a long period.

Currently, there are approximately 50 objects of this type that can be identified. These include, for example, Envisat, the largest satellite launched by the European Space Agency, which has a ballistic lifetime of 150 years, and NASA's Quick Scatterometer Earth satellite, which will remain in orbit for 90 years.

The controlled withdrawal of space objects that no longer function is carried out to the so-called Nemo Point – the least biologically active region of the World Ocean, located in the Pacific Ocean (48°52′ South Latitude and 123°23′ West Longitude) 3,300 km from the east coast of New Zealand.

Aerosol Pollution of the Upper Atmosphere

Aerosol in the form of liquid droplets and mineral solid particles of submicron size is found both in the troposphere and in the stratosphere as well as in the upper layers of the atmosphere (100 km or more). Atmospheric aerosol is characterized by a complex layered structure [9] (Figure 3).

Aerosol in the stratosphere has a sulfate base. It is formed from gases containing sulfur, and the most common among them in the atmosphere are carbonyl sulfide and sulfuric acid vapors [10].

In the structure of the stratospheric aerosol, a relatively stable Junge aerosol layer is allocated at the general background level, the maximum particle concentration in which corresponds to altitudes of 22–26 km in the equatorial belt, 17–22 km in the middle latitudes, decreasing parallel to the tropopause to 17–18 km in the polar regions. The layer is formed by drops of a high concentration sulfuric acid solution. The replenishment of the Junge layer is currently carried out by eruptions of large volcanoes during the oxidation of sulfur dioxide which makes up a significant part of volcanic gases [11].

At altitudes of 50–55 km, areas of increased concentration of mesospheric aerosol are distinguished at the background level. The thickness of this layer increases during periods of frequent volcanic eruptions. At altitudes of 60–70 km, there is a double quasi-stable aerosol layer. Stable aerosol layers are observed at mesopause heights of 80–85 km. After the passage of meteor showers, aerosol layers often appear in the lower thermosphere, above 95 km [12].

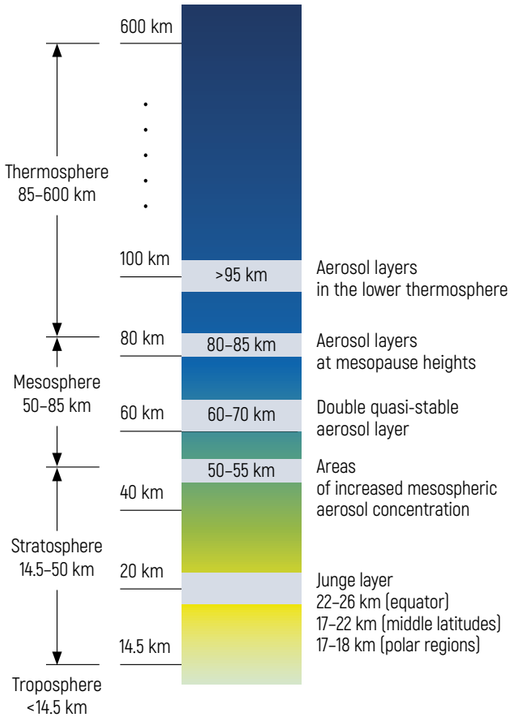
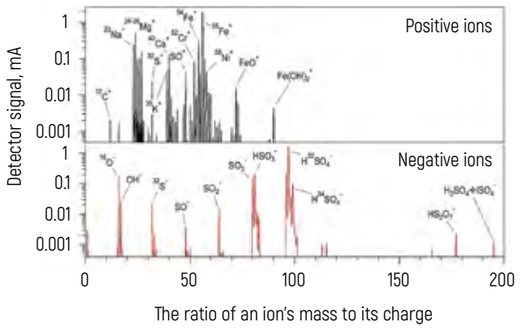


Figure 3 – Structure of atmospheric aerosol layers

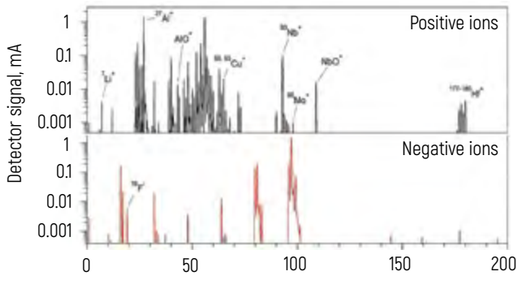
Among the sources of atmospheric aerosol formation, the collapse of artificial space objects in the atmosphere, particularly low-orbit small spacecraft, is playing an increasingly significant role. First of all, we are talking about the global multi-satellite Starlink system which will include tens of thousands of such devices. In total, there are about two dozen design studies for promising multi-satellite groupings underway around the world. It is predicted that by the end of this decade, there will be more than 57,000 small spacecraft in low-Earth orbits. [12]. In the future, the sources of aerosol formation will also include objects and technologies of the space industrial infrastructure.

According to source [13], stratospheric sulfuric acid particles already contain lithium, aluminum, copper, lead and other elements in ratios used in spacecraft structural

materials and in quantities exceeding the influx of cosmic dust of these metals into the Earth's atmosphere (Figure 4).



a)



b)

Figure 4 – Spectra characteristic
of a typical sulfuric acid particle:
a – with meteoric metals;
b – with meteoric metals and metals obtained upon entering
the atmosphere of a spacecraft, including niobium and hafnium
(only peaks are noted, which are significantly enhanced) [13]

The planned increase in the number of satellites in low-Earth orbits over the next few decades may lead to the fact that up to half of the stratospheric sulfuric acid particles will contain metals formed during atmospheric entry.

According to source [13], aerosol particles with a high aluminum content from spacecraft structural elements have at least 70 % of the total amount of aluminum found in stratospheric particles. The aluminum flux from meteoroids is estimated at 130 t/year, of which about 20 t/year is floated away, i.e., ablated. About 210 t/year of aluminum ablates are formed from space debris (spacecraft, stages of launch vehicles) entering the atmosphere.

The accumulation of aerosol in the atmosphere can cause various kinds of meteorological and climatic effects. These include:

- impact on the processes of cloud and precipitation formation due to changes in the microstructure of cloud particles;
- influence on the processes of transfer of solar and thermal radiation in the atmosphere and thereby on the temperature regime of the Earth's climate system.

At the same time, depending on the properties of aerosols, the structure and dynamics of aerosol layers, the consequences of these effects can vary significantly – from drought to a sharp cold snap [14].

Electromagnetic Pollution of Near-Earth Space

Currently, electromagnetic pollution is global in nature, and the electromagnetic situation in NES is significantly influenced by ground-based power lines (Figure 5) [15].

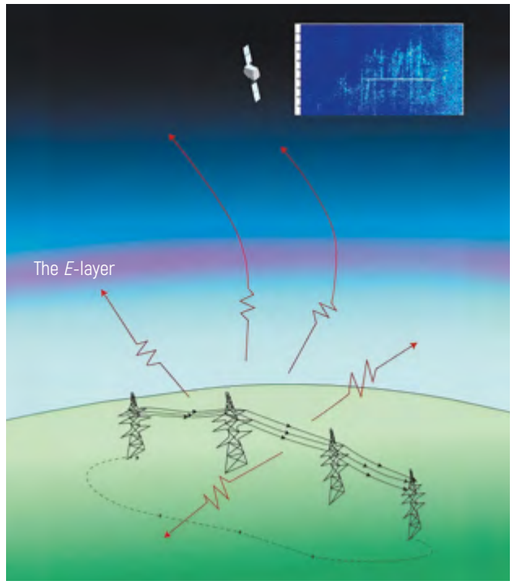


Figure 5 – The process of appearance of ground-based power line emission in the ionosphere and variations (noises) of electric field from ground-based power lines at the height of satellite orbit

Thus, observations of the Chibis-M and DEMETER satellites made it possible to register the spectral amplitude of emission from ground-based power lines in the range of 1–18 (μV/m)/Hz, which corresponds to the amplitude of the electric field ≈1 μV/m. To date, the emission intensity of power lines at frequencies of 50–60 Hz in NES turns out to be higher than the intensity of natural radiation in this range (Schumann resonances and ion whistles) and continues to increase with the technological development of humankind.

As for interference in NES, namely electromagnetic noise from space objects, so far this is important only for radio astronomy. In particular, in July 2023, the Low Frequency Array (LOFAR) radio telescope detected radio noise emission at relatively low frequencies (110–188 MHz) from SpaceX Starlink satellites [16][2]. Several narrowband as well as multiple broadband emissions were recorded in the entire specified range. The source of unintended artificial interference is radiation from onboard electronic facilities and electrical components of spacecraft.

With the increasing number of spacecraft in a multi-satellite grouping, the electromagnetic pollution of NES will increase as well, since the radiation from all satellites is added together [16]. As the production infrastructure in near space develops and electromagnetic pollution increases, individual spacecraft, orbital production modules and multi-satellite groupings will interfere with each other and affect the ionosphere.

Penetrating into the ionosphere and magnetosphere, electromagnetic pollution can cause a change in the ionization level of the near-Earth environment, which in turn can affect the quality of radio communications [17]. The ionosphere is an open nonlinear dynamic system. The high degree of its ionization and heterogeneity of its structure cause the nonlinearity of the manifestation of various physical, chemical and photochemical processes in it [18].

The nonequilibrium and nonlinearity of the ionosphere lead to the localization of electromagnetic energy in space-time structures which can disrupt the operation of satellite navigation and data transmission systems, among other things.

Sufficiently powerful electromagnetic influences, both from below (radio waves, television, radar signals, rocket launches, powerful explosions, etc.) and from above (objects of the space industrial infrastructure), disrupt the stability of the ionosphere, which leads to nonlinear effects that are currently impossible to predict.

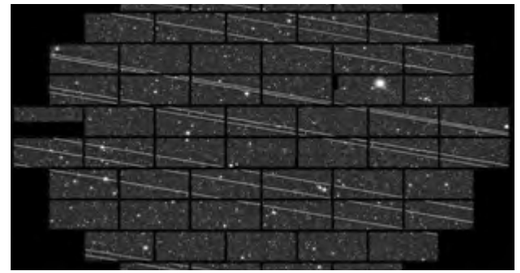
[2] For wideband access to the Internet, Starlink uses the range of 10.7–12.7 GHz.

Luminous Pollution of the Night Sky

Due to the deployment of multi-satellite orbital groupings, the problem of light interference for astronomical observations has emerged relatively recently [19]. There is even an opinion that astronomy has reached a critical point due to the impact of Starlink. Satellites can interfere with ground-based observations, making it more difficult to differentiate between artificial satellites and natural objects like asteroids and comets.

The thing is, at dusk, the sun's rays reflect off the surface of the flat, phased antennas of Starlink satellites. This causes light trails to appear in the original images of the night sky, and the glow from a single Starlink spacecraft can range from the third to seventh magnitude (Figure 6) [19].

a)



b)

Figure 6 – Luminous pollution of the night sky:
a – Starlink satellites depicted over the Netherlands;
b – Starlink satellites on an astronomical image mosaic
(National Optical-Infrared Astronomy Research Laboratory – NOIRLab)

SpaceX has met astronomers halfway and for more than three years has been launching satellites, the brightness of which has been reduced by about 4.6 times (the exact

value depends on the wavelengths that the equipment captures) due to two reasons:

- the use of a special coating for the flat antennas with phased arrays, known as DarkSat technology;
- the installation of a special visor to protect the antennas from sunlight, called VisorSat.

It should be noted that the total number of spacecraft in multi-satellite groupings belonging to different operators, as well as the number of failed devices, will increase in the future. Probably, not all operators will agree to take the above measures or similar ones.

However, a more serious luminous pollution of the night sky will occur in the case of the deployment of an orbital lighting system for certain areas of the Earth's surface [20]. Unfortunately, such projects still exist (Figure 7) [21].

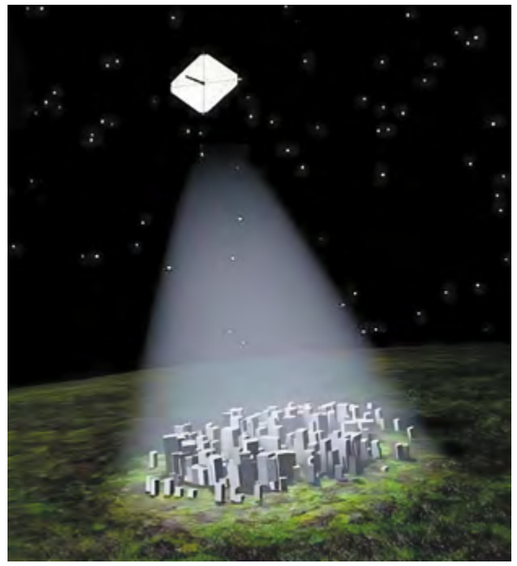


Figure 7 – Illuminator satellite

Luminous pollution is a type of physical pollution of the environment that can lead to various kinds of physiological disorders in plants and animals and even to the destruction of ecological systems due to changes in competitive interactions and predator–prey relationships [22]. As a result of the research, it was found that luminous pollution of freshwater locations disrupts the nutrition of zooplankton, which causing water blooms and, eventually, waterlogging [23].

The impact of light at night on a person and the disruption of circadian rhythms, also known as desynchronosis, are considered to be one of the main factors leading to a violation of the body's homeostasis [24]. Desynchronosis can lead to decreased mental and physical performance, insomnia, depression and digestive disorders [25]. There is unconfirmed data from the International Agency for Research on Cancer (IARC) regarding the carcinogenic effects that may arise as a result of night shift work, namely Group 2A carcinogens [26]. Finally, luminous pollution destroys nitrate radicals, preventing a natural nighttime decrease in atmospheric smog [27].

In the future, the deployment of space industrial infrastructure facilities will require special measures and technical solutions to prevent luminous pollution.

Impact of Launch Vehicles on Terrestrial Ecosystems

The most challenging aspect of space industrialization is the task of establishing a cargo flow capable of creating an industrial infrastructure in NES. A radical solution to this problem may be the General Planetary Vehicle (GPV), a geocosmic aircraft proposed in 1982 by A. Unitsky [28], which is currently being developed by Astroengineering Technologies LLC.

To ensure the industrialization of NES at the initial stage, it is likely that heavy and possibly superheavy reusable launch vehicles will be used. They will have liquid engines powered by a fuel pair of liquefied natural gas, or methane, with liquid oxygen. The prototype of such a transport system is SpaceX launch vehicles: Falcon 9, Falcon Heavy and Starship (Figure 8) [29, 30].

Due to the nontoxic nature of rocket fuel used in launch vehicles of a promising transport system, as well as to the fact that there will be no need to designate areas for the separable parts (rocket blocks) to fall, the impact of launches of such rockets on terrestrial ecosystems will primarily be acoustic. This is confirmed, in particular, by the environmental assessment of Starship launch vehicles [31].

Analysis of the maximum sound level in the area of the launch site of the SpaceX Starbase (USA) during the launch and flight of Starship/Super Heavy shows that at distances greater than 2.3 miles (≈3.7 km) from the launch site, the noise levels become lower that the maximum permitted value of 115 dB.

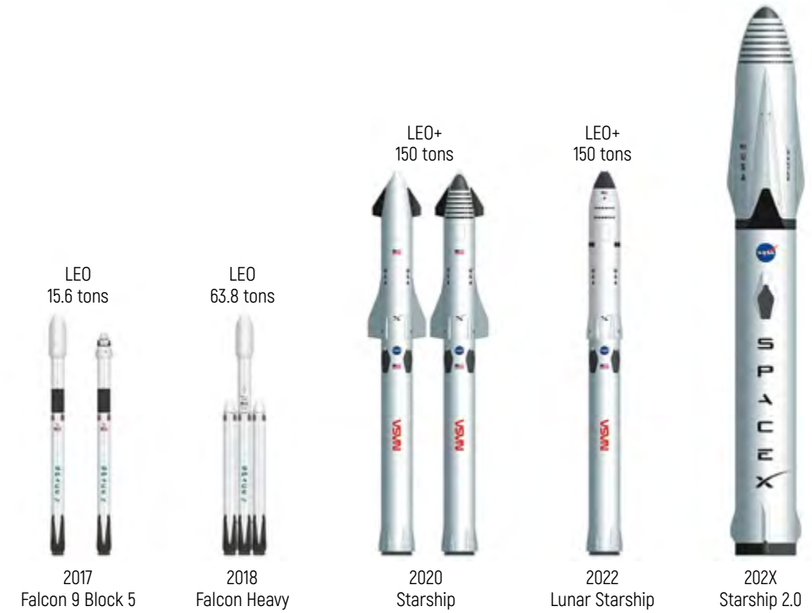


Figure 8 – SpaceX launch vehicles

However, due to the extremely large amount of energy locally released during launch and in flight of a superheavy carrier in various geospheres, including the ionosphere and NES, even a single launch can become crucial for the environment. The sources [32, 33] formulated a hypothesis regarding the mechanisms of possible initiation of trigger effects in geoenvironments (geospheres), such as earthquakes, hurricanes and typhoons, emerging as the result of the launch of such a rocket.

The main points of this hypothesis are as follows [34]:

1) geoenvironments should be considered as nonlinear synergetic systems;

2) when launching superheavy-class launch vehicles, physical impacts – potential initiators of catastrophic trigger effects in geoenvironments – should first of all include:

- atmospheric emissions of combustion products of rocket fuel components;
- low-frequency noises and vibrations from the operating propulsion system of the launch vehicle;

3) the initiation of trigger effects requires additional conditions in the geoenvironments that contribute to the development of catastrophic phenomena (pre-accumulated tectonic stress, heated humid air in the area of cyclone formation, etc.);

4) the trigger effect as a result of launching a superheavy-class launch vehicle is not fatal. It can occur with a certain probability.

Other environmental consequences of launches (chemical pollution of natural environments, destruction of the ozone layer, thermal heating, etc.), described, for example, in source [35], are local in nature, short-term and practically have no effect on the ecosystem around the spaceport.

Conclusion

A preliminary analysis of the global environmental problems of NES industrialization showed that:

- such problems will become especially relevant during the transition period, namely at the beginning of NES industrialization; in the future, with the systematic operation of the space industrial infrastructure, many of them will be solved or become less acute;
- the challenges of NES industrialization are significant due to the fact that one or another impact may go beyond

any single geosphere: the consequences of almost any type of pollution are transmitted to the lower geospheres, up to the Earth's surface (lithosphere);

• the impact of NES industrialization on the environment (global ecosystem) cannot be accurately predicted due to the dissipativity and nonlinearity of the properties of the Earth's geospheres (geoenvironments); currently, it is only possible to identify general trends that may lead to a worsening of the ecological situation on our planet.

The analytical calculations presented in the article can be considered as a guideline for preventing and resolving environmental problems of NES industrialization as the space industrial infrastructure is created.

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Space Industry Waste Management

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The results of an analysis present findings at optimizing the waste management within the space industry, a sector projected to generate billions of tons of waste annually in the future. Special attention is given to the ecology of the space environment, energy efficiency and the logistics of recycling technologies as well as the selection of a location for the first process stage of the space industry and zones within the Solar System for waste storage and potential disposal, with a planning horizon of at least 1,000 years.

It is justified that a significant portion of space industrial waste should be placed at the Lagrange points L_4 and L_5 in the Sun–Earth system. The remaining waste should be used as raw material for the production of eco-friendly construction materials and structures, which will be delivered to Earth via the General Planetary Vehicle for the needs of the terrestrial construction industry. Additionally, mineral waste could be utilized to create space "Noah's" Arks for the expansion of humanity and Earth life into deep space, particularly to Earth-like exoplanets.

Keywords:
energy efficiency of waste disposal, General Planetary Vehicle (GPV), Industrial Space Necklace "Orbit" (ISN "Orbit"), Lagrange points, space environment ecology, space industrial waste, space logistics, space "Noah's" Ark.

Introduction

Any industry, including the space one, functions according to a technological scheme: raw materials and energy are input into the system, while product (service) and industrial waste are output produced as a result of extracting the industrial product (service) from the raw materials. It is fundamentally impossible to eliminate waste from technological processes that reduce entropy, in accordance with the second law of thermodynamics. Even the more ecologically advanced forms of life that originated on Earth about 4 bln years ago could not escape this.

Living organisms have had to adapt their complex biotechnological processes, or metabolism, to the biogenic waste produced, including that which results from the completion of life cycles – after death. Consequently, all waste has been integrated into the food (biotechnological) chain. Thus, the biosphere emerged on our planet – a shared habitat for billions of species of living beings, entirely constructed from waste – oxygen in the atmosphere, the protective ozone layer, biohumus that provides soil fertility, etc.

Life on Earth has established a biosphere based on biogenic waste; similarly, the industrial activities in space will inevitably create a technosphere of comparable scale, founded on technological waste. In this regard, the disposal of waste produced by space industry will become highly pertinent in the future, practically following the deployment of the General Planetary Vehicle (GPV) – a self-sustaining spacecraft designed to facilitate large-scale geocosmic logistics.

Space Industrialization and Extraterrestrial Ecology

The era of industrial (technological) exploration of space can only be opened for Earth's technocratic civilization through the utilization of the GPV. This vehicle promises ecological cleanliness and significant logistical potential, capable of delivering approximately 10 mln tons of cargo and 10 mln passengers to space and back in a single trip. Notably, the cost of geocosmic transportation is reduced by three orders of magnitude compared to current launch vehicles. The GPV will act as a crucial link between Earth's civilization and the cosmic technological environment – a technosphere forming around our planet, where humanity, as the primary consumer of industrial output, will continue to live.

The term "ecology" (from the Ancient Greek οἶκος, meaning dwelling or habitat, and λόγος, meaning study) was introduced by the German biologist E. Haeckel in 1869. Meanwhile, the Universe, of which Earth is merely a grain of sand and humanity is a speck of dust, operates independently of this concept. It does not comprehend notions like "hot" or "cold." For instance, a temperature of 10,000,000 K at the center of the Sun – the engine of thermonuclear fusion essential for our nearest star to ignite and for the life on Earth to exist – might seem extreme; yet, it pales in comparison to the billions of degrees reached during supernova explosions. And that's great. These conditions have disastrous effects on Earth due to their level of temperatures and pressures, however, they are also responsible for synthesizing all heavy chemical elements that constitute our planet and every living organism upon it – from bacteria to humans. Indeed, we are made of stardust, which was expelled at high speed during the explosion of supernova, sweeping through nearby star systems and planets, "polluting" the surrounding cosmic space, consisting of hydrogen and helium, with elements from the entire periodic table. This cosmic "pollution" is perhaps more accurately viewed as "enrichment," as all planets and living organisms that emerged subsequently are composed of this "dirt."

Thus, the concept of "ecology" is not applicable to the Universe: everything occurring within it over billions of years of evolution of dead matter (inanimate matter) is ecological. Consequently, humanity on Earth, along with any extraterrestrial technological (engineering) civilizations, if they exist in our Universe, cannot fundamentally disrupt the ecology of the cosmic environment through industrial activities in space and, then, through the technogenic waste produced by the space industry, as such ecology does not actually exist in nature. The concept of "ecology" is pertinent primarily to "living" planets: those with life and a living environment – a biosphere, as well as for nearby space due to the potential negative impacts of cosmic industry on planetary biospheric processes.

Lagrange Points and Space Industry

In any star system, including our Solar System, there exist Lagrange points (L-points), also known as libration points (from the Latin *librātiō*, meaning oscillation). These points represent regions in a system of two massive bodies where a third body with negligible mass and not influenced by any other forces aside from the gravitational pull of the two primary bodies, can maintain a stable position relative to them [1].

The Figure depicts the Lagrange points within the Sun–Earth system. Similar configurations are observed in the Earth–Moon system as well. In this case, L_4 and L_5 are considered conditional points: they occupy quite large areas. For example, in the Sun–Earth system, the bottom of the gravity well stretches over tens of millions of kilometers, which is sufficient to accommodate all the planets of the Solar System. In contrast, the corresponding region within the Earth–Moon system spans tens of thousands of kilometers.

The triangular Lagrange points L_4 and L_5 are of particular interest within the context of the space industrial environment. These points correspond to the third vertices of triangles, situated 60° ahead and behind the second body in its orbital plane.

At the Lagrange points, gravity is virtually absent. Celestial bodies positioned at L_4 and L_5 find themselves in a state of equilibrium within a gravity well characterized by extremely gentle slopes. If an object at these points is displaced by any external force, it will "roll back" toward the center of the gravity well due to the microgravity conditions. In contrast, the Lagrange points L_1, L_2 and L_3 are marked by unstable equilibrium. Here, celestial bodies reside on the peaks of gentle gravitational hills. If displaced from equilibrium position, they will "roll off" and will not return back without external assistance.

Science fiction writers have long recognized the significance of Lagrange points, creatively placing various objects in these regions. For instance, Larry Niven's features alien artifacts in his work "Protector," while Charles Sheffield's "The Mind Pool" and Andrey Balabukha's "Neptune's Harp" envision these points as sites for garbage dumps. Paul Anderson even imagines entire planets located at Lagrange points in his story "Planet of No Return." Additionally, Isaac Asimov proposed the idea of sending radioactive waste to these points in his essay collection "View from a Height" [1].

Lagrange Points and the First Process Stage

Space production, regardless of its location, should not occur in isolation but rather serve in the interests of their creators and consumers – Earthlings, who number nearly 10 bln people in the future [2–8]. It is fundamentally inhumane to consider relocating people from Earth to other planets, asteroids or into space. The evolutionary history of humanity, spanning billions of years on our Blue Planet, is encoded in the material units of heredity – our genes, located in the chromosomes of nuclei and the DNA of organelles [9]. In our view, there is no more deserving place for humanity to live and work in the Universe, both now and in the distant future, than its cradle – the biosphere of Earth.

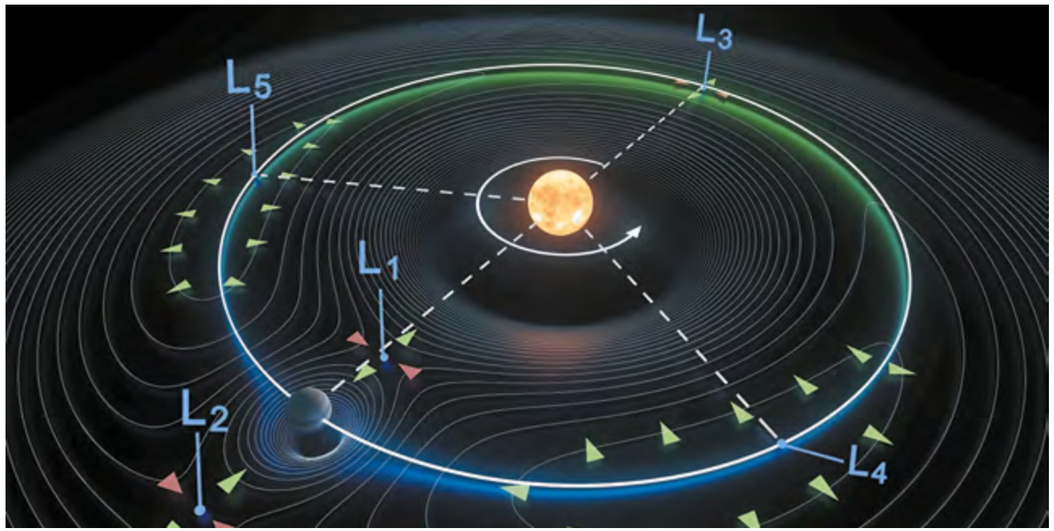

Figure – Lagrange points in the Sun–Earth system

The alien industry, or technosphere, created by humans must be relocated from the planet and its biosphere to a more suitable technological environment, where there is weightlessness and deep vacuum, conditions that are absent on Earth; where there is virtually unlimited access to solar energy and mineral resources. Such resources can be found in the main asteroid belt between Mars and Jupiter. This transition would elevate all existing industrial technologies on Earth to a fundamentally new engineering and economic level. For instance, the entirely metallic asteroid (16) Psyche contains trillions of tons of native metals – possibly the remnants of a destroyed planet's core – such as iron, nickel, gold and platinum, the estimated value of which exceeds 10,000 quadrillion USD [10].

The first process stage for the production of space semifinished products is proposed to take place at the Lagrange points L_4 and L_5 within the Sun–Earth system. These locations are ideal for constructing factories and workshops dedicated to produce semifinished products by processing raw materials sourced, for example, from the asteroid Psyche. A robust energy system harnessing inexpensive solar energy will also be established here, facilitating energy-intensive operations of this emerging space industry, which we propose to call the Lagrangian industry, in recognition of its location. In microgravity environment, industrial waste generated by manufacturing processes can be stored. Waste can be contained within zones enclosed by foil and/or fine mesh. These zones can be solid or hollow, shaped as spheres or cylinders. These configurations are easily achievable under microgravity conditions. This method of space burial will not only serve to contain waste but also as a meteoroid barrier for the space industries situated inside these zones. For instance, a wall constructed in a specific manner from mineral waste with a thickness of 10 m, could protect against meteoroid weighing up to 1 ton traveling at a speed of 10 km/s. Similarly, a wall with a thickness of 50 m could safeguard against meteoroid weighing up to 10 tons.

If the volume of the first process stage exceeds 10 bln t/year of space semifinished products – a figure significantly surpassing the current output of similar production on Earth – then the resulting mass of industrial waste is expected to be approximately double that amount, around 20 bln t/year. To effectively manage this waste, a hollow sphere with a diameter of 100 km and a wall thickness of 1 km could be constructed. The walls of such a structure would require about 30,000 km^3 (50 tln tons) of industrial waste. This volume represents the amount of waste that the Lagrangian industry would generate over a period of 2,500 years. Furthermore, a wall with a thickness of 1 km would provide protection for the inner space of the hollow sphere formed from waste against meteoroid weighing up to 1,000 tons. It is essential that this protective structure be built gradually, prioritizing construction on the side most likely to face incoming space "travelers" to ensure safety.

In the Lagrange zones L_4 and L_5 of the Sun–Earth system, it is envisioned that thousands of such production spheres, each with a diameter of 100 km are supposed to be freely located, which will ensure the space industry operation of the first process stage for millions of years ahead. Initially, these production facilities can be smaller, starting with spheres measuring 100 m in diameter and featuring a protective shell thickness of 1 m.

An essential aspect of this initiative is not only the ecological safety of burying industrial waste at the Lagrange points but also the remarkable energy efficiency of this approach. Alternative ways of waste disposal – such as sending it to the Sun, Moon or deep space (e.g., the asteroid belt) – would be highly energy-intensive. For every ton of industrial waste transported using these methods, the energy required in fuel equivalent would exceed 1 ton of gasoline. Conversely, moving that same ton of waste within the bottom of the gravity well of the L_4 and L_5 zones, where microgravity prevails, would require only the energy contained in 1 g of gasoline to transport it, for example, from the center of a hundred-kilometer hollow sphere to its wall.

Furthermore, dumping industrial waste on the Sun and Moon, even at the first cosmic velocity, could have detrimental effects on the surfaces of these celestial bodies. Such actions could induce tremors – solar and lunar – while also leaving additional "scars" on the Moon. At the same time, not all waste would reach the Sun's surface: depending on their mass and size, some materials evaporate. The remaining waste would be absorbed by the star, just as it consumes billions of tons of comets, meteoroids and cosmic dust each year. Importantly, this influx does not interfere with the ongoing thermonuclear fusion processes within the Sun or affect its luminosity over billions of years.

ISN "Orbit" and Space Logistics

A semifinished product is not yet a finished product, making it more advantageous to produce closer to the end consumer – humanity residing on Earth. This is particularly relevant within the framework of the Industrial Space Necklace "Orbit" (ISN "Orbit"), situated at altitudes of 400–500 km. This location is also ideal for manufacturing final space products,

including chemically pure, high-strength and specialized structural materials and composites as well as pharmaceuticals, electronics, machinery and other equipment.

Logistics between the Lagrangian production facilities and ISN "Orbit" will be energy-efficient, leveraging microgravity conditions along the Earth's orbit around the Sun. Only non-orbital logistics – such as flights to and from the asteroid belt – will necessitate more energy-intensive operations, requiring powerful rocket engines. The type of engine used can vary significantly based on mission requirements, encompassing chemical, ion, electric, kinetic, nuclear, solar sail, etc.

In the ISN "Orbit" zone, it is essential that engines are environmentally friendly, reflecting the values and understandings of Earth's inhabitants, particularly given the proximity to Earth's biosphere. Water being not harmful to the biosphere and essential for life – comprising approximately 75 % of any living organism – serves as an ideal resource for rocket fuel. Thus, rockets utilizing chemical fuel, specifically hydrogen-oxygen rocket engines that produce H_2O as a combustion byproduct, should be employed for launches from Earth's orbit into space. Water transported from Earth to orbit, where it is stored within the ballast system of the GPV, can be decomposed with solar energy. This process yields H_2 and O_2, which can then be used to refuel the tanks of space tugs assembled in ISN "Orbit." Thus, solar energy harnessed from the Sun outside of Earth will be utilized in interplanetary travel, ensuring that these logistics do not negatively impact the ecology of our planet and its biosphere.

Industrial Waste – Building Materials and Energy Source for Earth

Most mineral industrial wastes are chemically inert and environmentally safe. After additional thermal processing in a vacuum – such as sintering with concentrated solar radiation, which can be easily harnessed in outer space – these materials are intended for use on Earth as durable and lightweight (foamed) building elements, including bricks, blocks, facing tiles, panels, etc. Some of this waste can also be recycled, again with solar energy, weightlessness and deep vacuum conditions, into binding substances like cement and its stronger analogs. In relation to the Earth's surface, these orbital construction products possess significant energy – both potential and kinetic – that can be recuperated into electrical energy upon landing on Earth through the GPV.

A key feature of the GPV operations is that its mass with cargo should remain approximately the same during takeoff and landing. If the balance is not maintained, the flight modes can become suboptimal, leading to higher accelerations or significant energy losses that must be discharged into the environment as heat. To address this, a ballast system is essential. For ascent to space, it is advisable to use water as ballast, which can be converted in orbit into hydrogen-oxygen fuel for space tugs. As return ballast for the GPV, building materials obtained from industrial waste in space should be employed, along with a certain surplus.

Every additional ton of cargo delivered to Earth will provide the GPV with energy approximately equivalent to that contained in 1 ton of oil. Therefore, if the annual return cargo flow from space exceeds the direct cargo flow by 1 bln tons, this is energetically equivalent to extracting 1 bln tons of oil on Earth. In this scenario, industrial waste effectively becomes an eco-technological solution "2 in 1": serving both as a building material and as an extraterrestrial source of green energy.

Thus, it is anticipated that, oil extraction and the production of mineral building materials on Earth will cease, eliminating the need for oil wells and quarries for construction raw materials. Only the production of organic building materials, substances and fuels will remain, such as wood processing and the production of alcohol from plant materials, as alcohol is a more environmentally friendly fuel compared to natural gas, which is recognized as the greenest fuel.

The quality and quantity of construction products obtained in space can be significantly improved while simultaneously reducing raw material consumption and production costs by manufacturing building elements in the form of closed-cell foams. While producing such materials under gravity on Earth poses challenges, the conditions of weightlessness and deep vacuum in space enable the creation of not only mineral foams (such as foam glass) but also various elements made from foamed composites, metals and their alloys, including foam steel and foam aluminum. Foam steel, for instance, can match the strength of traditional building materials like brick, concrete, wood, while also being lightweight, with a density ranging from 100 to 500 kg/m^3, allowing it to float in water. This material is not only durable and noncombustible, but also exhibits excellent thermal insulation properties due to its foamed structure.

The mass of Earth gradually increases over time due to cosmic dust accumulation and meteor showers. What does an additional 1 bln tons of material per year mean for our planet? If this material were evenly distributed as a thin layer across the entire surface of Earth, it would correspond to a mineral and environmentally clean layer approximately 1 mm thick over the course of 1,000 years of construction material supply. This negligible increase poses no danger to Earth as natural processes are occurring at much greater intensity. Herewith, the relative movement of continents, sediment accumulation on land and ocean floors, mountain growth and land subsidence can measure in meters – and sometimes even tens or hundreds of meters – over the same period.

Space Industrial Waste as Building Material for Long-Distance Space Travel Arks

Interstellar flights demand high speeds; for instance, travelling to the nearest star, Proxima Centauri, which is 4.244 light-years away, would take over 12,000 years at a speed of 100 km/s. To achieve the goal of expanding humanity and earthly life into deep space, travel must not be conducted in a conventional spacecraft but rather in the EcoCosmoHouse (ECH) [11]. This advanced vessel is designed for a sustainable society capable of long-term autonomous existence and progress over approximately 500 generations. This means that a crew size (more accurately, the inhabitants of the ECH) must be numerous – several thousand individuals.

Inside the ECH, an enclosed biosphere ecosystem will be established, characterized by a circulation of materials and energy, and optimized for living in a subtropical climate. This ecosystem will feature a genetically diverse biospheric "population," comprising millions of species from all kingdoms of Live Nature, including bacteria, viruses, fungi, plants and animals.

Such an Ark will require not only genetic diversity but also specialists from dozens, if not hundreds, of professions. It will serve as a miniature version of Earth's biosphere while functioning as a complex, autonomously operating flying vehicle for thousands of years. It will be equipped with its own energy systems, engines, fuel reserves and finite resources that are not involved in the biospheric circulation, engineering communications, maintenance facilities, living and production areas, agrotechnics, agro- and aquaculture, nurseries, schools, a university as well as medical institutions, etc.

A primary safety concern during such extended flights is protection against radiation and meteoroid impacts. At a speed of 100 km/s, even a single collision with a cosmic object, such as an ice chunk the size of a boulder, which has destructive energy comparable to that of a meteoroid weighing 1 ton at a speed of 10 km/s, could have devastating consequences for the entire expedition. Given that the probability of collision is nonzero, the ECH must be fortified with a robust shell made of foamed minerals and metals, several meters thick, especially at its forebody. This armor will not only provide crucial protection but also serve as a repository for minerals needed throughout the journey. In addition, minerals can be utilized as a working mass to create a braking impulse, decelerating the Ark from 100 km/s to planetary orbital speeds upon arrival.

Consequently, it is proposed that the waste from the Lagrangian industry in the Earth's orbit be immediately used to create the protective shell of future interplanetary spacecraft. For instance, this Ark could be designed as a hollow spindle, measuring 1,500 m in length with an internal diameter of 300 m. The internal surface area of such a structure would exceed 1 mln m^2, providing approximately 200–500 m^2/person. This configuration would offer a comfortable living environment for inhabitants. Moreover, the internal environment of the Ark, which includes natural ecosystems, living quarters and production areas, can be structured in multiple layers, significantly increasing the available space.

To achieve Earth-level gravity (acceleration of gravity of 9.81 m/s^2), the "spindle" should be rotated around its longitudinal axis to an angular velocity of 38.3 m/s (one revolution every 24.6 s). A layer of fertile soil several meters thick, covering the inner surface of the ECH, required for planting orchards and forests, will provide additional radiation and meteoroid protection.

In one year of operation, the Lagrangian industry established in Earth's orbit around the Sun will be capable of outfitting dozens of space "Noah's" Arks for journeys to various corners of our Milky Way galaxy, if necessary.

Conclusion

The relocation of industrial production into space promises to fundamentally improve the global ecology of Earth while having no impact on the ecology of the inert cosmic space, where the concept of "ecology" does not exist. It is most reasonable to establish first process stage of industrial production at the Lagrange points L_4 and L_5 of the Sun–Earth system. Industrial waste that poses a danger to Earth's biosphere should remain at these points, forming a protective spherical shell around the facilities. The shell would range from 100 m to 100 km in diameter, with a wall thickness varying from 1 to 1,000 m, effectively shielding the factories and workshops from meteoroids and cosmic dust. Inside these spherical shells, a relevant technological environment for space industrial technologies can be achieved, characterized by deep vacuum, complete

weightlessness (without microgravity) and technological cleanliness (free from cosmic dust and radiation).

An optimal location for the burial of some mineral industrial waste from the space industry is not only the Lagrange points L_4 and L_5 but also the Earth itself. Rather than transporting waste back to the planet, the focus should be on delivering environmentally safe building materials derived from these wastes, primarily foams made from minerals and/or metals. Each ton of such products delivered from space to the Earth's surface is energetically equivalent to extracting 1 ton of oil, as the kinetic and potential energy will be recovered through the kinetic energy of the GPV flywheels, which can be converted into electrical energy for the Earth's energy needs.

Waste generated by the Lagrangian industry in Earth's orbit will also be used in the construction of space "Noah's" Arks, designed with enclosed biosphere ecosystems for autonomous flights lasting thousands of years at speeds around 100 km/s. Launches will be conducted from the Lagrange points in the Sun–Earth system with specialized space tugs. They will carry not only fuel for deceleration at the end of their millennia-long journey but also the working mass necessary for generating a braking impulse. This approach will facilitate the expansion of human civilization and earthly life into deep space, utilizing Lagrange points in other star systems that host exoplanets with conditions suitable for Earth's life forms.

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Origin of “Relict” Radiation According to Hyperuniverse Theory

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Modern data from astronomical and astrophysical observations and measurements regarding the large-scale distribution of the cosmic microwave background (“relict”) radiation (CMBR) which can affect space objects in near-Earth orbit, including the Industrial Space Necklace “Orbit,” are considered. The origin of the CMBR is described based on the Hyperuniverse theory, and the features of its distribution are noted.

There are the key positions and conclusions of the Hyperuniverse theory, through which the laws of periodic changes in the radius, velocity and acceleration of the expansion/contraction of our Universe during its cyclic movement along the four-dimensional hypersurface of the five-dimensional torus of the Hyperuniverse are obtained. The nature of gravity is explained, the structure and properties of multidimensional closed time are outlined, the main parameters of the five-dimensional torus of the Hyperuniverse are determined, and the process of matter and energy exchange between parallel universes through black holes is characterized.

It is shown that, according to the Hyperuniverse theory, the cause of the occurrence and existence of CMBR is the inherent oscillations of the three-dimensional closed contour of our Universe during its cyclic movement along the four-dimensional hypersurface of the five-dimensional torus of the Hyperuniverse.

Keywords:
cosmic microwave background (“relict”) radiation (CMBR), cosmology, five-dimensional torus, Hyperuniverse theory, mathematical modeling.

Introduction

Recent measurements of temperature fluctuations in the cosmic microwave background radiation (CMBR), often referred to as “relict” radiation, have facilitated the creation of detailed maps showing its distribution throughout the Universe. In this paper, we propose to elucidate the peculiarities of this phenomenon through the lens of Hyperuniverse theory and its associated mathematical model [1–34]. It is crucial to recognize that the use of mathematical modeling and methods to address various challenges [35–58] will become increasingly vital as humanity advances in its exploration and research of outer space. In addition to governmental agencies, private organizations are making significant contributions in this arena. A notable example is the research conducted by Unitsky Group of Companies [59–62], which focuses on the industrialization of near space through initiatives such as the General Planetary Vehicle and the Industrial Space Necklace “Orbit.”

Large-Scale Distribution of “Relict” Radiation in the Universe

Figure 1 illustrates the large-scale distribution of “relict” radiation throughout the Universe, as captured by several space observatories, including renowned missions like COBE, WMAP and Planck.

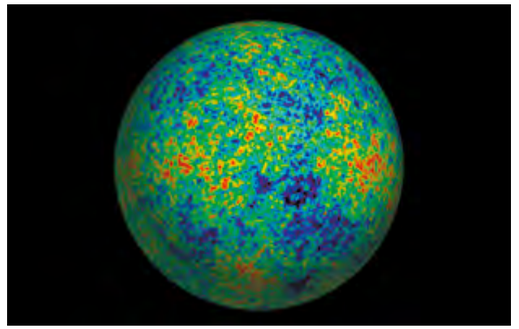

Figure 1 – Large-scale distribution of CMBR in the Universe

The presence of fluctuations in temperature, and consequently in the intensity of the CMBR at various angular scales, poses a significant challenge to explanation within the framework of the Big Bang theory. To address this, researchers often resort to artificial methods that rely on quantum uncertainty and other related effects. However, the approach fails to uncover the true physical essence of the observed phenomena and processes, ultimately leading to a dead end that does not reveal the fundamental laws governing the origin and structure of our Universe. For instance, if we accept the premise that absolute uncertainty pervades the fundamental subatomic level, it raises a logical question: how can any laws exist at the macro level?

This challenge extends to a core assumption of the Big Bang theory regarding the Universe’s origin, positing that it resulted from the explosion of some superdense “singularity.” The concept leaves unanswered three critical questions:

1. Where did this unique “singularity” originate?

2. What caused it to explode suddenly?

3. How did the immense energy necessary for such an explosion come into existence, enabling the Universe to continue expanding in accordance with Hubble’s law, accompanied by additional positive acceleration?

In essence, the Big Bang theory attempts to replace the question of “Where did the Universe come from?” with three others, for which it does not provide answers.

Every cubic millimeter of the matter that surrounds us, in any of its forms and states, contains trillions of such singularities. Yet, throughout the entirety of our Universe’s history, none of these singularities have exploded – neither in a vacuum, nor within stars, nor in liquids, solids, living matter or even in synchrophasotrons of any magnitude. Therefore, the primary assumption (axiom) of the Big Bang theory not only lacks empirical support but is further unsubstantiated except by a straightforward linear extrapolation of the observed Hubble’s law.

Basic Provisions and Conclusions of the Hyperuniverse Theory

Contemporary astronomical and astrophysical observations indicate that our Universe is currently expanding in accordance with Hubble’s law, accompanied by additional positive acceleration. The Hyperuniverse theory [1–34] offers a comprehensive explanation for this phenomenon without relying on artificial constructs such as “dark matter” and “dark energy.”

To facilitate a clearer understanding of the proposed mathematical model, let us simplify by removing three spatial dimensions. In this scenario, our Universe can be conceptualized as a circle with a radius of curvature of approximately

10 bln light-years [1–34]. Universes parallel to ours would also be represented as circles situated at varying distances from a common center (Figure 2).

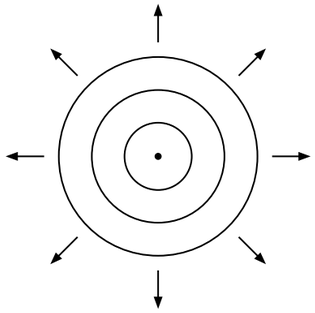

Figure 2 – Two-dimensional scheme
of expanding parallel universes having a common center

We can visualize these circular universes as positioned on the surface of a torus (Figure 3), which, according to the Hyperuniverse theory, rotates, transitioning from the inside to the outside and back again. Alternatively, the circles may be viewed as "sliding" along the toroidal surface, cyclically increasing and decreasing their radii. The period of expansion seamlessly transitions into a period of contraction, and vice versa. It is crucial to emphasize that parallel universes with larger radii that have initiated contraction do not collide with those of smaller radii that continue to expand. Such a collision would be inevitable if they were situated on a plane (Figure 2), but this is not the case on the surface of the torus (Figure 3).

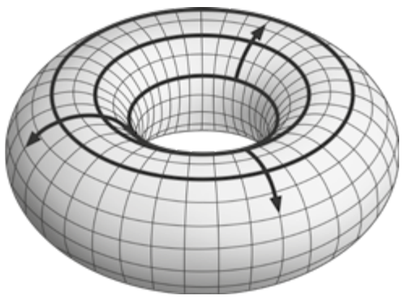

Figure 3 – Three-dimensional scheme
of five-dimensional torus of the Hyperuniverse

The mechanism elucidates the existence of cyclically expanding and contracting parallel worlds. The radius of curvature of our universe, as well as that of parallel universes, will never reach zero; the minimum value will correspond to the inner radius of the torus, while the maximum value will align with its outer radius (Figure 4).

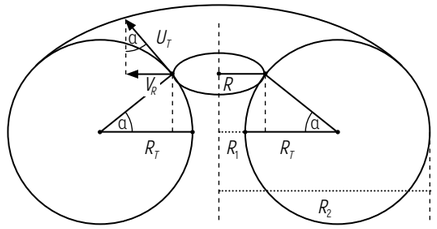

Figure 4 – Three-dimensional scheme
of five-dimensional torus of the Hyperuniverse in section

Through theoretical studies [1–34] rooted in current astronomical and astrophysical data, the approximate dimensions of the five-dimensional torus of the Hyperuniverse have been established (Figures 3, 4). Additionally, several laws governing the periodic changes in size, velocity and acceleration of the expansion/contraction of our Universe during its motion along the five-dimensional torus of the Hyperuniverse have been derived:

$$R(t) = R_1 + R_T(1 - \cos\alpha) = R_1 + R_T\left[1 - \cos\left\{t\,\frac{C}{R_T}\right\}\right],$$

$$V_R(t) = C\sin(\alpha) = C\sin\left\{t\,\frac{C}{R_T}\right\},$$

$$A_R(t) = C\omega_T\cos(\alpha) = \frac{C^2}{R_T}\cos\left\{t\,\frac{C}{R_T}\right\},$$

where R – current radius of curvature of our Universe (≈10 bln light-years);

t – time;

$R_1 = R - R_T(1 - \cos\alpha)$ – inner radius of the Hyperuniverse torus (≈4.7 bln light-years);

R_T – radius of the body of the Hyperuniverse torus (≈20 bln light-years);

$\alpha = \omega_T t$ – angle of rotation of the torus surface from the onset of the expansion period of our Universe (≈0.73 rad ≈ 42°);

C – speed of light in a vacuum;

V_R – expansion/contraction velocity of our Universe as it moves along the five-dimensional torus of the Hyperuniverse;

A_R – acceleration of the expansion/contraction of our Universe during its movement along the five-dimensional torus of the Hyperuniverse;

$\omega_T = \dfrac{C}{R_T}$ – angular velocity of rotation of the torus surface.

The outer radius of the Hyperuniverse torus R_2 can be calculated using the formula:

$$R_2 = R_1 + 2R_T \approx 44.7 \text{ bln light-years.}$$

Using the derived laws and parameters of the five-dimensional torus of the Hyperuniverse, we can compute the acceleration of the Universe's expansion for distances equal to the radius of its curvature (R_0 ≈ 10 bln light-years) at the present moment:

$$A_{R_0} = \frac{C^2}{R_T}\cos(\alpha_0) \approx 5 \times 10^{-10} \times 0.745 = 3.725 \times 10^{-10} \text{ m/s}^2.$$

This theoretical value aligns closely with the most current astrophysical measurements.

The positive acceleration of the Universe's expansion was first discovered and quantified by astrophysicists S. Perlmutter, B. Schmidt and A. Riess, who received the Nobel Prize for their groundbreaking work in 2011. The acceleration of the expansion A_{R_0} calculated using the principles of Hyperuniverse theory corresponds remarkably well with their experimental data [1–34].

Therefore, according to the Hyperuniverse theory, the Big Bang event never occurred. The Universe did not emerge from a singularity and will not collapse into one; instead, it will continue to cyclically expand and contract its radius as it moves along the five-dimensional torus of the Hyperuniverse (Figure 3). It is worth mentioning that if the internal radius of the Hyperuniverse's five-dimensional torus is equal to or near zero in the mathematical model, it will suggest an expansion of the universe from a singularity. Nevertheless, even under these circumstances, the derived laws [1–34] governing the periodic changes in size, velocity and acceleration of the expansion/contraction of our Universe as it traverses the five-dimensional torus of the Hyperuniverse will still hold true.

"Relict" Radiation According to the Hyperuniverse Theory

The distribution of CMBR in the Universe aligns seamlessly with the principles of the Hyperuniverse theory and is effectively explained by it. This distribution exhibits a regular structure at various scales, which is challenging to account for through random processes. It resembles a wave interference pattern (Figure 1), similar to what can be observed on the ocean's surface when viewed from a high altitude. This observation is well-supported by the Hyperuniverse theory [1–34], which posits that the three-dimensional sphere of the Universe vibrates as it traverses the five-dimensional torus of the Hyperuniverse (Figure 3). These vibrations produce the CMBR, often inaccurately referred to as "relict" radiation. Electromagnetic waves generated at each point within our closed Universe repeatedly superimpose on one another, creating a stable interference pattern that has persisted for hundreds of billions of years within the closed three-dimensional space of the Universe. It is noteworthy that the existence of the CMBR is indicative of the fact that the linear speed of the Universe's movement along the four-dimensional hypersurface of the five-dimensional torus of the Hyperuniverse (Figure 3) is equivalent to the speed of light in a vacuum.

Conclusion

According to the Hyperuniverse theory [1–34], the CMBR is not "relict" radiation formed from the cooling of superhot matter shortly after the hypothetical Big Bang. Instead, it arises from the intrinsic oscillations of the three-dimensional closed contour of our Universe as it moves along the surface of the five-dimensional torus of the Hyperuniverse (Figure 3). These oscillations result from a multitude of inhomogeneities and local curvatures of space – predicted by the general theory of relativity – within both the Universe and the Hyperuniverse, which are associated with the presence and distribution of various massive objects such as planets, stars, galaxies, black holes, etc. Given that electromagnetic radiation propagates at the speed of light in a vacuum, it is reasonable to conclude that the speed of the Universe's motion along the torus of the Hyperuniverse, which generates the CMBR, must also equal the speed of light in a vacuum.

Just a few centuries ago, when humanity was unable to traverse great distances, a simple model of the world sufficed: Earth was flat, with a hypothetical edge where ocean waters cascaded into an abyss; the Sun and Moon were thought to be flat disks circling Earth; and stars were perceived as holes in the celestial sphere, allowing the light of another realm to shine through, among other misconceptions. However, as expeditions began to uncover new continents – rather than simply reaching the edge of Earth – it became necessary to develop a more comprehensive and accurate model of the world's structure. Without this enhanced understanding, conscious

circumnavigations and, later, explorations of airspace and near space would have been unfeasible.

Until recently, our replacement for the flat-world model served us well, but as we explored greater cosmic distances and began to utilize near-light speeds, such models of the Universe proved inadequate for accurately describing the processes occurring around us. This must be recognized in the context of space industrialization – an endeavor that Belarusian scientist A. Unitsky emphasizes in his works. For future explorations of near and far space, a more detailed and precise model, as provided by the Hyperuniverse theory, is essential. The peculiarities in the large-scale distribution of CMBR in the Universe serve as one confirmation of this concept. Moreover, a correct and profound understanding of the Universe's structure is critical for humanity to appreciate the extraordinary beauty and grand vision guiding our journey into space exploration.

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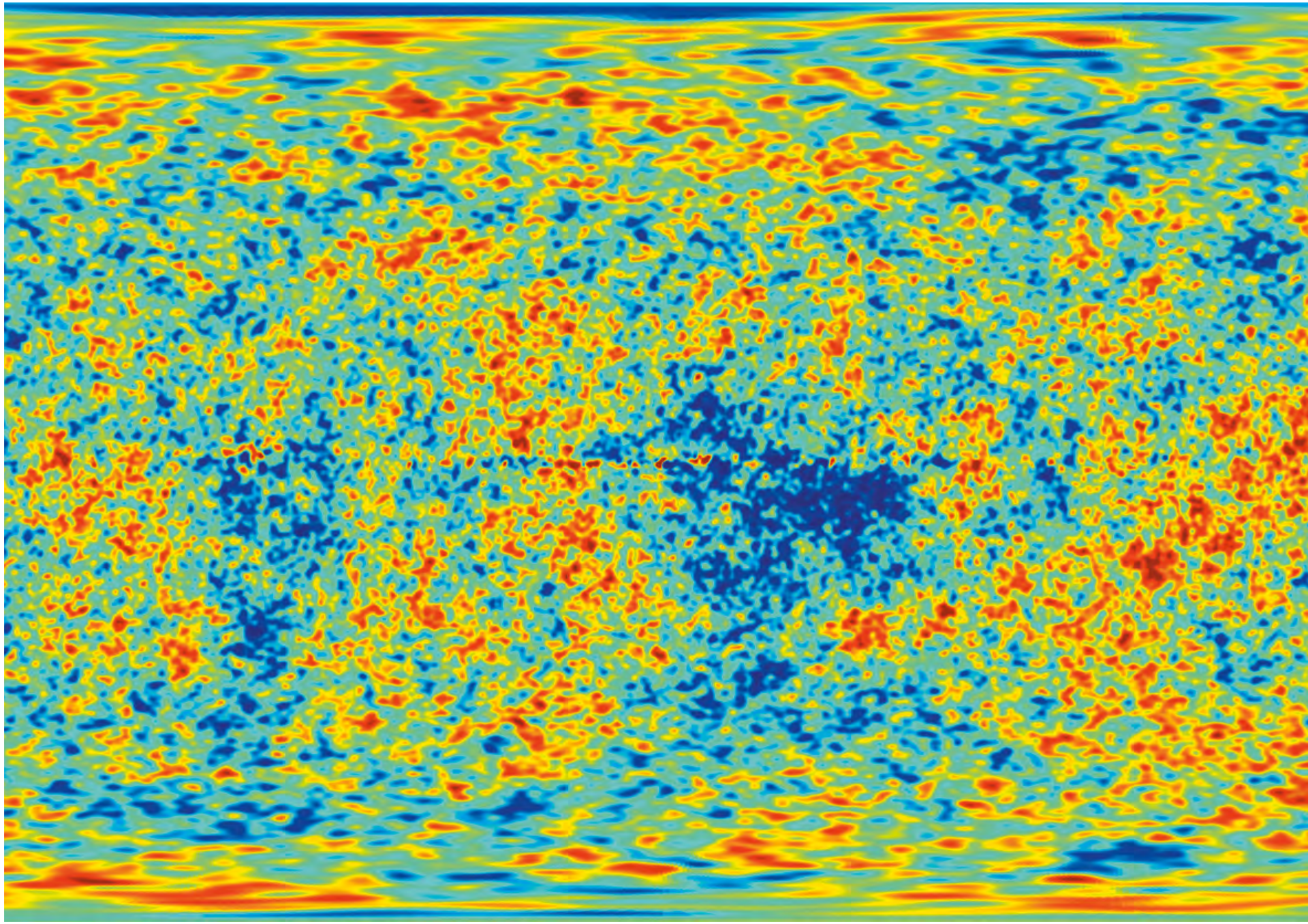

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Motion Control System of Linear Rotors in General Planetary Vehicle

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The project of the General Planetary Vehicle (GPV) is global in scope and has no analogues in the history of Earth's civilization. A key factor for the successful transition of the GPV to the equatorial orbit is its ability to accelerate linear rotors' system to cosmic velocity – at least 12 km/s. This system consists of numerous identical modules designed to maintain the rotors within the vacuum channel, as well as modules equipped with linear thrust motors that provide initial acceleration for the rotors and redistribute kinetic energy between the rotors and the body of the GPV. Scheduled acceleration and braking of the GPV are impossible without a centralized rotor motion control system. Currently, there are no ready-made solutions that ensure the safety and reliability of the control system for the hypervelocity rotors of the GPV which spans the length of the Earth's equator – about 40,000 km.

The purpose of this paper is to develop a mathematical model that finds functions for calculating the radial and tangential changes in the velocity of the GPV shell during flight, as well as a function to determine the law governing the change in the GPV flight altitude.

The control system proposed by the authors is a sophisticated hardware and software complex that enables all necessary operating modes of the rotor unit.

The simulation results form the algorithms for the hardware and software complex of the GPV rotor control system and can serve as a foundation for further detailed development of the component base.

Keywords:
General Planetary Vehicle (GPV), Industrial Space Necklace "Orbit" (ISN "Orbit"), linear motors control system, mathematical model, orbit insertion, radial acceleration.

Introduction

The primary function of the General Planetary Vehicle (GPV) is to ascend and dock with the Industrial Space Necklace "Orbit" (ISN "Orbit") located in a circular equatorial orbit as well as descend to Earth and dock with the equatorial takeoff and landing overpass. The GPV design enables it not only to reach near-Earth orbit at the first cosmic velocity, transporting passengers and cargo, but also to remain at the required altitude for a specified duration (with zero velocity relative to the ISN "Orbit"), then return to the planet's surface (with zero velocity relative to the overpass) and repeat this cycle multiple times [1].

The GPV structure includes two linear flywheel rotors driven by two linear electric motors. This combination of flywheels and linear motors serves as the GPV propulsion system and as an energy accumulator, essential for the operation of the entire geocosmic transport complex [2].

The control system for the linear motors must process data from a range of parameters set by the mission control center and received from sensors. Analyzing this information in real time, the system generates signals to control the motors of each linear flywheel. These motors, responding to the generated signals, ensure the required flight parameters of the GPV, such as the velocity and acceleration of the shell fragments and the GPV as a whole.

The overarching goal of this work is to present the mathematical framework necessary for programming the GPV flight control system.

The objective is to develop a mathematical model for determining the functions that calculate changes in the radial and tangential components of the GPV shell velocity during flights, as well as a function that defines the law of altitude variation for the GPV ascent.

Thus, this article focuses on the algorithmic actions of the mathematical apparatus – the brain of the control system.

Problem Statement

To calculate the motor control function, it is necessary to know the law governing the change in the GPV shell coordinates during flight. In turn, the shell motion law must be derived based on permissible acceleration limits during the GPV ascent, the orbit altitude of ISN "Orbit," the specific masses and velocities of the linear flywheels as well as the shell mass and payload.

At this stage of development, the laws of radial and tangential movement of the GPV shell should be determined.

Input Data and Assumptions

The input data includes the values of variables and constants [3], presented in Table.

At the initial stage of solving the problem, a number of simplifying assumptions were introduced, which will have an insignificant impact on the calculation results. At later stages of developing the mathematical model, these assumptions will be removed, and the accuracy of the calculations will improve [4].

Table – Input data for calculation

Parameter	Value
Variables	
Orbital position, φ, °	0
Target orbital altitude, h_0, m	400,000
Overpass height, h, m	10
Radial acceleration of the shell in the interval $t0$–$t1$, A_{R0_1}, m/s^2	0.03
Radial acceleration of the shell in the interval $t1$–$t2$, A_{R1_2}, m/s^2	0.03
Radial acceleration of the shell in the interval $t3$–$t4$, A_{R3_4}, m/s^2	0.03
Radial acceleration of the shell in the interval $t4$–$t5$, A_{R4_5}, m/s^2	0.03
Maximum permissible tangential acceleration of the shell, A_T, м/s^2	3
Maximum permissible radial acceleration of the shell, A_R, m/s^2	2
Relative initial velocity of rotor 1, V_1, m/s	15,600
Relative initial velocity of rotor 2, V_2, m/s	2
Relative initial velocity of the shell, V_{shell}, m/s	0
Initial vertical velocity during ascent, V_{RV0}, m/s	0
Final vertical velocity during ascent, V_{RV2}, m/s	0
Time spent in orbit, T_{R2_3}, s	3,000
Initial vertical velocity during descent, V_{RV3}, m/s	0
Final vertical velocity during descent, V_{RV5}, m/s	0
Constant values	
Gravitational constant, G, m^3/(kg·s^2)	6.6743×10^{-11}
Mass of Earth, M_{Earth}, kg	5.9723×10^{24}
Equatorial radius of Earth, R_{Earth}, m	6,378,137
Acceleration of gravity at the equator, g, m/s^2	9.807

Additionally, changes in acceleration of gravity and the first cosmic velocity depending on the GPV flight altitude were not taken into account. The latitude of the takeoff and landing overpass was assumed to be zero. In further research, the mathematical model will include the latitude value and account for changes in centrifugal acceleration associated with the Earth's rotation on its axis. Precession and nutation of the Earth's rotation axis, along with other parameters influencing the motor control function during descent, were assumed to be zero. Changes in the angular momentum of the rotors and the shell depending on the GPV flight altitude, as well as atmospheric aerodynamic resistance, were disregarded.

Calculation of Parameters Required to Determine GPV Flight Altitude as a Function of Time

The entire flight cycle can be divided into five conditional time intervals ($t0$–$t5$). In the interval $t0$–$t1$, the GPV lifts off from the takeoff and landing overpass and gains altitude with increasing vertical (radial) velocity. In the interval $t1$–$t2$, the altitude gain continues, but the vertical velocity gradually decreases, reaching zero at the moment of docking with the ISN "Orbit." In the interval $t2$–$t3$, the GPV remains in space, rigidly docked with the ISN "Orbit." This time can be arbitrary (3,000 s is assumed in the calculation). From moment $t3$, the GPV begins its descent, which occurs in the interval $t3$–$t4$ with increasing vertical velocity. By $t4$, the GPV reaches a maximum vertical velocity of 110 m/s. In the interval $t4$–$t5$, the vertical velocity decreases. At the conditional point $t5$, the vertical velocity of the GPV is zero, and the flight altitude is 1 m (relative to the runway located on top of the overpass). The GPV is ready for landing.

To define the function of altitude changes throughout the flight cycle, several parameters must first be calculated.

Time of acceleration during ascent in the interval $t0$–$t1$:

$$T_{R0_1} = \sqrt{\frac{h_0}{A_{R0_1}}} = \sqrt{\frac{400{,}000}{0.03}} = 3{,}651.5 \text{ s}. \quad (1)$$

Vertical velocity at moment $t1$:

$$V_{RV1} = V_{RV0} + A_{R0_1}T_{R0_1} = 0 + 0.03 \times 3{,}651.5 = 109.545 \text{ m/s}. \quad (2)$$

Radial acceleration in the interval $t0$–$t1$:

$$A_{V0_1} = \frac{V_{RV1} - V_{RV0}}{T_{R0_1}} = \frac{109.545 - 0}{3{,}651.5} = 0.03 \text{ m/s}^2. \quad (3)$$

Deceleration duration during ascent in the interval $t1$–$t2$:

$$T_{R1_2} = \frac{V_{RV1} - V_{RV2}}{A_{R1_2}} = \frac{109.545 - 0}{0.03} = 3{,}651.5 \text{ s}. \quad (4)$$

Duration of ascent:

$$T_{R0_2} = T_{R0_1} + T_{R1_2} = 3{,}651.5 + 3{,}651.5 = 7{,}303 \text{ s}. \quad (5)$$

Radial acceleration in the interval $t1$–$t2$:

$$A_{V1_2} = \frac{V_{RV2} - V_{RV1}}{T_{R0_2} - T_{R0_1}} = \frac{0 - 109.545}{7{,}303 - 3{,}651.5} = -0.03 \text{ m/s}^2. \quad (6)$$

Starting time of the GPV descent from orbit:

$$T_{R0_3} = T_{R0_2} + T_{R2_3} = 7{,}303 + 3{,}000 = 10{,}303 \text{ s}. \quad (7)$$

Duration of radial acceleration during descent in the interval $t3$–$t4$:

$$T_{R3_4} = \sqrt{\frac{h_0}{A_{R3_4}}} = \sqrt{\frac{400{,}000}{0.03}} = 3{,}651.5 \text{ s}. \quad (8)$$

Time of radial deceleration start during descent:

$$T_{R0_4} = T_{R0_3} + T_{R3_4} = 10{,}303 + 3{,}651.5 = 13{,}954.5 \text{ s}. \quad (9)$$

Vertical velocity at moment $t4$:

$$V_{RV4} = V_{RV3} + A_{R3_4}T_{R3_4} = 0 + 0.03 \times 3{,}651.5 = 109.545 \text{ m/s}. \quad (10)$$

Radial acceleration in the interval $t3$–$t4$:

$$A_{V3_4} = \frac{V_{RV4} - V_{RV3}}{T_{R0_4} - T_{R0_3}} = \frac{109.545 - 0}{13{,}954.5 - 10{,}300} = 0.03 \text{ m/s}^2. \quad (11)$$

Duration of radial deceleration during descent in the interval $t4$–$t5$:

$$T_{R4_5} = \frac{V_{RV4} - V_{RV5}}{A_{R4_5}} = \frac{109.545 - 0}{0.03} = 3{,}651.5 \text{ s}. \quad (12)$$

Time of landing on the overpass at moment $t5$:

$$T_{R0_5} = T_{R0_4} + T_{R4_5} = 13{,}954.5 + 3{,}651.5 = 17{,}606 \text{ s}. \quad (13)$$

Radial acceleration in the interval $t4$–$t5$:

$$A_{V4_5} = \frac{V_{RV5} - V_{RV4}}{T_{R0_5} - T_{R0_4}} = \frac{0 - 109.545}{17{,}606 - 13{,}954.5} = -0.03 \text{ m/s}^2. \quad (14)$$

The flight parameters allow us to define and calculate the function of the GPV flight altitude change.

Calculation of GPV Flight Altitude as a Function of Time

The GPV flight altitude as a function of time is as follows:

$$h(t) = \begin{cases} \frac{A_{R0_1}t^2}{2}, \text{ if } t < T_{R0_1}; \\ V_{RV1}t - \frac{A_{R1_2}T_{R0_1}^2}{2} - \frac{A_{R1_2}(t - T_{R0_1})^2}{2}, \text{ if } T_{R0_1} < t < T_{R0_2}; \\ h_0, \text{ if } T_{R0_2} < t < T_{R0_3}; \\ h_0 - \frac{A_{R3_4}(t - T_{R0_3})^2}{2}, \text{ if } T_{R0_3} < t < T_{R0_4}; \\ \frac{h_0}{2} - \left(V_{RV4}(t - T_{R0_4}) - \frac{A_{R4_5}(t - T_{R0_4})^2}{2}\right), \text{ if } T_{R0_4} < t < T_{R0_5}. \end{cases} \quad (15)$$

The function was solved using Mathcad 15 software. The graph of the function, based on the given input data, is shown in Figure 1.

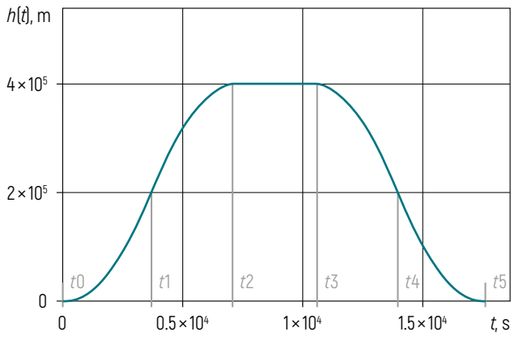

Figure 1 – Graph of GPV flight altitude as a function of time (for one flight cycle)

The linear electric motors, controlled according to the obtained function, will enable smooth ascent and descent, as shown in Figure 1.

Calculation of the Radial Velocity of GPV Shell as a Function of Time

Throughout the flight cycle, the GPV accelerates and decelerates twice in the radial direction.

The function that defines the radial velocity of the GPV shell as a function of time is as follows:

$$V_R(t) = \begin{cases} V_{RV0} + A_{V0_1}t, \text{ if } t < T_{R0_1}; \\ V_{RV1} + A_{V1_2}(t - T_{R0_1}), \text{ if } T_{R0_1} < t < T_{R0_2}; \\ V_{RV3}, \text{ if } T_{R0_2} < t < T_{R0_3}; \\ V_{RV3} + A_{V3_4}(t - T_{R0_3}), \text{ if } T_{R0_3} < t < T_{R0_4}; \\ V_{RV4} + A_{V4_5}(t - T_{R0_4}), \text{ if } T_{R0_4} < t < T_{R0_5}. \end{cases} \quad (16)$$

The function can take different forms due to the nature of the acceleration change. When the acceleration increment ("jerk") is equal to zero, the graph of the function takes the form shown in Figure 2.

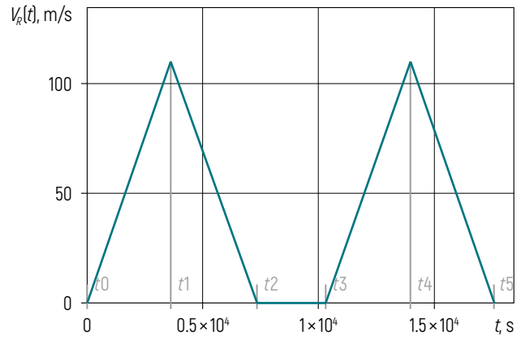

Figure 2 – Radial velocity of GPV shell in uniformly accelerated motion

In the intervals $t0$–$t1$ and $t3$–$t4$, there is a uniform increase in vertical velocity. During $t0$–$t1$, the velocity is directed away from the center of the Earth, while during $t3$–$t4$, it is directed toward the center of the Earth. At moments $t1$ and $t4$, the acceleration changes sign to negative: from $A_{V0_1} = 0.03 \text{ m/s}^2$ to $A_{V1_2} = -0.03 \text{ m/s}^2$. The deceleration interval begins. During this time, passengers will experience a slight jolt and feel a reduction in their weight. In real life, the change in acceleration would occur gradually. To solve the function in this case, several additional parameters must be calculated.

Acceleration increment ("jerk") of the shell in the interval $t0$–$t1$:

$$J_{R0_1} = \frac{A_{R0_1}}{T_{R0_1}} = \frac{0.03}{3{,}651.5} = 8.216 \times 10^{-6} \text{ m/s}^3. \quad (17)$$

Acceleration increment of the shell in the interval $t1$–$t2$:

$$J_{R1_2} = \frac{A_{R1_2}}{T_{R1_2}} = \frac{0.03}{3{,}651.5} = 8.216 \times 10^{-6} \text{ m/s}^3. \quad (18)$$

Solution to the function takes the form shown in Figure 3.

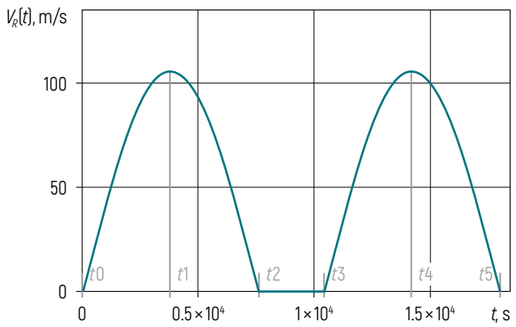

Figure 3 – Radial velocity of GPV shell in smoothly accelerated motion

As we can see, the change in velocity occurs smoothly. As moments $t1$ and $t4$ approach, the radial acceleration begins to decrease and becomes zero at moments $t1$ and $t4$. After passing through points $t1$ and $t4$, the acceleration changes sign to negative, and the radial velocity decreases – eventually reaching zero at moments $t2$ and $t5$.

Calculation of Parameters Required to Compute the Tangential Velocity of GPV Shell as a Function of Time

During ascent, the GPV gains not only vertical (radial) velocity but also horizontal (tangential) one. During the ascent to a given altitude, the GPV shell must achieve a tangential velocity equal to the first cosmic velocity for that altitude. To define the tangential velocity change function, a number of parameters must be calculated in advance.

The tangential acceleration of the shell in the interval $t0$–$t1$:

$$A_{T0_1} = \frac{\frac{V_{1cosmic}}{2} - V_{TV0}}{T_{R0_1}} = \frac{\frac{7{,}669}{2} - 0}{3{,}651.5} = 1.05 \text{ m/s}^2. \quad (19)$$

Acceleration increment of the shell in the interval $t0$–$t1$:

$$J_{T0_1} = \frac{A_{T0_1}}{T_{R0_1}} = \frac{1.05}{3{,}651.5} = 2.9 \times 10^{-4} \text{ m/s}^3. \quad (20)$$

Tangential acceleration of the shell in the interval $t1$–$t2$:

$$A_{T1_2} = \frac{V_{TV2} - \frac{V_{1cosmic}}{2}}{T_{R1_2}} = \frac{7{,}669 - \frac{7{,}669}{2}}{3{,}651.5} = 1.05 \text{ m/s}^2. \quad (21)$$

Acceleration increment of the shell in the interval $t1$–$t2$:

$$J_{T1_2} = \frac{-A_{T1_2}}{T_{R1_2}} = \frac{-1.05}{3{,}651.5} = -2.9 \times 10^{-4} \text{ m/s}^3. \quad (22)$$

Duration of tangential acceleration increase in the interval $t1$–$t2$:

$$T_{T0_1} = \frac{\frac{V_{TV2}}{2} - V_{TV0}}{A_{T0_1}} = \frac{\frac{7{,}669}{2} - 0}{1.05} = 3{,}651.9 \text{ s}. \quad (23)$$

Duration of the GPV shell acceleration:

$$T_{T1_2} = T_{T0_1} + \frac{V_{TV2} - \frac{V_{TV2}}{2}}{A_{T1_2}} = 3{,}651.9 + \frac{7{,}669 - \frac{7{,}669}{2}}{1.05} = 7{,}303.8 \text{ s}. \quad (24)$$

Calculation of the Tangential Velocity of GPV Shell as a Function of Time

The function of the horizontal (tangential) velocity of the GPV shell as a function of time is as follows:

$$V_T(t) = \begin{cases} \frac{A_{T0_1} t^2}{2} \times \frac{1}{\text{s}}, \text{ if } t < T_{T0_1}; \\ \left(\frac{V_{TV2}}{2} t - \frac{A_{T1_2} T_{T0_1}^2}{2} - \right. \\ \left. - \frac{A_{T1_2} (t - T_{T0_1})^2}{2} \right) \frac{1}{\text{s}}, \text{ if } T_{T0_1} < t < T_{T1_2}; \\ V_T(T_{T1_2} - 1\text{s}), \text{ if } t > T_{T1_2}. \end{cases} \quad (25)$$

The solution for the horizontal (tangential) velocity of the GPV shell as a function of time is shown in Figure 4.

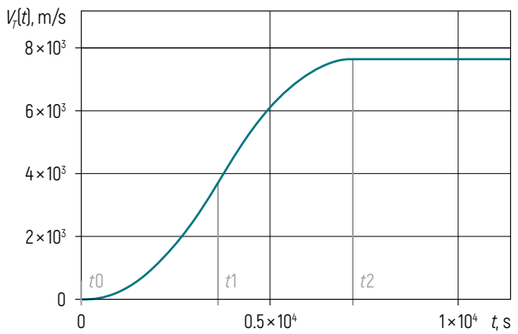

Figure 4 – Graph of GPV horizontal velocity as a function of time

$$V_T(T_{T1_2} - 1\text{s}) = V_T(7{,}303.8 - 1) = 7{,}609 \text{ m/s}; \quad (26)$$

$$V_{1cosmic} = \sqrt{\frac{GM_{Earth}}{R_{Earth} + h_0}} = \sqrt{\frac{6.6743 \times 10^{-11} \times 5.9723 \times 10^{24}}{6{,}378{,}137 + 400{,}000}} = 7{,}669 \text{ m/s}. \quad (27)$$

As we can see, the shell velocity when reaching the designated altitude (the value of the $V_T(t)$ function at moment $t2$) is 7,609 m/s, which is nearly identical to the actual first cosmic velocity at an altitude of 400 km, 7,669 m/s.

The primary influence on the GPV flight characteristics comes from the linear motors. Therefore, the final result of the mathematical model for the control system is the control functions for the linear motors, which, in one of the variants, could be total about 20,000 fragments of the overall linear electric motor in the GPV system. A separate control function with discrete values must be created for each of these motors. The motor will operate in one of three modes: the mode of accelerating the flywheel relative to the shell; the mode of regenerative braking of the flywheel; the mode where the motor does not affect the flywheel. The final stages of the power electronics will operate in the switching mode, characterized by minimal dissipated power in the transistor channels, which means minimal heat generation and energy loss. This will help achieve one of the key objectives: bringing the overall efficiency factor of the power system closer to 100 %.

Conclusion

The calculation outlined in this article is the first stage in creating a mathematical model for the control system of linear motors for the GPV linear flywheels. This mathematical model will, in turn, serve as the foundation for writing the program code, under which numerous microprocessors and microcontrollers will make the GPV flights a safe reality.

The next stage of the model development will involve deriving control functions for the linear motors of the first and second flywheels based on the laws of motion of the shell. These functions will need to account for longitudinal oscillations caused by changes in the velocities of individual sections of the flywheels and shell due to the orbital eccentricity of the GPV. During flight, the motors will aim to reduce the orbital eccentricity to zero and stabilize the velocity change of the GPV fragment along its path around the Earth. Herewith, it is planned to add the functions considering the law of rotors angular momentum conservation upon the GPV radius changing during the flight and the linear density of the flywheels and shell by 1.57 % for every 100 km of ascent or descent, respectively.

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UDC 537.814+629.7

Development of Hybrid Electromagnetic Suspension for Rotor of General Planetary Vehicle

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Relying solely on electromagnets in the design of the General Planetary Vehicle (GPV) to power the linear electric motor and rotor (for suspension and movement at cosmic velocities) leads to significant power consumption and heat generation. In the event of a cooling system failure (even localized), this can result in catastrophic outcomes, i.e., the failure of the magnetic suspension system and a cascading collapse of the GPV.

Using only permanent magnets presents challenges in regulating magnetic fields, minimizing the rotor's controllability and increasing the risk of it becoming stuck at cosmic velocities, which could also lead to disaster.

To address these issues, a hybrid suspension design is proposed, optimally combining permanent magnets with electromagnets. This solution ensures a stable, self-regulating linear rotor position within the vacuum channel, allowing motion at speeds of 0–12 km/s with minimal energy consumption and reduced heat generation.

Keywords:
electromagnetic stabilization, General Planetary Vehicle (GPV), GPV rotor, magnetic levitation, magnetic suspension.

Introduction

The General Planetary Vehicle (GPV) is a self-supporting reusable spacecraft encircling the planet along the equator, which will make it possible to explore near space without using rockets [1, 2]. Linear rotors accelerated in vacuum channels to cosmic velocities (10–12 km/s) provide the required lifting force to perform geocosmic logistics by the GPV – equatorial orbit insertion (with obtaining the first cosmic velocity of the body travel around the planet) and landing on the takeoff and landing overpass with zero velocity relative to it.

During rotor braking and acceleration, linear electric motors can develop power up to 5,000 kW/m [2]. At the same time, the total power of energy recovery in the GPV in the orbit insertion mode, for example, during 2 h, will reach the value of 200 bln kW. Consequently, a fundamentally important task is to create linear flywheel (rotor) drives with the highest possible efficiency factor, since even a few percent of losses can lead to unacceptable overheating of linear electric motor systems and magnetic suspensions (each 1 % of losses corresponds to no more than 50 kW of thermal power per 1 m length of the GPV).

Hybrid suspension based on the combination of permanent magnets with electromagnets ensures the highest possible efficiency factor of the GPV drive and self-stabilization, which is especially important in extreme modes, such as local vertical overloads about 10g (on the mountain sections of the overpass, where the radii of curvature of rotor motion can be smaller than the equatorial radius of the planet by a factor of 10). Permanent magnets will provide a basic level of suspension, reducing the energy required to keep the rotor in a set position. At the same time, electromagnets will allow flexible control of rotor positioning, compensation of external disturbances and automatic change of suspension characteristics in real time.

A key advantage of such a system is its capacity to combine low power consumption with high controllability. This makes the suspension particularly attractive for the GPV applications, for which stability and accuracy of the rotor positioning are critical.

This paper analyzes the basic principles of operation of the hybrid electromagnetic suspension specially designed for the GPV. The advantages and disadvantages of using permanent magnets and electromagnets are considered, and the methods of their integration and optimization are discussed as well. Special attention is paid to the interaction of the system components as well as simulation of its characteristics at cosmic velocities.

The purpose of this research is to create an efficient and stable hybrid suspension system capable of ensuring high accuracy and reliability of the GPV rotors (there should be two of them) in various operating conditions: while on the planet, in takeoff/landing and multi-hour ascent/descent modes as well as while in orbit in weightlessness.

Analysis of the Existing GPV Rotor Suspension Variants

Suspensions for creating a magnetic field, for example, in ground transport, use permanent magnets, which have stable characteristics over a long period of operation and are energy independent. The suspended object should be partially or completely made of ferromagnetic materials and carry permanent magnets on itself, upon that the suspension itself is realized by repulsive and/or attractive forces [3]. Magnetic suspension is an environmentally friendly, reliable and durable system that eliminates noise, vibration, wear and tear caused by friction.

One of the popular levitation methods is electromagnetic suspension (EMS). However, this system faces the problems of high-power consumption and overheating, as it requires a direct current to maintain the proper air gap.

The reference [4] considers a possible design of the magnetic suspension of the rotor in a system of permanent magnetic fields, calculations of the load capacity of the magnetic system, the amount of substracted heat and maps of the magnetic flux distribution in the suspension.

The cross section of the rotor, magnetic system and linear motors are shown in Figure 1. The power magnets, which absorb the lifting force from the flywheel, are placed at the top and bottom. The remaining magnets provide transverse stabilization of the rotor in the vacuum channel and prevent contact with its walls.

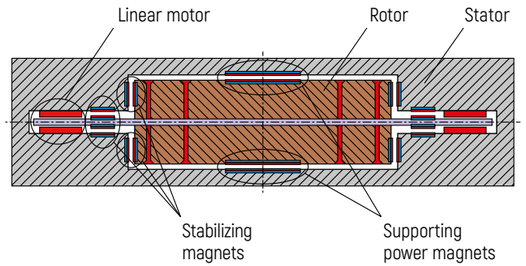


Figure 1 – GPV rotor design (option) [4]

The advantages of this system include high non-volatility due to the lack of electromagnets in the system, hence, the entire load falls on permanent magnets. At the same time, there is a significant disadvantage – the system does not offer a control part responsible for the autostabilization of the rotor position in the process of motion as well as compensation of the nonuniformity of magnetic fields, in particular edge effects [3]. In addition, the authors note the need for a powerful cooling system due to demagnetization of N40 brand magnets at temperatures above or close to 70 °C [4].

The reference [5] considers a similar suspension design consisting solely of permanent magnets (Figure 2).

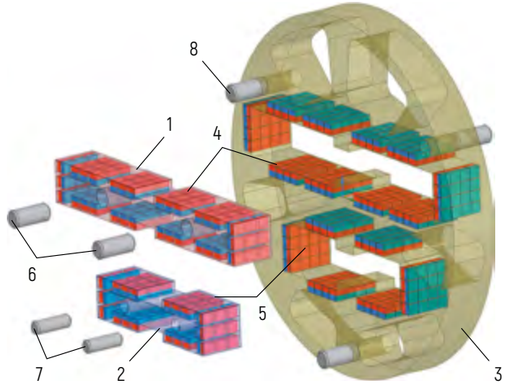


Figure 2 – Assembly of the GPV elements:
1 – segment of the rotor 1; 2 – segment of the rotor 2; 3 – segment of the stator; 4 – magnetic system of stabilizing unit of the rotor 1; 5 – magnetic system of stabilizing unit of the rotor 2; 6 – guiding elements of the rotor 1; 7 – guiding elements of the rotor 2; 8 – guiding elements of the stator [5]

The authors attribute the main advantages of this system to the insignificant change in the normal repulsive force at the tangential displacement of the stator and rotor magnetic groups relative to each other; the absence of variability in the force properties of the magnets; the simplicity of the system fabrication; universality and small linear dimensions of the magnetic group. However, the disadvantages are also present here, including the mandatory availability of a cooling system due to the demagnetization of permanent magnets of N52 brand at temperatures above 120 °C; the need for about 4 mln tons of neodymium, which is about 4 % of its world reserves, due to the scale of the design [5].

Hybrid Electromagnetic Rotor Suspension Design

The GPV operation is based on principles of the laws of physics. The flywheels inside the body are accelerated to a speed higher than the first cosmic velocity at sea level. Due to internal centrifugal force, the GPV increases in diameter (stretches) and takes off with the cargo. Since the GPV is located in the equator plane and has the shape of a torus, its center of mass coincides with the center of mass of Earth in all possible positions: on the planet, in flight and in orbit. That is why this self-supporting spacecraft performs ascent into space and descent to Earth solely due to its internal forces [1].

Based on the analysis of rotor suspension variants, it was concluded that it is necessary to use cooling systems regardless of the employment or lack of electromagnets in the system. When developing the hybrid rotor suspension, special attention was paid to the safety of flywheel operation at cosmic velocities, since even the slightest instability in the system with a length of more than 40,000 km can result in catastrophic consequences.

In this regard, the GPV rotor suspension system must meet a number of key requirements:

- stable and long-term levitation of the rotor moving at speeds of 0–12 km/s with minimal energy losses, which is achieved by using permanent magnets for the main load;
- high stabilization accuracy (considering small gaps – about 10 mm) to prevent any lateral or vertical displacements of the rotor relative to the walls of the linear vacuum chamber, including those associated with lateral and vertical local overloads up to 10*g*, which is due to the use of electromagnets. In addition, the suspension should be resistant to external vibrations and mechanical effects (e.g., shocks) and be able to respond quickly and automatically to changes in the rotor position;
- optimization of the suspension design to minimize maintenance and operation costs as well as to ensure the durability and reliability of the entire system and, consequently, the GPV.

Figure 3 shows the offered system of the GPV hybrid electromagnetic rotor, the essence of which is as follows: the main load is held by permanent magnets 2, while the gap and oscillations are compensated by additional energy from the electromagnets 3. With this suspension arrangement, the required amount of energy for rotor stabilization is reduced by several orders of magnitude, since the coils can operate alternately independently one from the other with the help of a navigational two-stage PID regulator [6], which eliminates the possibility of excessive overheating and does not require the use of intensive cooling.

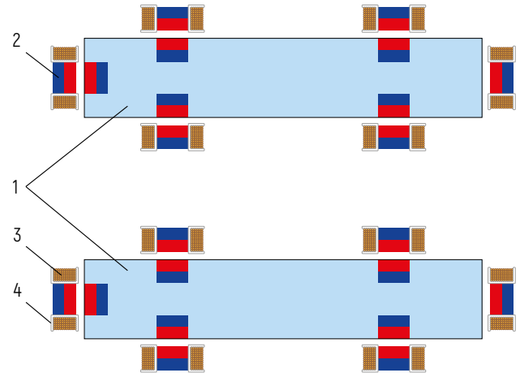


Figure 3 – System of hybrid electromagnetic suspension of the GPV rotor:
1 – linear rotors; 2 – permanent (power) magnet;
3 – electromagnet coil; 4 – coil box

The electromagnetic system should ensure the availability of a safe gap in the cross-sectional plane in all modes of operation of the GPV and under the action of all kinds of destabilizing external and internal loads on its body and, at the same time, should not prevent the rotor from moving along the vacuum channel with cosmic velocities.

In order to further determine the number of permanent magnets per linear meter of the rotor, at the first stage the standard values of the rotor–stator interaction forces were calculated by the formula:

$$Q_{max} = (m_1 + m_2)gC_d, \quad (1)$$

where m_1 – mass per unit length of the rotor, kg/m;

m_2 – mass per unit length of the body, stator and payload, kg/m;

g – acceleration of gravity at the equator, m/s^2;

C_d – dynamic coefficient, $C_d = 2$ [5].

Substituting the data into formula (1), we obtain (in one of the possible design variants of the GPV):

$$Q_{max} = (360 + 500) \times 9.78 \times 2 = 16{,}800 \text{ N/m}.$$

The system of permanent magnets in the proposed design holds the entire payload, hence, 16.8 kN has to hold two rows of pairs of permanent magnets.

As a solution to the problem, it is suggested to use a system (Figure 4) consisting of a base component in the form of a magnet 1 with a size of 30 × 40 × 40 mm, around which a coil of electromagnet 2 is placed to provide dynamic stabilization of the rotor.

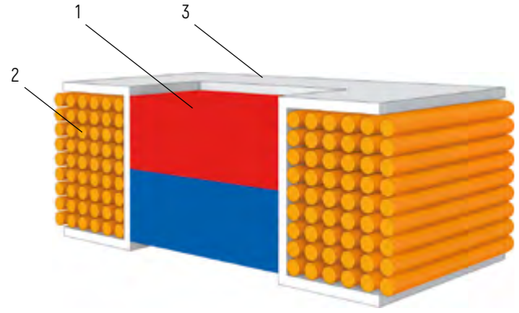


Figure 4 – Power unit of hybrid rotor suspension in section (option):
1 – permanent (power) magnet; 2 – electromagnet coil; 3 – coil box

The power unit is designed to exclude the effect of excessive heating of the magnet from the electromagnet coil, the gap between the walls of the magnet and the coil is also considered.

The key advantages of the proposed hybrid rotor suspension design are as follows:

- availability of effective electromagnetic stabilization due to the electromagnet coils: since the permanent magnets carry the major load, the electromagnets just need a small amplification of the electromagnetic field to balance the system;
- relative simplicity of the system manufacturing due to the small range of materials used: neodymium parallelepiped of N52 brand with a size of 30 × 40 × 40 mm and electromagnet coils of the same size and shape along the entire length of the rotor;
- lack of impact of variability of power properties of individual magnets: in case of defect of the magnet or crack initiation in it during the rotor operation, the electromagnet takes over the load, otherwise the occurrence of oscillations in the system may lead to rotor destabilization;
- availability of electromagnets: allow to carry out diagnostics of permanent magnets condition, and thus, to carry out their replacement on time.

Disadvantages of the proposed design:

- presence of a cooling system for coils and permanent magnets: it has to maintain the operating temperature during the operation of the system, since a magnet of N52 brand retains magnetization up to 120 °C [5];
- additional power consumption compared to the design based solely on permanent magnets;

• need to use a large number of neodymium magnets, but unlike the previous permanent magnet assembly, which requires 4.5 mln tons of rare earth neodymium, this system will require 2 mln tons (approximately 2 % of the world's reserves) [5].

The proposed design is developed with due regard to the overall dimensions of the GPV body. The power unit is an assembly of a neodymium magnet of N52 brand with a size of 30 × 40 × 40 mm and an electromagnet coil (Figure 4) which amplifies the magnet fields by sufficient energy for stabilization. The weight of one unit will be no more than 1.5 kg (magnet is 0.4 kg, nonconducting coil box is 0.1–0.3 kg, electromagnet coil is about 0.5 kg), which excludes the assembly of the rotor suspension using heavy machinery.

Determination of Interaction Forces of Power Elements of GPV Rotor Suspension

The interaction of the power elements of the rotor suspension is a key factor in the development and optimization of their location, since in the offered design all the load is taken by permanent magnets. To accurately determine the bearing capacity, it is necessary to take into account such parameters as magnetic permeability, coercive force and weight and dimensional characteristics of the suspension elements.

At the first stage of operation, the design should compensate the gravity action (when accelerating the flywheels to normal speeds and being on the overpass), at the second stage – the effect of centrifugal forces in the modes of cosmic velocities of motion (above the first cosmic velocity) as well as upon ascent/descent of the GPV. On the basis of formula (1), the value of the standard centrifugal force (with a double coefficient of reserve) per each linear meter of the GPV is equal to 16,800 N.

In order to determine the bearing capacity of the system and to establish the optimal gap between the power magnets, a parametric 3D-calculation was carried out in specialized software. The properties of the N52 magnet and the variability of the distance between the magnets from 0.5 to 18 mm are accepted as initial parameters. The outcome is the sum of the resulting repulsive force by modulo.

Table 1 summarizes the calculation data, which shows that the smaller the distance between the magnets, the greater the repulsive force. Based on the presented information, the optimal gap can be selected. If we know that the peak force of interaction between the rotor and the stator is 16,800 N/m, and the length on the largest side of one power unit is 40 mm, we will accept the optimal number of power pairs – 30 pcs/m.

If the maximum load is evenly distributed, the force per pair will be as follows:

$$q = \frac{Q_{max}}{n_p} = \frac{16{,}800}{30} = 560 \text{ N}, \quad (2)$$

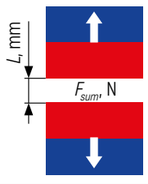
where n_p – the number of power pair units per 1 lin m of the GPV rotor, pcs/m.

According to Table 1, the gap L will not exceed 9 mm in static mode. Given possible lateral oscillations and the influence of dynamic centrifugal force, a pair of power units for each 1 mm of displacement from the "zero" position creates a field with a force 10 % greater than the previous one, which is enough to support the vertical and lateral forces (centrifugal and weight forces) applying to the rotor during the ascent of the GPV to and descent from Earth's orbit.

Determination of Impact of Electromagnet Coils on Resulting Magnetic Field of Power Unit

Based on Maxwell's equations and the finite element method, the magnetic field of the power unit was simulated.

Table 1 – Dependence of the repulsive force F_{sum} on the gap between magnets L



L, mm	0.5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
F_{sum}, N	1,530	1,386	1,192	1,046	930	834	758	688	628	576	530	488	452	418	386	358	334	310	288

The orientation of magnetic induction vectors in the longitudinal section of the power unit without and with switched coils is shown in Figure 5. The input data are the weight and dimensional properties of the materials and the applied magnetomotive force of 1,000 ampere-turns.

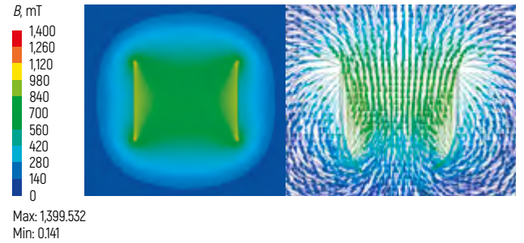


Figure 5 – Distribution of magnetic induction vectors:
a – permanent magnet; b – electromagnet; c – assembly

Figure 5c shows the amplification of the permanent magnet fields – the induction increases in proportion to the supplied current. In order to compare the dependence of magnetic induction intensity on distance above the magnet, the dependence diagrams for the power unit with no current passage and with current passage are plotted (Figure 6).

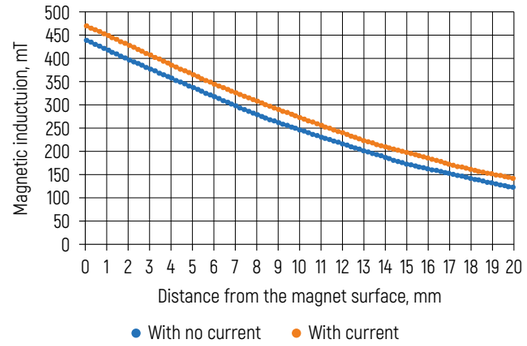


Figure 6 – Dependence of magnetic induction on the distance above the permanent magnet

We can make a conclusion that the magnetic induction in the case of a magnetomotive force of 1,000 ampere-turns at a distance of 4.5 mm from the surface has a value 6 % higher with current than with no current. The repulsive forces will depend proportionately on the force field over the permanent magnet, which can be increased by supplying current to the electromagnet coils.

It is assumed that an increase of even 1–5 % of induction per power unit is sufficient to stabilize the rotor in a set position. To optimize power consumption and heat generation, it is possible to propose a rotor suspension configuration with the arrangement of power units with coils through a certain number of power units consisting exclusively of permanent magnets.

Prototype Model of Hybrid Suspension Power Unit

To experimentally verify the performance of the power unit, a model was created (Figure 7) which is made of a permanent magnet of N40 brand with a size of 15 × 15 × 15 mm, a coil box made of ABS-max plastic and a copper winding of 300 turns.

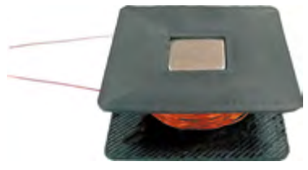


Figure 7 – Prototype model of the power unit

In the tests performed, the voltage was generated by a PS-3003 power supply having a maximum output current of 3 A. For comparison with the calculated part, where the magnetomotive force was 1,000 ampere-turns, for this winding of 300 turns the magnetomotive force at a current of 3 A will be equal to 900 ampere-turns. The magnetic field induction was measured with AKTAKOM ATE-8702 instrument characterized by a measuring range of 0–3,000 mT.

At the first stage, the magnetic field over the coil with current without a magnet was measured (Figure 8a). At the second stage, the value of magnetic induction over the magnet surface was determined without voltage supply to the coil (Figure 8b). In the third and fourth cases, the measurement was made with the current in the coil flowing in the forward and reverse direction, respectively, including the operation of the permanent magnet (Figures 8c, 8d). The results are summarized in Table 2.

a)

b)

c)

d)

Figure 8 – Measurement of magnetic induction over the surface of:
a – coil with current; b – permanent magnet;
c – assembly with current flowing in the forward direction;
d – assembly with current flowing in the reverse direction

Table 2 – Results of the experiment

Characteristic	Item			
	Coil	Magnet	Assembly	
Current, A	3	3	–3	
Magnetomotive force, ampere-turn	900	–	900	
Distance from surface to sensor, mm	1	1	1	
Magnetic induction, mT	20	465	487	442
Increase, %	–	–	5	–5

According to the results of the experiment, the magnetic induction over the permanent magnet is 465 mT, over the coil – 20 mT. When measuring over the complete system, 487 mT was obtained, where the difference of 2 mT can be related to the measurement error of the device. The field induction increases with these system characteristics reached 5 % of the value above the surface of a single magnet. When the current was passed in the reverse direction, the induction was 442 mT, showing a difference of –5 %.

As a result of analyzing the measurements, the following conclusion was made: the value of magnetic induction over the magnet surface is equal to the sum of magnetic induction of the permanent magnet and the coil; the latter, for its part, is adjusted by the current strength. This is confirmed by the principle of magnetic field superposition [7]. Another advantage of such an assembly is that the magnitude of the magnetic induction above the surface can be equally reduced by passing current in the reverse direction.

Conclusion

Hybrid rotor suspension design based on the combination of permanent magnets with electromagnets represents an advanced direction for the practical implementation of the GPV. Permanent magnets provide a basic level of suspension, reducing energy consumption, which in this respect is necessary to maintain the rotor in a stable vertical position and ensure the bearing capacity of the GPV during ascent and descent. Electromagnets allow flexible control of rotor positioning, automatic compensation of external disturbances and real-time modification of suspension vector quantities.

In this research the design of the hybrid electromagnetic suspension of the GPV rotor is offered, the concept of its running based on the laws of physics is formulated. The advantages and disadvantages of using a combination of permanent magnets and electromagnets are analyzed, and the principles of integration of magnetic and electromagnetic elements are considered in order to increase the efficiency of operation and ensure the dynamic stability of the giant in size and weight self-supporting spacecraft – the GPV – during large-scale near space industrialization.

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Analysis of Impact of Wind, Waves and Ocean Currents on Floating Overpass of General Planetary Vehicle

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A comprehensive analysis of the effects of wind, waves and currents on the structures of the oceanic sections of the General Planetary Vehicle (GPV) takeoff and landing overpass is presented. The study examines the loads acting on supports and other critical elements of this floating system.

Special attention is given to modeling and calculating the force impacts, enabling the determination of magnitudes and directions at the attachment nodes for anchor cables and supporting load-bearing underwater floats. These data are crucial for further design and optimization of the GPV overpass elements. The results enhance the reliability and durability of the structures, improving their resistance to extreme operational conditions.

The article offers a relevant and significant study aimed at developing a calculation model for the oceanic section of the GPV overpass to assess the impact of wind, wave and current forces on the structure strength and reliability.

Keywords:
climate, current, General Planetary Vehicle (GPV), load, takeoff and landing overpass, waves, wind.

Introduction

Climate change stands as one of the most pressing and alarming challenges of our time. Over the past few decades, scientists have noted a significant transformation in the global climate system, primarily driven by human activities. The combustion of fossil fuels, deforestation, intensive agriculture and other anthropogenic factors have led to an increase in greenhouse gas concentrations in the atmosphere, resulting in global warming. Since the preindustrial era, the Earth's average temperature has risen by approximately 1–2 °C, triggering the melting of glaciers and polar ice caps, rising sea levels, altered weather patterns and irreversible changes in ecosystems that threaten the planet's biodiversity.

This is unequivocally a global issue that necessitates urgent and coordinated international action. While reducing greenhouse gas emissions, transitioning to sustainable energy sources and enforcing stricter penalties for environmental violations are essential steps, these measures alone will not suffice over the next 200 years or beyond.

The only viable and secure solution for humanity lies in eliminating all sources of pollution that lead to catastrophic consequences – specifically, the harmful aspects of Earth's industrial activities. The project of non-rocket space industrialization developed by A. Unitsky [1] proposes a resolution to this dilemma, aiming to relocate industrial and residential infrastructure to equatorial orbits and establish large-scale logistics between space and Earth using a General Planetary Vehicle (GPV).

A crucial phase of this non-rocket space exploration involves the construction and operation of the GPV. Its takeoff and landing overpass, extending over 40,000 km, will be situated both on land and over water, encircling the planet along the equator. Special attention must be given to oceanic sections, as humanity currently lacks the experience and designs necessary for constructing such facilities. It is essential to account for the shear loads imposed by wind, waves and ocean currents on the floating supports of the GPV overpass [2], as these factors significantly impact the structure and pose risks to the runway's flatness and the GPV's takeoff and landing trajectory.

This paper examines the effects of wind, waves and currents on the GPV geocosmic transport and infrastructure complex. It determines the forces acting on the overpass supports and conducts structural calculations to ensure safety and efficiency.

Justification for Considering Effects of Wind, Waves and Currents on Floating Supports of GPV Overpass

The impact of wind, waves and currents on the floating supports of GPV overpass structures is intricate and multifaceted, influencing various aspects of design integrity, durability and performance. These natural forces generate significant dynamic and static loads, presenting numerous challenges that engineers and designers must address to ensure the reliability and safety of the structures. Notably, 31,170 km of the supports will be situated in water bodies with an average depth of 4 km [3].

Wind exerts forces that are distributed across the entire surface area of structural elements. The magnitude of these forces varies with wind speed, direction and gust frequency. Continuous wind loads can induce deflections and vibrations in long-span structures such as bridges and towers, leading to fatigue damage over time. High wind loads may also cause resonance phenomena, particularly when the frequency of wind-induced vibrations aligns with the structure's natural frequency, resulting in amplified vibrations that could cause harm or even collapse. Furthermore, wind erosion can deteriorate the surfaces of structures, compromising the material's strength and integrity. Prolonged exposure to strong winds may cause a structure to tilt out of horizontal axis, introducing stresses and deformations that can undermine its strength and stability.

Waves, driven by wind and other natural factors, exert an even more complex influence on structures, generating variable and shock loads that apply significant pressure to their surfaces. These wave actions can result in both static and dynamic deformations. During storms, particularly high waves can produce peak loads that exceed design specifications, potentially leading to damage or failure. Additionally, wave action can erode the soil around anchors, diminishing their stability and load-bearing capacity. In tidal regions, waves can also affect submerged structures, causing corrosion and degrading material quality. Moreover, waves contribute to vibrations that exacerbate fatigue damage, further diminishing structural durability and performance.

Currents in oceans and seas exert a persistent and significant influence on structures. These hydrodynamic forces lead to stresses and deformations in materials, which can be critical for underwater and coastal facilities. Currents can cause erosion and scouring around support elements, compromising their stability and potentially leading to displacement or failure. In strong, turbulent currents, soil erosion can create voids that reduce the load-bearing capacity of foundations.

Continuous exposure to currents accelerates the corrosion of metal components, particularly in saline environments, resulting in surface degradation. Vibrations from turbulent currents can also contribute to fatigue damage, manifesting as microcracks that may evolve into more severe structural issues.

Collectively, wind, waves and currents exert a complex and unpredictable influence on the GPV overpass. The dynamic interplay of these natural forces can result in cumulative negative effects, such as resonant vibrations and increased erosion, significantly raising operational costs related to structural maintenance and repair. Continuous monitoring and prompt repairs of damaged components become essential to ensure the functionality and safety of the structures, particularly in marine climates where economic costs can be substantial.

Design failures due to the effects of wind, waves and currents can lead to serious accidents, posing risks to human safety and the environment. The collapse of portions of the overpass could have catastrophic consequences, including loss of life and environmental disasters. Without adequate consideration of these natural factors during the design and construction phases, many elements of the GPV transport and infrastructure complex may become vulnerable to failure.

The durability and performance of the GPV overpass elements are directly linked to their capacity to withstand the forces exerted by wind, waves and currents. Neglecting these considerations can lead to reduced service life and heightened accident risks. For instance, metal structures under constant dynamic loads may quickly lose strength and stability, necessitating frequent repairs and replacements. Similarly, concrete structures may experience diminished load-bearing capacity due to erosion and scouring, increasing the likelihood of accidents.

Changing climatic conditions will lead to an increase in the strength and frequency of storms, as well as ascension of the wind and wave loads on offshore structures. Sea level rise will exacerbate the problem of erosion and scour, increasing the risks to coastal and offshore structures. Thus, the impact of wind, waves and currents on the GPV overpass elements will be even greater. As a result, the requirements for the design and construction process become more stringent, taking into account possible extreme factors and developing appropriate protection measures.

An analysis of the Unified State System of Information on the Situation in the World Ocean [4] shows that in the equatorial zones of the Pacific, Indian and Atlantic Oceans, winds blowing in the western direction at an angle of 30–45° to the equator dominate (Figure 1). At the equator itself, winds from the Southern and Northern Hemispheres collide to create a steady westward flow. The prevailing wind speeds are 5.9–8.1 m/s, with gusts up to 15 m/s.

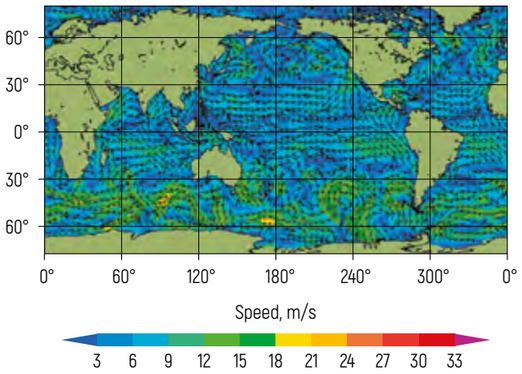

Figure 1 – Map of wind flow distribution (arrows show directions)

The impact of wind, waves and currents on the structures of the GPV transport and infrastructure complex will be a critical factor determining their reliability, durability and safety. Compensation of these influences at the stage of design of GPV overpass elements is necessary to ensure the above-mentioned characteristics in the conditions of aggressive marine environment.

Justification for Considering Dynamics of Wind Speed and Wave Height

I. Young, the scientist from the University of Melbourne, Australia, and A. Ribal, the scientist from Hasanuddin University, Indonesia, have observed a substantial increase in wind speed and wave height across the World Ocean since 1985. These changes are particularly pronounced in the Southern Ocean, where wind speed has risen by 8 % and wave height by 5 % [5].

The parameters are crucial for various atmospheric and oceanic processes. For instance, wind speed significantly influences heat exchange and the movement of carbon dioxide between the atmosphere and the ocean, while wave height is a critical factor in coastal flooding. The scientists highlight that detecting even minor trends related to climate change in these parameters poses considerable challenges. They utilized satellite data from 13 altimeters, 11 radiometers and 7 scatterometers across 31 satellites from 1985 to 2018, which they compared against readings from 80 ocean buoys [5]. This effort resulted in the creation of the largest dataset on wind speed and wave height available.

Their findings indicate a weak but statistically significant increase in wind speed of 1–2 cm/s/year in the southern Pacific, Atlantic Oceans and northern Atlantic. In terms of wave height, positive trends were observed in the Southern Ocean and parts of the Atlantic, while negative trends were noted in the North Pacific. No significant deviations were recorded in other regions of the World Ocean.

The most notable changes occurred in the Southern Ocean, where maximum wind speeds increased by 1.5 m/s (8 %), and maximum wave heights rose by 30 cm (5 %) during the study period. The scientists emphasize that their results (Figures 2, 3) are corroborated by all satellite instruments used, thereby minimizing the potential for errors related to data quality.

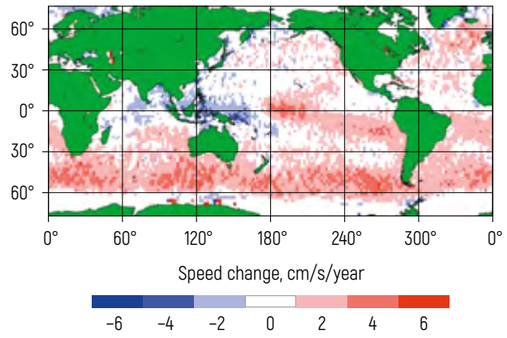

Figure 2 – Visualization of wind speed change from U10 altimeters for 1985–2018 (via annual Mann–Kendall test) [5]

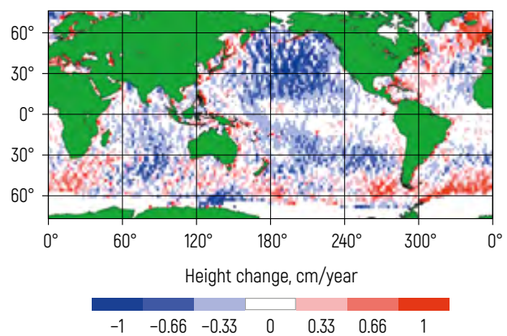

Figure 3 – Visualization of wave height change from Hs altimeters for 1985–2018 (via annual Mann–Kendall test) [5]

Alterations in currents in the southern parts of the World Ocean can significantly influence equatorial regions through several key mechanisms. One of the primary mechanisms is global ocean circulation, which connects various oceanic zones, creating a complex network of interacting currents. Currents in the southern oceans, such as the Antarctic Circumpolar Current, play a crucial role in the transport of water and heat, subsequently affecting equatorial currents.

In the southern Pacific, Atlantic and Indian Oceans, changes in currents can modify the speed and direction of water flows that reach the equatorial zone. This, in turn, impacts sea surface temperatures and nutrient levels, which are critical for ecosystems and climate conditions in equatorial regions. For example, increased currents from the southern oceans can introduce more cold water into equatorial zones, leading to shifts in local climate and wind dynamics.

Additionally, fluctuations in southern currents can affect the formation and movement of ocean fronts and eddies, which are vital for redistributing heat and salinity throughout the ocean. These processes can indirectly influence equatorial currents by altering their structure and intensity.

Therefore, understanding the relationship between currents in the southern oceans and their effects on equatorial zones is essential for the calculation and design of structures such as floating overpasses. This knowledge enables more accurate predictions of potential changes in dynamic loads, thereby enhancing the reliability and durability of these structures.

Designing facilities that can withstand wind forces is a critical challenge for engineers, particularly in regions prone to high winds. Achieving this objective requires the implementation of various methods and approaches, which can be categorized into several key areas: aerodynamic design, material selection, active and passive control systems, and monitoring and forecasting.

Overpass Design

Figure 4 presents an example of a floating overpass designed by A. Unitsky [6]. The structure is anchored to the seabed using a system of rods, while floats positioned at the upper part of the supports. This ensure stability during the operation of the GPV. The design features streamlined shapes and smoothed angles on the truss elements, which help minimize aerodynamic drag and turbulence. Each spatial truss cell measures 2.5 × 2.5 m, with the vertical spatial trusses having a projection size of 15 × 15 m [6].

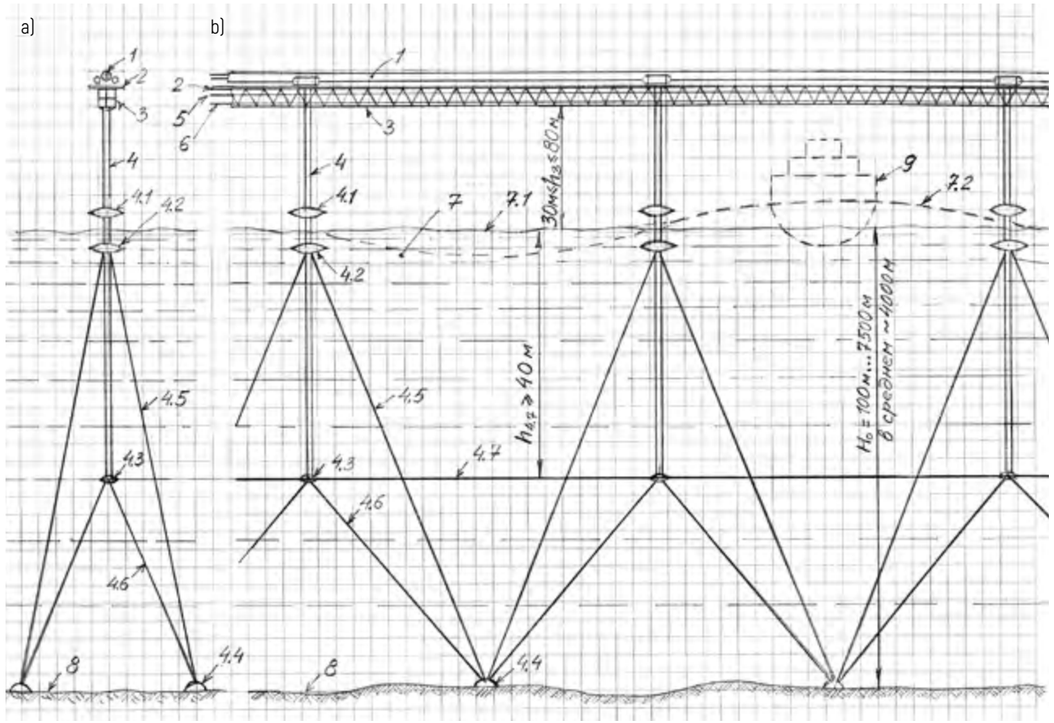

Figure 4 – Diagram of the GPV takeoff and landing overpass on oceanic section:
a – cross section; b – side view; 1 – GPV body; 2 – runway; 3 – load-bearing string truss;
4 – supports: 4.1 – emergency (surface) float, 4.2 – load-bearing (underwater) float,
4.3 – counterweight (sinker), 4.4 – anchor (sinker), 4.5, 4.6, 4.7 – stabilizing rods (ropes);
5 – urban uST (Unitsky String Transport) (speed up to 150 km/h); 6 – high-speed uST (speed up to 360 km/h);
7 – sea water: 7.1 – sea/ocean surface, 7.2 – wave; 8 – seabed; 9 – ship

Calculation of Current Loads

The support structure is designed as a spatial truss, necessitating the determination of forces acting on 1 lin m of the truss element with a circular cross section of 100 mm in diameter.

To calculate the forces exerted by underwater currents on the supports, we use the formula:

$$F = \frac{1}{2} V^2 \rho S C_x, \qquad (1)$$

where V – the speed of water flow, set at 1.5 m/s [2];

ρ – the density of seawater, approximately 1,020 kg/m^3;

S – the square of 1 lin m of the structure affected by the current is 0.1 m^2;

C_x – the aerodynamic drag coefficient, valued at 0.75 [7].

Substituting these values into the formula (1) yields:

$$F = \frac{1}{2} \times 1.5^2 \times 1{,}020 \times 0.1 \times 0.75 = 86 \text{ N}.$$

Calculation of Wind Loads

We can also utilize the same formula (1) to determine the wind loads acting on 1 lin m of the structure:

$$F = \frac{1}{2} V^2 \rho S C_x = \frac{1}{2} \times 15^2 \times 1.22 \times 0.1 \times 0.75 = 10.3 \text{ N},$$

where V – the wind speed, equal to 15 m/s;

ρ – the density of air, approximately 1.22 kg/m^3;

S – the frontal area of 1 lin m of the structure affected by the wind is 0.1 m^2;

C_x – the aerodynamic drag coefficient, valued at 0.75 [7].

Calculation of Wave Loads

Next, we calculate the force experienced by the overwater part of the overpass due to wave action.

The maximum linear wave load q_{max} (kN/m) on a vertical cylindrical barrier at a depth $z \geq 0$ (from the calculated water level) is determined using the following formula [8]:

$$q_{max} = \frac{1}{8} \rho g \pi k C_i D^2 \frac{C_i h k (d - z)}{C_i h k d}, \qquad (2)$$

where ρ – the density of seawater, 1.02 t/m^3;

g – the acceleration of gravity, approximately 9.81 m/s^2;

k – the wave number, equal to 6.28 rad/m and calculated by the formula $2\pi/L$;

L – the wavelength, equal to 1 m;

C_i – the inertial coefficient, which depends on the parameter $\frac{\pi D}{L}$ and is taken from a graph [8], equal to 2;

D – the diameter of the barrier, set at 0.1 m;

h – the wave height, valued at 1.5 m [2];

d – the water depth, equal to 4,000 m [3];

z – the barrier depth, equal to 70 m.

Substituting the relevant values into the formula (2) results in:

$$q_{max} = \frac{1}{8} \times 1.02 \times 9.81 \times 3.14 \times 6.28 \times 2 \times 0.1^2 \times \times \frac{2 \times 1.5 \times 6.28(4{,}000 - 70)}{2 \times 1.5 \times 6.28 \times 4{,}000} = 0.49 \text{ kN/m}.$$

Justification of Calculation Scheme

The structure's analysis was conducted using the RFEM program, employing the finite element method. The truss structures are represented as rod elements with a circular cross section measuring 102 mm in diameter. The rods are made from S355 steel. It is assumed that the truss elements will be adequately protected against corrosion, so the reduction in material properties is not considered in the calculations. In the model, the nodes – depicted in green – serve as attachment points for ropes, floats and adjacent supports, which have restricted movement and rotation (Figure 5). The truss elements are subjected to wind loads directed along the equatorial line in the Y direction, as well as loads from currents and waves acting in the $-Y$ direction (Figures 6a, 6b, 6c).

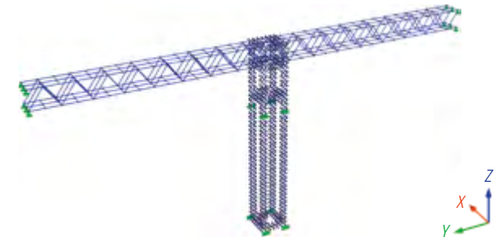

Figure 5 – Calculation scheme of the structure
(points of ropes, floats and adjacent supports attachment are marked in green)

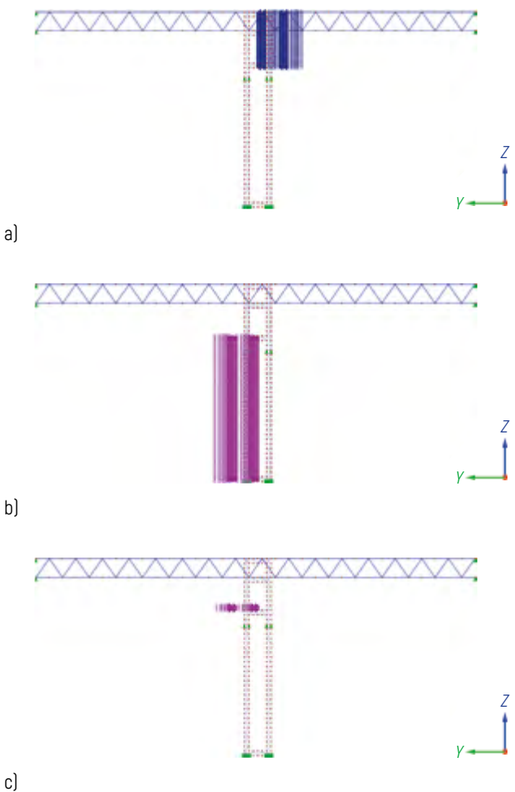

Figure 6 – Load application schemes, kN/m:
a – from wind; b – from current; c – from wave

Analysis of Results

Figure 7 illustrates the deformations of the structure (scaled at 50 : 1) when subjected to a combination of loads from self-weight, wind, waves and currents. The maximum strain observed is 50.4 mm, occurring in the underwater section.

The stresses within the elements, as shown in Figure 8, vary between 14.44 and –32.14 kN/cm², representing 92 % of the allowable limits for the specified material.

The forces and their directions at the rope attachment points are shown in Figures 9–13.

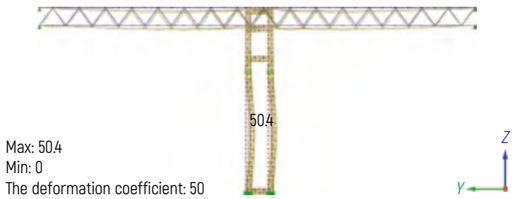

Figure 7 – Visualization of structural deformations, mm

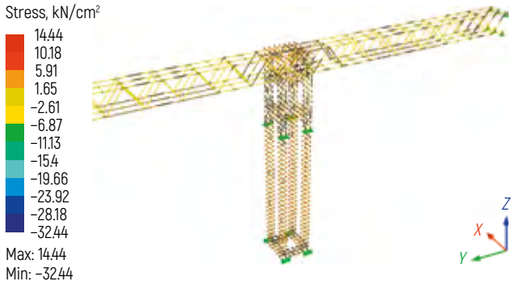

Figure 8 – Visualization of stresses in the structure

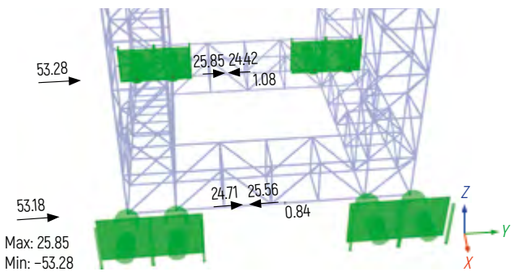

Figure 9 – Reaction force values in nodes in *Y* direction (bottom ropes), kN

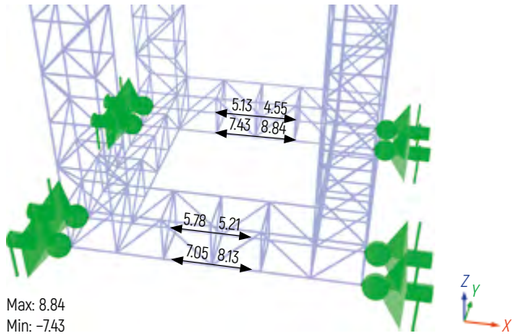

Figure 10 – Reaction force values in nodes in *X* direction (bottom ropes), kN

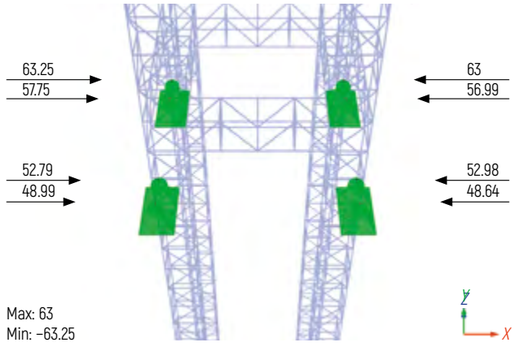

Figure 11 – Reaction force values in nodes in *X* direction (top ropes), kN

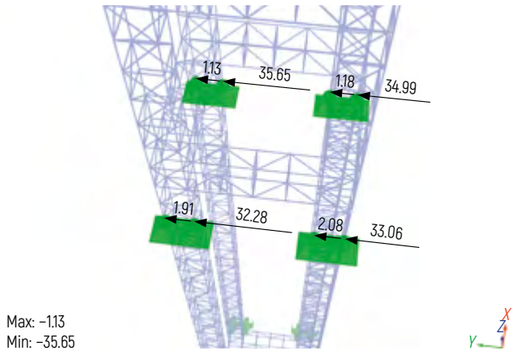

Figure 12 – Reaction force values in nodes in *Y* direction (top ropes), kN

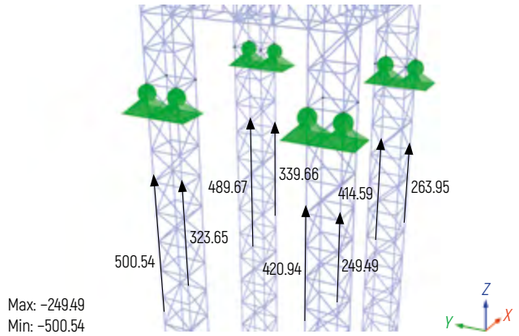

Figure 13 – Reaction force values in nodes in *Z* direction (top ropes), kN

Conclusion

The research has thoroughly examined the loads from wind, waves and currents on the GPV takeoff and landing overpass. Key types and directions of impacts on the floating supports have been identified, and a computational model of the structure has been developed to account for these natural loads.

Based on the established model and calculations, we obtained values for the forces and their directions at critical nodes, such as the attachment nodes for anchor cables and load-bearing underwater floats. This information serves as a foundation for further design and optimization of the GPV overpass elements. Specifically, it can guide the selection of cross sections and profiles for the rod structure components, tailored to the unique conditions of the overpass site.

Moreover, the calculation results enable us to determine the optimal characteristics for the underwater floats and their connections to the main structure of the floating supports. This includes evaluating strength characteristics and assessing the stability and durability of structural elements when subjected to external loads like wind, waves and currents.

In summary, this study provides valuable engineering insights that can be applied in the design, construction and operation of the GPV takeoff and landing overpass in oceanic environments, ensuring its reliability and safety. These findings will help mitigate accident risks, extend the service life of the structures, and ultimately reduce operating costs while enhancing the overall efficiency of the GPV geocosmic transport and infrastructure complex.

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Aerodynamic Characteristics of General Planetary Vehicle Equatorial Overpass

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This article presents a study of the aerodynamic characteristics of the tunnel transport track structure of the General Planetary Vehicle equatorial overpass, providing an in-depth analysis of the impact of various factors on its aerodynamic qualities. The influence of the shape of this object elements on its external (wind loads) and internal (rolling stock movement) aerodynamics is considered in order to identify the optimal geometric parameters for minimizing movement resistance and improving the overall energy efficiency of the structure.

The obtained results may be applied to optimize the design of transport overpasses and similar structures, thereby improving their aerodynamic efficiency and stability. This article makes a substantial contribution to the development of structural aerodynamics and may be useful for engineers and designers involved in the development and enhancement of such transport and infrastructure facilities.

Keywords:
aerodynamics, container ship, equatorial overpass, General Planetary Vehicle (GPV), tunnel, tunnel transport, wind loads.

Introduction

In today's world, where the pace of urbanization is steadily increasing, the need for reliable and efficient transport systems becomes more and more evident. The equatorial overpass of the General Planetary Vehicle (GPV) [1], as a key element of the geocosmic transport and infrastructure complex, ensures the uninterrupted movement of high-speed rolling stock along the GPV. This innovation reduces congestion and enhances access to geocosmic logistics. However, with the increase in the height of supports and the length of span structures, aerodynamic characteristics influenced by wind loads, especially lateral ones, are critically important for ensuring the strength and safety of structures [2, 3].

The shape of the cross section of the equatorial overpass tunnel plays a key role in ensuring structural integrity, aerodynamic efficiency and resistance to external influences. The main aspect to consider when choosing this parameter is resistance to lateral wind loads, precipitation, temperature fluctuations and the impact of transport loads. The most acceptable cross-sectional shapes of tunnels – circular, oval, teardrop-shaped [4] – allow reducing aerodynamic drag and turbulence, minimizing the accumulation of snow and ice, achieving uniform stress distribution under temperature deformations and dynamic loads from rolling stock.

This article focuses on studying the impact of wind loads on the transport overpass [5]. The main factors, such as the shape of the tunnel cross section and wind speed, affecting aerodynamic characteristics, are considered. Additionally, modern calculation and modeling methods that allow engineers to predict and optimize aerodynamic properties at the design stage to minimize risks and increase the efficiency of overpass-type structures are studied [6–8].

The purpose of this study is to examine the aerodynamic characteristics of the design forms of GPV transport overpass tunnels, focusing on both single- and double-track configurations. Particular attention is given to investigating the effect of this parameter on air resistance at various lateral wind speeds. The research seeks to identify optimal aerodynamic tunnel profiles that enhance smooth airflow and reduce resistance along the equatorial overpass. The findings are intended to inform recommendations for designing and refining transport overpasses to meet contemporary standards.

Assessment of Influence of Tunnel Shape on Aerodynamic Characteristics

The aerodynamic characteristics of a tunnel, as influenced by the shape of its cross section under lateral wind conditions, were analyzed using the finite element method. The *k*-ω SST (Shear Stress Transport) turbulence model was chosen for this study due to its ability to deliver highly accurate predictions of flow separation and boundary layer behavior [9].

The tests employed an ideal compressible gas model [1] to represent the viscous medium, with the relationship between viscosity and temperature defined using Sutherland's formula [2]:

$$P = \rho RT, \tag{1}$$

where P – pressure in the volume, Pa;
ρ – medium density, kg/m^3;
R – gas constant, J/(mol·K);
T – temperature, K.

$$\frac{\mu}{\mu_0} = \left(\frac{T}{T_0}\right)^{3/2} \times \frac{T_0 + S_\mu}{T + S_\mu}, \tag{2}$$

where μ – medium viscosity, Pa·s;
μ_0 – reference viscosity value, Pa·s;
T – medium temperature, K;
T_0 – reference temperature value, K;
S_μ – Sutherland's constant [10].

To evaluate aerodynamic parameters, several variants of tunnel cross-sectional shapes were selected for analysis (Figure 1).

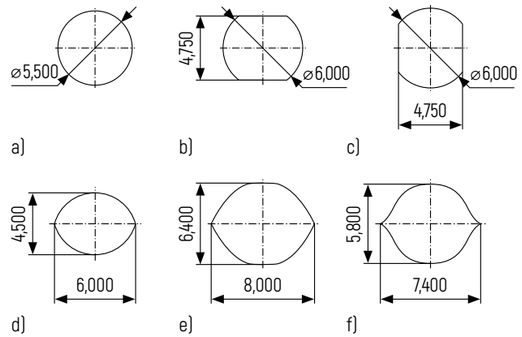


Figure 1 – Variants of tunnel cross-sectional shapes:
a – variant 1; b – variant 2; c – variant 3;
d – variant 4; e – variant 5; f – variant 6

Initial Data for Calculation

The initial parameters set include the dimensions of the tunnels and the speed of the cross-sectional airflow.

Wind speed can vary significantly depending on specific environmental factors and facility location. To calculate loads on tunnel structures, an average range of wind speeds from moderate (10 m/s) to hurricane force (110 m/s) with a step of 20 m/s was used. Standard conditions were taken as air characteristics: atmospheric pressure of 101,325 Pa and a temperature of 20 °C.

Based on the results obtained for various tunnel shapes, the most promising ones were identified.

Description of the Mathematical Model

For simplification of calculations, two-dimensional modeling was used. The calculation model is shown in Figure 2. The boundary parameters are: inlet flow speed (from 10 to 110 m/s), outlet atmospheric pressure (101,325 Pa); symmetry conditions were met on the boundary surfaces; adhesion conditions (zero velocity on the wall surface) were set for the stationary wall of the tunnel.

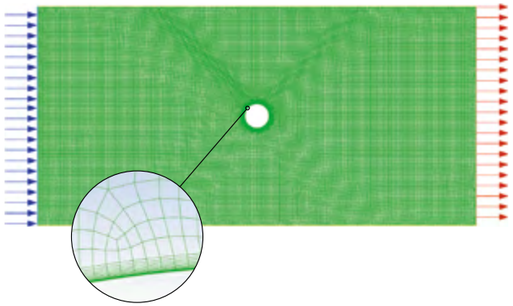


Figure 2 – Calculation model

As shown in Figure 2, the calculation grid was formed with gradual refinement approaching the tunnel wall. Additionally, wall layers were created to describe the flow behavior in the boundary layer. This distribution of calculation nodes allows achieving residual values of less than 10^{-4} within 800–2,000 iterations.

Results of Mathematical Modeling

Based on the calculated data obtained during virtual tests, the resistance forces acting on the tunnel were determined, the aerodynamic drag coefficient C_x was calculated, and its dependence on wind speed for the considered tunnel cross sections was plotted (Figure 3).

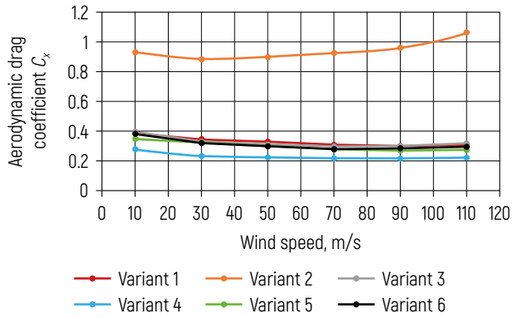


Figure 3 – Dependence of aerodynamic drag coefficient C_x on wind speed and variant of tunnel cross-sectional shape

The aerodynamic drag coefficient is calculated using the formula:

$$C_x = \frac{2F}{\rho v^2 A}, \qquad (3)$$

where F – aerodynamic drag force, N;

ρ – air density, kg/m^3;

v – wind speed, m/s;

A – midsection area of the tunnel, m^2.

According to the Figure 3, it is obvious that variant 4 is the best in terms of the aerodynamic characteristics.

Figure 4 shows the airflow streamlines obtained using the Ansys software suite for the worst (variant 2) and best (variant 4) tunnel shapes in terms of aerodynamic efficiency at wind speeds of 30, 70 and 110 m/s.

Figure 4 clearly illustrates the streamlining of different tunnel shape variants by the airflow. In variant 4, the rear part of the tunnel is an area of flow separation where vortices and turbulence form. This leads to the creation of a vortex trail with varying wind direction and speed. The vortex trail is smaller compared to that of variant 2: around such a shape, the flow separation occurs at the frontal part, resulting in the formation of large, stable coherent vortex structures. At wind speed of 110 m/s, these vortices lose stability and periodically detach from the tunnel surface. They maintain their form for some time, creating a wake (vortex street or Kármán vortex street [11]) behind the streamlined object, slowly dissipating in the flow due to friction until they disappear.

Figure 5 shows the pressure distribution for the considered tunnel shape variants at a maximum wind speed of 110 m/s, obtained using the Ansys software suite. The availability of such data, combined with numerical values, allows for thorough analysis.

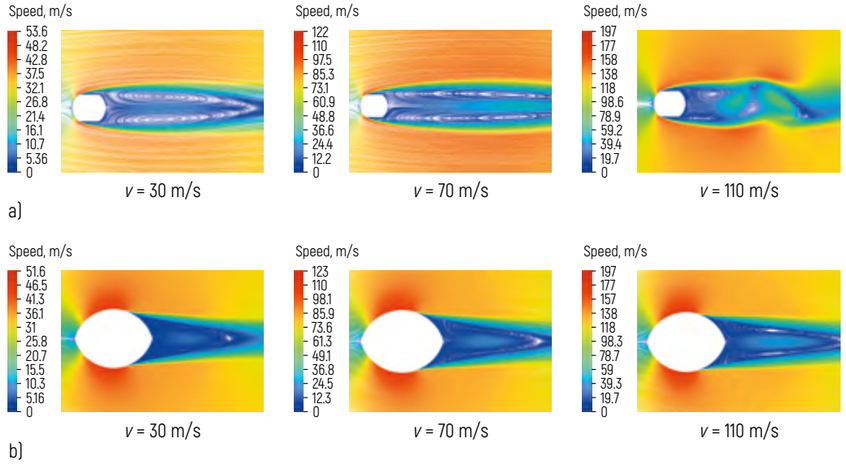


Figure 4 – Airflow streamlines around variants of tunnel cross-sectional shapes:
a – variant 2; b – variant 4

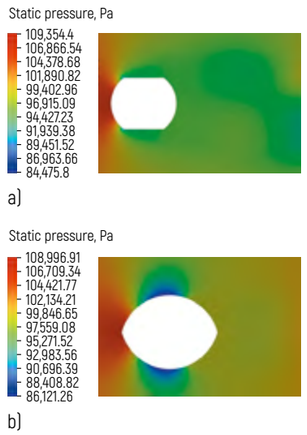


Figure 5 – Pressure distribution
around variants of tunnel cross-sectional shapes:
a – variant 2; b – variant 4

Figure 5a shows that a stagnation zone with maximum pressure forms on the windward side of the tunnel, where the airflow separates and detaches, creating an extensive low-pressure area and increasing wind pressure forces.

The results indicate that the shape of the tunnel significantly influences aerodynamic pressure forces, with differences in their numerical parameters being substantial. For instance, variant 4 is 29–33 % more efficient than the circular cross section (variant 1) and 70–80 % more efficient than the truncated circle (variant 2, which has the worst aerodynamic characteristics).

It can be concluded that when designing a transport overpass, the cross-sectional shape of the tunnel must be considered, as this directly affects the loads perceived by both the tunnel itself and its supporting structures.

Assessment of Influence of Tunnel Shape Truncation Length on Aerodynamic Characteristics

According to the calculations performed, the most aerodynamically efficient tunnel cross-sectional shape is an elongated oval. However, it requires more labor-intensive calculations and design work to ensure uniformity of loads and stability of the entire structure. This is especially true for determining the curvature and precision of manufacturing tunnel parts. Oval elements with pointed ends require specialized equipment and corresponding technology, which may increase the production cost. Therefore, specific steps must be taken to facilitate tunnel construction. It is worth noting that the truncated part is parasitic, as it will not contain any structural elements, and its absence will significantly reduce snow load, material consumption and tunnel cost.

At the same time, truncating the tunnel cross-sectional shape is one optimization method that allows balancing between the structural advantages of an oval shape and the simplicity of manufacturing characteristic of more standard shapes. The truncation process of the oval shape may include, for example, the use of semi-oval sections, where the lower part remains circular, and the upper and side parts can be slightly smoothed or straightened, which will simplify assembly and retain aerodynamic and structural advantages while reducing production complexity.

In this regard, the study calculated the aerodynamic parameters of truncated tunnel shapes of the transport overpass, based on the shape of variant 4 (Figure 6).

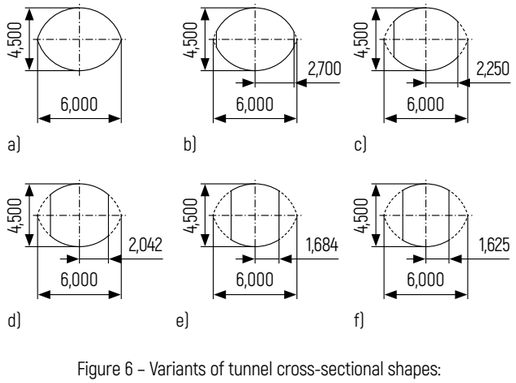


Figure 6 – Variants of tunnel cross-sectional shapes:
a – variant 4; b – variant 4.1; c – variant 4.2;
d – variant 4.3; e – variant 4.4; f – variant 4.5

Results of Mathematical Modeling

As a result of mathematical modeling, a graph of the dependence of the aerodynamic drag coefficient C_x on wind speed for the considered tunnel cross-sectional variants was constructed (Figure 7).

Figure 8 shows the graph of the aerodynamic drag coefficient C_x dependence on the size of the tunnel shape truncation at different lateral wind speeds.

The graphs shown in Figures 7 and 8 clearly demonstrate that variants 4.1 and 4.2 (truncation sizes of 300 and 750 mm) have an insignificant impact on aerodynamic drag (within 0.6–5.5 %). Variant 4.3 is a "transitional" variant, as its drag significantly depends on the velocity of the incoming flow and can vary between 13–76 % of the original shape's drag. Variants 4.4 and 4.5 perform significant wind resistance (coefficient C_x exceeds by 96–454 %).

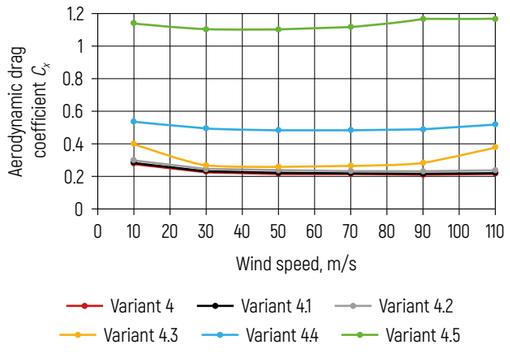


Figure 7 – Dependence of aerodynamic drag coefficient C_x on wind speed and variant of tunnel cross-sectional shape

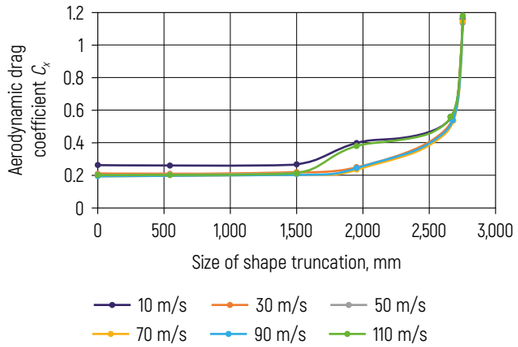


Figure 8 – Dependence of aerodynamic drag coefficient C_x on the truncation size of tunnel cross-sectional shape at different lateral wind speeds

Figure 9 provides the visualization of airflow streamlines around the considered truncated oval cross sections at minimum (30 m/s) and maximum (110 m/s) wind speeds.

The calculation results clearly demonstrate the transition from stable zones around the tunnel to a sharp increase in the area of vortex structures as the flow separates, changes its shape and ultimately disturbs the airflow, forming extensive zones of turbulent vortices and subsequently generating a vortex street. In this context, variant 4.5 stands out significantly, both in terms of vortex street formation and boundary layer separation occurring immediately at the frontal part. Thus, it can be concluded that the tunnel truncation is permissible up to a value not exceeding 25 % of their width.

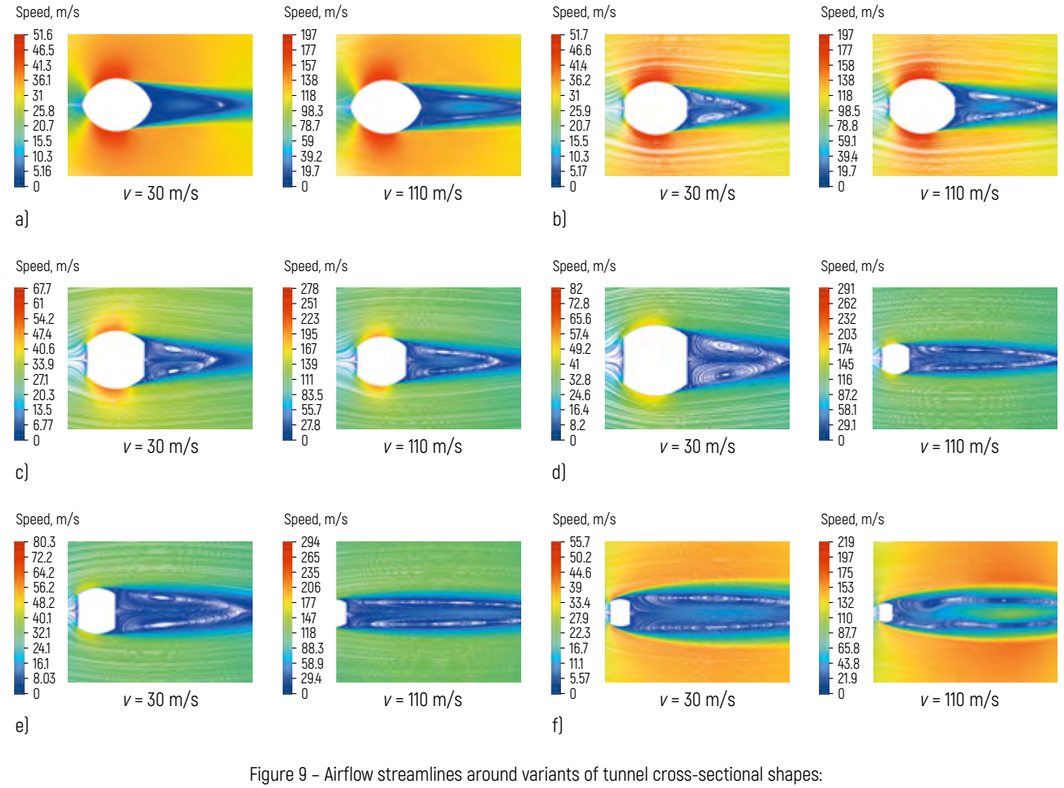


Figure 9 – Airflow streamlines around variants of tunnel cross-sectional shapes:
a – variant 4; b – variant 4.1; c – variant 4.2; d – variant 4.3; e – variant 4.4; f – variant 4.5

Double-Track Tunnels

To enhance capacity, optimize schedule management, minimize delays and disruptions as well as ensure more efficient utilization of infrastructure, the construction of double-track transportation systems is increasingly prioritized in the development of tunnel overpasses.

We will calculate the aerodynamic parameters of the double-track tunnel overpass with varying distances between tunnels to determine the impact of wind load on the coefficient C_x.

For an initial assessment of aerodynamic drag, double-track circular-section tunnels are considered at various distances from each other to identify the optimal value. Additionally, the effect of wind on the combined ("stitched") model of a double-track tunnel is analyzed to calculate the permissible distance between the tracks. The calculation model variants are presented in Table 1.

Table 1 – Distance variants between tunnels

Variant	Distance between tunnels, m	Model
Single-track tunnel		
1	–	5,500
Separate tracks		
2	1	5,500 5,500
3	3	
4	5	
5	7	
Combined ("stitched") tracks		
2.1	1	5,500 5,500
3.1	3	
4.1	5	
5.1	7	

Results of Mathematical Modeling

As a result of numerical modeling, aerodynamic characteristics were determined, based on which dependencies of the aerodynamic drag coefficient C_x on two tunnels of the considered track structures were constructed. Figure 10 shows the graph of the C_x dependence on wind speed for the first tunnel (for variants 2–5 according to Table 1).

The graph shows that, when the tunnels are spaced 1 and 3 m apart, the coefficient C_x intersects with the values of the single-track tunnel, depending on wind speed. Hence, it can be concluded that these distances practically do not affect the first tunnel. Further spacing to 5 and 7 m leads to a decrease in C_x. This is caused by drafting – a phenomenon where two objects placed one behind the other at a certain distance can reduce the overall effect of wind pressure [12].

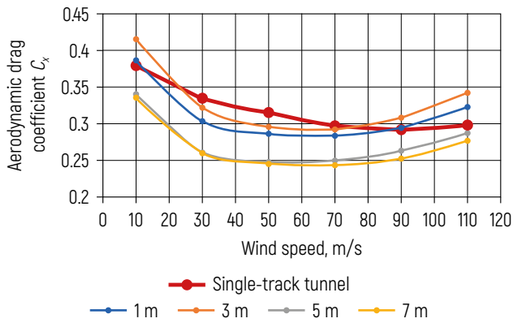


Figure 10 – Dependence of aerodynamic drag coefficient C_x on wind speed for the first tunnel and the distance between the tunnels

Figure 11 shows the graph of the C_x dependence on wind speed for the second tunnel (for variants 2–5 according to Table 1).

The obtained results indicate that, depending on the distance between the tunnels, the coefficient C_x of the second tunnel can be either positive or negative. This phenomenon is explained by the occurrence of a rarefaction zone between the tunnels when they are sufficiently close, causing them to be attracted to each other. As the distance increases, this effect weakens, and the drag force becomes positive.

Figure 12 shows the graph of the resulting C_x dependence on wind speed at different distances between separate and "stitched" double-track tunnels.

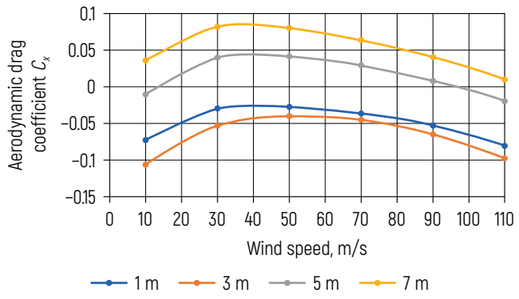


Figure 11 – Dependence of aerodynamic drag coefficient C_x on wind speed for the second tunnel and the distance between the tunnels

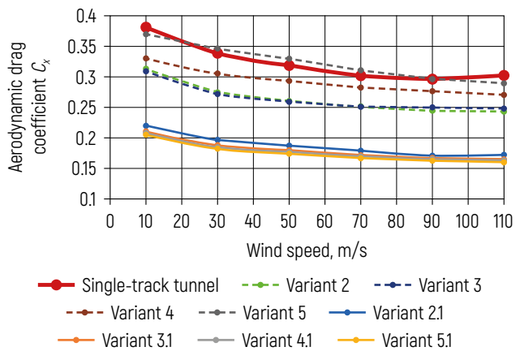


Figure 12 – Dependence of resulting aerodynamic drag coefficient C_x on wind speed for the considered tunnel variants

Figure 12 demonstrates the total component of the coefficient C_x compared to the single-track tunnel. It is evident that with a spacing of 1, 3 and 5 m, there is a decrease in the coefficient C_x by an average of 7 to 20 % for double-track separated tunnels. However, it is worth noting that a similar but combined double-track tunnel has a lower C_x value, with differences ranging from 29 to 46 %.

The results of the airflow streamlines simulated in the Ansys software suite are shown in Figure 13, clearly illustrating the locations and sizes of the vortices.

Figure 13 shows that with a small inter-tunnel distance between the first and second tunnels, a separation stagnation zone is formed, and they are essentially enveloped by air as a single entity, with the vortex structure beginning to form behind the second tunnel. Under these conditions, a low-pressure front arises between the tunnels, causing a negative C_x for the second tunnel. As the distance increases, a new stable vortex system with symmetric vortices behind the front tunnel appears, where the descending airflow starts to impact the second tunnel, leading to an increase in both its C_x and the overall system C_x, ultimately resulting in wind pressure exceeding that on the single-track tunnel.

A different picture is shown by the "stitched" tunnels. Regardless of width, they have an advantage over the separate double-tunnel structure, as there is no impact from turbulent flows in the gaps, and the elongated shape ensures a smooth airflow, preventing the formation of extensive vortex zones and reducing resistance.

Based on the results of the previous calculations, it is necessary to analyze the dependence of the aerodynamic drag coefficient C_x on the design of double-track tunnels with an elongated oval cross section. The variants for their calculation models are presented in Table 2. A variant with truncated ovality (variant 6.2) is also considered.

As a result of the calculations, a graph of the C_x dependence on wind speed for the considered variants of double-track tunnels is obtained (Figure 14).

The graph shows that all the considered cross sections have a similar nature of C_x changes depending on wind speed. The best aerodynamic characteristics belong to variants 5.2 and 6.2.

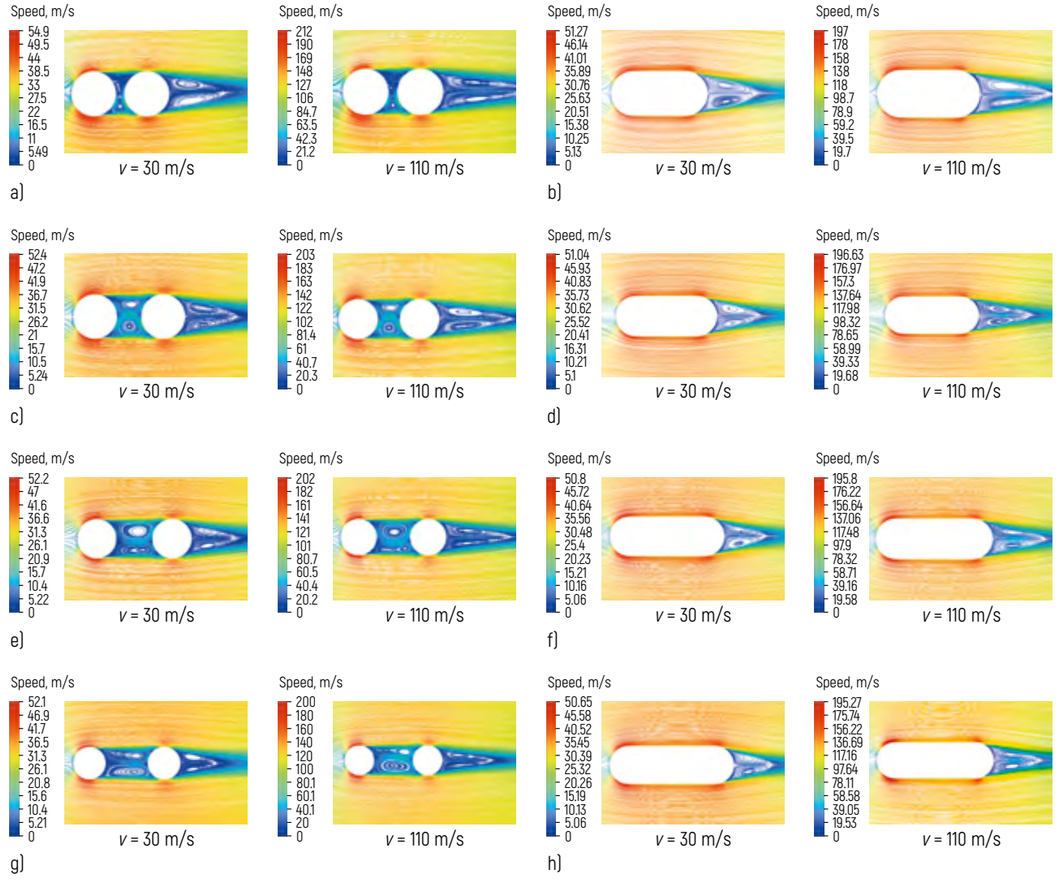
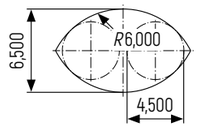
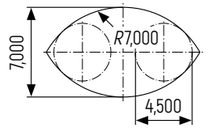
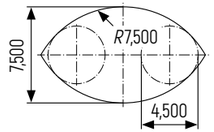
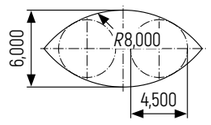
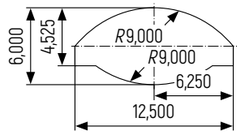


Figure 13 – Airflow streamlines for the calculated tunnel variants:
a – variant 2; b – variant 2.1; c – variant 3; d – variant 3.1; e – variant 4; f – variant 4.1; g – variant 5; h – variant 5.1

Table 2 – Variants of double-track tunnel shapes

Variant	Width-to-height ratio	Model
2.2	1.25	
3.2	1.73	
4.2	1.73	
5.2	2.1	
6.2	2.1	

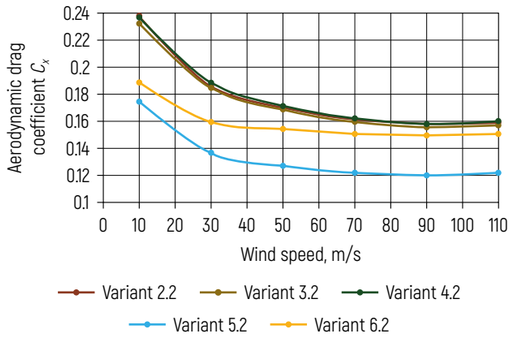


Figure 14 – Dependence of aerodynamic drag coefficient C_x on wind speed and variant of tunnel shape

Figure 15 presents the simulation results of airflow streamlines at speeds of 30 and 110 m/s for all cross-sectional variants.

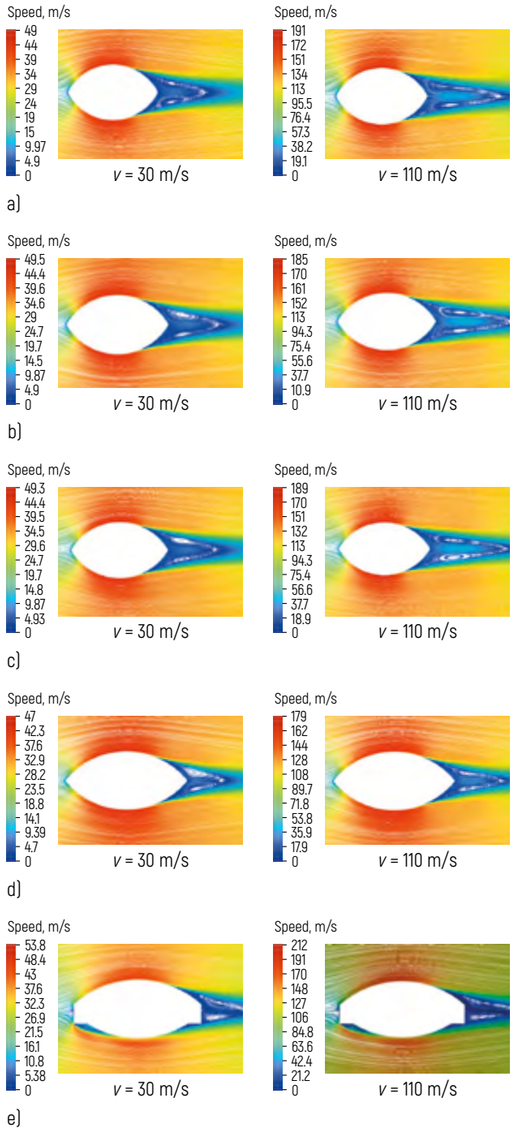


Figure 15 – Airflow streamlines around variants of tunnel cross-sectional shapes: a – variant 2.2; b – variant 3.2; c – variant 4.2; d – variant 5.2; e – variant 6.2

Figure 15 shows that the considered shapes are well streamlined. There are no vortex streets in all variants, and the "tails" are small. In variants 5.2 and 6.2, the rear part of the tunnel becomes the separation zone of the flow, where vortices and turbulence form, leading to the creation of a vortex wake with variable flow direction and speed. All these factors contribute to low resistance.

Mathematical modeling confirmed that the most optimal variants for minimizing lateral wind pressure are 5.2 and 6.2. Compared to the circular-section tunnel (Table 1, variant 1), shapes 5.2 and 6.2 are 49–59 % more efficient, which is the best result among all considered cross sections.

Open Double-Track Tunnels

Double-track transport overpasses with an open-type tunnel cross section allow optimal use of space, especially in densely populated urban areas. Such structures can be built over roads, railways or rivers and are easier to manufacture compared to fully closed tunnel overpass. The absence of side walls in the tunnel eliminates the choked flow effect when moving high-speed transport and reduces its aerodynamic drag.

Below is the calculation of the aerodynamic parameters of open double-track tunnels, modeled based on the truncated double-track tunnel variant. The shapes of such cross sections with their different internal mobile compositions (discrete – uCont for container transportation, as well as continuous – uTrans for bulk cargo transportation) are presented in Table 3.

Results of Mathematical Modeling

The efficiency of the aerodynamic drag coefficient C_x for open tunnel variants was evaluated in comparison to the truncated shape of a double-track tunnel.

The data obtained through modeling is presented in Tables 4 and 5.

Table 4 indicates that variant 1.3 demonstrates the lowest coefficient C_x, even lower than that of a closed tunnel (variant 1). Although variants 1.1 and 1.2 experience lower forces, their midsection areas are smaller as well.

Table 5 highlights that the overall lateral C_x for container trucks within the tunnel ranges from 0.48 to 0.49, depending on wind speed. This suggests that the nature of airflow around a group of objects induces a counterforce on the tunnel. Vortices formed between objects can create turbulence and resistance, which can either diminish or enhance the overall efficiency of the system. Therefore, understanding and mitigating such vortices could lead to significant design improvements for the tunnel.

Table 3 – Variants of open double-track tunnel shapes

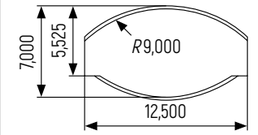
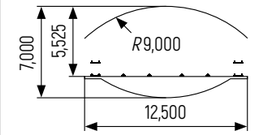
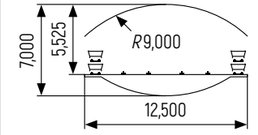
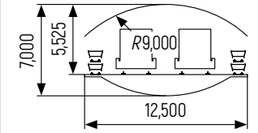
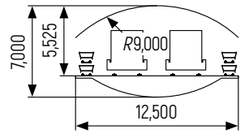
Variant	Midsection area per 1 lin m, m^2	Shape
1	7 (closed)	
1.1	4.55 (with double-track structures)	
1.2	5.51 (with two uTranses on the sides)	
1.3	7 (with two uTranses and two uConts)	

Table 4 – Results of aerodynamic characteristics calculations for open tunnels

Variant	Lateral wind speed, km/h (m/s)	Lateral force, N	C_x
1	108 (30)	744	0.2
	396 (110)	9,479	0.19
1.1	108 (30)	593	0.24
	396 (110)	7,602	0.23
1.2	108 (30)	662	0.22
	396 (110)	8,655	0.22
1.3	108 (30)	638	0.17
	396 (110)	8,453	0.17

Table 5 – Aerodynamic characteristics of container trucks in a tunnel

Variant	Tunnel shape	Lateral wind speed, km/h (m/s)	Lateral force on the first container truck, N	C_x of the first container truck	Lateral force on the second container truck, N	C_x of the second container truck
1.3		108 (30)	621	0.4	118	0.08
		396 (110)	8,549	0.41	1,739	0.08

Visualization of airflow streamlines for the analyzed open double-track transport overpasses at lateral wind speeds of 30 and 110 m/s is shown in Figure 16.

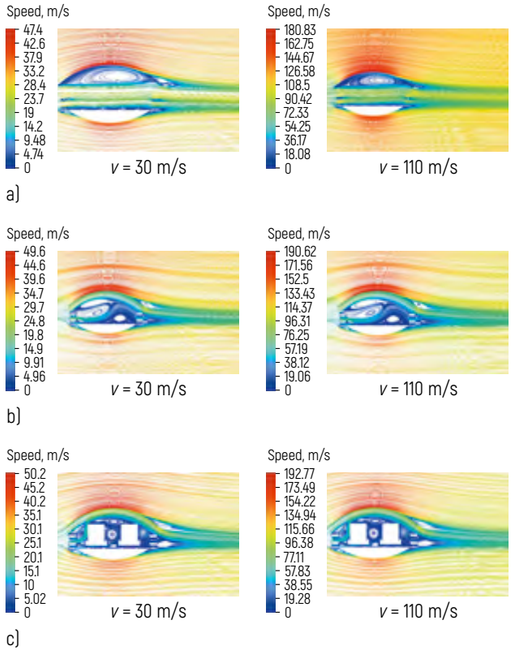


Figure 16 – Airflow streamlines
around variants of double-track open tunnels shapes:
a – variant 1.1; b – variant 1.2; c – variant 1.3.

The analysis of Figure 16 reveals that when air flows around open tunnels, there is no vortex formation behind the tunnel, thereby lateral resistance is reduced.

However, the airflow impacts the tunnel's interior walls and elements within, including the moving vehicles. Additionally, vortices form that, depending on their location, can either increase or decrease the overall lateral wind pressure.

Conclusion

The study highlights the importance of analyzing the aerodynamics of tunnel track structure as a component of the equatorial takeoff and landing overpass for the GPV. A range of cross-sectional tunnel configurations and their impacts on aerodynamic wind pressure were examined, enabling the identification of the key advantages and limitations associated with each reviewed design.

The findings revealed that oval cross sections with sharp ends and a width-to-height ratios of 2 or greater demonstrate superior aerodynamic performance. Depending on wind speed, their efficiency is 29–33 % higher than that of circular shapes and 70–88 % higher compared to the least optimal design. However, the manufacturing of oval elements with sharp ends necessitates specialized technology and equipment, which increases production costs. To address this, the truncation of sharp edges was proposed as an alternative. Modeling results indicated only a marginal reduction in efficiency – ranging from 0.6 to 5.5 % – provided that the truncation does not exceed 25 % of the tunnel's original width.

The research also advanced understanding of double-track transportation systems, particularly in the context of spacing tunnels at specific intervals. It was determined that two connected tunnels are more efficient than two separate ones. Moreover, increasing the separation distance between integrated tunnels from 1 to 7 m significantly improved their aerodynamic efficiency. A pivotal discovery was the performance of a twin ("stitched") circular tunnel, formed by two circular tunnels. This configuration exhibited a substantially lower aerodynamic drag coefficient C_x of 0.15–0.2, which is 48 % lower than that of a single-track circular-section tunnel. Additionally, the "stitched" tunnel showed enhanced lateral rigidity, a feature particularly valuable for the GPV equatorial overpass design on oceanic sections where floating supports are planned.

The modeling of open tunnels further demonstrated that, in some cases, their use can reduce overall aerodynamic drag; however, it is accompanied by increased airflow effects on moving vehicles, which are absent in closed tunnels. For instance, in variant 1.3, the aerodynamic drag coefficient C_x is 15 % lower than that of a comparable closed tunnel (variant 1). In variants 1.1 and 1.2, C_x is higher than in closed tunnel due to smaller midsection area, though the resulting loads are less significant.

Thus, both the advantages and disadvantages of open and closed tunnels must be carefully considered when selecting a tunnel design. While open tunnels may reduce overall aerodynamic drag, they can influence moving vehicles. Closed tunnels, on the other hand, provide a more stable and predictable airflow environment, eliminating external effects.

In conclusion, this study emphasizes the significance of aerodynamic design in modern transportation infrastructure systems. Properly designed tunnels can substantially reduce wind loads, thereby decreasing construction and maintenance costs. Oval tunnels with optimized dimensions and shapes demonstrated the best performance in minimizing aerodynamic drag, making them a preferred choice for future projects. Furthermore, the integration of two tunnels into a unified complex presents opportunities to enhance the efficiency of transport corridors and alleviate stress on the transport system. These findings can serve as a foundation for developing new standards and construction methods that will contribute to the creation of more sustainable and cost-effective structures.

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UDC 624.195+629.7

Aerodynamics of Ultrahigh-Speed uPod when Traveling in Tunnel of General Planetary Vehicle Overpass

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This study evaluates the impact of the annular shell of the transport tunnel on the aerodynamic characteristics of rolling stock. The optimal ratios between the midsection area of the vehicle and the cross-sectional area of the tunnel have been identified. The maximum movement speeds before gas medium flow choking have been calculated to prevent a sharp increase in aerodynamic drag and a sudden decline in the energy efficiency of the rolling stock.

The research highlights fundamental differences in aerodynamic processes that occur in an open environment versus those in a tunnel. This understanding will facilitate the effective use of calculated data during the preliminary design phase of high-speed and ultrahigh-speed transport systems, enabling the formulation of upper-level requirements.

Keywords:
aerodynamics, flow choking, forevacuum tunnel, gas medium, General Planetary Vehicle (GPV), takeoff and landing overpass, tunnel, tunnel transport, ultrahigh-speed vehicle.

Introduction

The General Planetary Vehicle (GPV) represents a monumental engineering project poised to propel humanity into a new era of technological advancement [1]. The GPV takeoff and landing overpass, spanning the planet's equator, connects two major continents and traverses islands inhabited by nearly 300 mln people. This structure is ideally suited for intercontinental cargo and passenger transportation. At the same time, the design of the overpass provides for the placement of several track structures at once.

The incorporation of an ultrahigh-speed transport system, designed as a forevacuum tunnel, enables rapid intercontinental connectivity. The operational speeds of ultrahigh-speed transport, comparable to mainline aviation, ensure competitive transport intensity, while the rarefied gas medium minimizes energy expenditure needed to overcome aerodynamic drag. Unlike airplanes, the ultrahigh-speed rail vehicle, specifically the uPod, does not require energy for lift generation via speed. Instead, steel wheels assume this function, and their low rolling resistance, combined with the aforementioned factors, makes this transport the most energy-efficient in the world.

Aircraft rely on toxic aviation kerosene, burning it in turbines within the most vulnerable lower layers of the stratosphere, resulting in contrail formation and ozone layer depletion. Conversely, the tunnel-based transport complex ensures complete isolation of harmful emissions and wear residues from the surrounding environment. Its enclosed structure provides protection both internally and externally, shielding transport operations from rain, snow, hail, ice, fog, wind, birds and wildlife.

The oceanic sections of the GPV overpass could be equipped with high-speed tunnels [2]. In contrast to ultrahigh-speed models, the high-speed uPod (an unmanned rail electric vehicle on steel wheels [2]) operates within an atmospheric air environment. With an operational speed of 600 km/h, it can facilitate transportation processes with the same efficiency while eliminating the additional costs associated with maintaining a rarefied gas medium.

On the continental sections of the GPV overpass, it is advisable to incorporate lower-speed transport structures with branches extending inland to establish a well-developed transport network [3].

The fundamental concept underlying the development of all transport systems is guided by criteria aimed at increasing travel speed while ensuring efficiency and compliance with safety standards [4]. The optimal transport complex is characterized by minimal costs for design and construction, as well as low operational expenses.

Given that ultrahigh-speed transport moves at velocities comparable to or exceeding aviation speeds, it is crucial to understand its distinctive motion dynamics within the confined space of a tunnel versus an open environment.

Research findings indicate that the impact of tunnels on the aerodynamic properties of rail transport has only recently attracted scientific attention. According to [5], active studies in this domain began in 1994. Interest in the subject grew proportionally with increasing operational speeds of trains and the extension of tunnel segments. Despite the broad scope of the research, a comprehensive conceptual framework was lacking, with authors primarily focusing on individual aspects. Scientists were particularly interested in the transition phases of entering and exiting a tunnel [6–14], during which transport conditions undergo abrupt changes [15–21]. These moments are marked by maximum disturbances in rolling stock, accompanied by vibrations, oscillations and acoustic waves. Consequently, most studies emphasize mitigating negative effects. A secondary focal point in published research concerns the dynamics of oncoming train interactions within double-track route tunnels [22–27], as train encounters constitute yet another transition phase of a different nature. When two long transport vehicles converge, the gas flow within the tunnel undergoes significant shifts, and the cross-sectional area of the passage changes, leading to the sharp destabilization of both train systems. Other aspects of tunnel-based transport dynamics have been studied in less detail, primarily because tunnel segments generally account for no more than 1 % of the total route length.

The objective of this study is to determine the impact of tunnel effects on the aerodynamic properties of transport vehicles based on completed model testing. Specifically, it examines the influence of fuselage midsection area ratios in high-speed uPods relative to the cross-sectional area of tunnels integrated with the equatorial GPV overpass. Additionally, the study aims to establish recommendations for optimal parameters across different speed ranges and define speed limitations for various section-area ratios. The findings will serve as a foundation for developing core solutions that ensure maximum energy efficiency of transportation process within the GPV equatorial overpass.

Influence of Tunnel on Aerodynamic Characteristics of Vehicles

Choked Flow Effect in Tunnels

During the acceleration of a vehicle within a tunnel to operational speeds, the velocity of air passing through

the section between the vehicle and the tunnel walls can reach the speed of sound long before the vehicle itself attains Mach speed [28]. The gas flow, moving into a lower-pressure region through aerodynamic drag caused by a reduction in cross-sectional area, increases in velocity. If subsonic flow conditions are maintained in the upstream section (before constriction), the velocity rises at the narrowing point, following the law of mass conservation. Simultaneously, the Venturi effect leads to a drop in static pressure and, consequently, density at the constriction. At a certain gas velocity, conditions arise where further pressure reduction beyond the constriction does not result in an increase in mass flow rate (assuming constant pressure before the constriction).

The aerodynamic characteristics of the uPod are determined by its speed and can vary significantly depending on the relative dimensions of the vehicle and the tunnel [29]. The critical value of flow choking at uPod speeds up to 1 Mach is defined by the isentropic limit using the formula [30]:

$$\frac{A_t}{A_p} = \frac{1}{M_0}\left[\frac{1+\frac{\gamma-1}{2}M_0^2}{\frac{\gamma+1}{2}}\right]^{\frac{\gamma+1}{2(\gamma-1)}}, \quad (1)$$

where A_t – tunnel's cross-sectional area, m^2;

A_p – passage cross-sectional area, $A_p = A_t - A_v$, m^2;

A_v – frontal projection of the uPod's cross-sectional area (hereinafter – midsection), m^2;

M_0 – Mach number;

γ – adiabatic index of gas.

The Mach number is determined by the formula:

$$M_0 = \frac{v}{v_s}, \quad (2)$$

where v – uPod speed, m/s;

v_s – speed of sound in gas, m/s.

The speed of sound is one of the key parameters of a gas, influenced by its composition, temperature and pressure. It governs the rate at which pressure propagates within the gas, thereby facilitating the distribution of aerodynamic forces within the tunnel.

The speed of sound is determined by the following formula:

$$v_s = \sqrt{\frac{\gamma RT}{M}}, \quad (3)$$

where R – universal gas constant, equal to 8.314 J/(mol·K);

T – temperature, K;

M – molar mass, kg/mol.

Kantrowitz limit is determined by the following formula (at velocities exceeding 1 Mach):

$$\frac{A_t}{A_p} = \frac{1}{\left[\frac{\gamma-1}{\gamma+1}\right]^{\frac{1}{2}}\left[\frac{2\gamma}{\gamma+1}\right]^{\frac{1}{\gamma-1}}} \times \frac{1}{\left[1+\frac{2}{\gamma-1}\times\frac{1}{M^2}\right]^{\frac{1}{2}}\left[1-\frac{\gamma-1}{2\gamma}\times\frac{1}{M^2}\right]^{\frac{1}{\gamma-1}}}. \quad (4)$$

In the design of tunnel-based transport systems, it is crucial to prevent choked flow, as its occurrence significantly increases energy expenditure due to aerodynamic drag. Formula (1) relies on the ratio of the tunnel and passage cross-sectional areas, which can be complex to interpret, as it requires calculating the midsection area by subtracting these values. To simplify the analysis, the study introduces the coefficient β_t, defined as the ratio of the uPod's midsection area to the tunnel's cross-sectional area.

Thus, applying formula (4), we obtain the necessary data for constructing the isentropic limit graph (Figure 1) within the β_t range from 0 to 1, allowing for the determination of maximum allowable speed for the uPod and other transport vehicles in tunnels with an air-based gas medium.

Figure 1 – Isentropic limit graph for an air-based gas medium

The presented graph enables the determination of the ratio between the midsection area of the uPod and cross-sectional area of the tunnel, which is critical for achieving the intended operational speeds of the transport complex (Table 1).

Table 1 – Calculated maximum speed of a uPod without gas medium choked flow

Parameter	Coefficient β_t							
	0.5	0.4	0.3	0.25	0.2	0.15	0.1	0.05
Maximum speed, Mach	0.305	0.378	0.458	0.503	0.553	0.61	0.679	0.769
Maximum speed, km/h	376.5	466.6	565.7	620.8	682.7	753	838.2	949.3

Notably, when β_t equals 0.5, the choked flow occurs at 376.5 km/h, rendering this ratio unsuitable for ultrahigh-speed transport applications. A coefficient of 0.05 allows movement without flow choking at speeds of up to 949.3 km/h, thus enabling the operation of hypervelocity transport.

The key indicator of the energy efficiency of both the transport vehicle and the tunnel in which it operates is the aerodynamic power P, required to overcome resistance in the gas medium:

$$P = Fv, \quad (5)$$

where F – frontal resistance force, N.

$$F = C_x\frac{\rho v^2}{2}A_v, \quad (6)$$

where C_x – aerodynamic drag coefficient, determined through physical or virtual testing;

ρ – density of the gas medium, kg/m^3.

Formulas (5) and (6) demonstrate that the vehicle velocity significantly affects the power required to overcome aerodynamic drag, as the final result exhibits an implicit cubic dependence. Based on formula (6), reducing aerodynamic energy losses in high-speed motion necessitates control over the C_x coefficient. A comprehensive series of aerodynamic tests is conducted to determine the optimal balance between C_x, the external geometry of the uPod and the configuration of its fuselage volume.

To conduct further studies on the movement of rolling stock in atmospheric air and other low-pressure gaseous environments, it is necessary to establish the governing laws of the gas medium. This requires evaluating a key criterion that characterizes the degree of gas flow rarefaction – the Knudsen number (Kn) [31].

The choice of methodology for calculating gas flow behavior depends on the magnitude of Kn. If $Kn \ll 1$ (theoretically $Kn \to 0$), then the basic assumption of hydroaeromechanics about the continuity of the medium is valid, which means that the Euler or Navier–Stokes equations with appropriate boundary conditions [32] can be used in the calculation of the flow of the gas medium. Practically, these methods are valid even at $Kn \leq 10^{-3}$. If $Kn \gg 1$ (theoretically $Kn \to \infty$), the aerodynamic characteristics of bodies streamlined by rarefied gas should be calculated without considering collisions of molecules among themselves, but only their impacts on a solid surface (free molecular flow) [33].

The Kn number is defined as:

$$Kn = \frac{\lambda}{L}, \quad (7)$$

where λ – mean free path of gas molecules, m;

L – characteristic flow dimension (e.g., tunnel diameter), m.

The mean free path of gas molecules is given by:

$$\lambda = \frac{1}{\sqrt{2}\pi\sigma^2 n}, \quad (8)$$

where σ – molecular diameter, for air 4×10^{-10} m;

n – molecular concentration, m^{-3}.

Molecular concentration is determined by:

$$n = \frac{p}{kT}, \quad (9)$$

where p – gas medium pressure, Pa;

k – Boltzmann constant, equal to 1.38×10^{-23} J/K.

Substituting formula (9) into formula (8), we obtain:

$$\lambda = \frac{kT}{\sqrt{2}\pi\sigma^2 p}. \quad (10)$$

For atmospheric air, the mean free path of molecules is 5.6×10^{-8} m, and the Kn number is 1.9×10^{-8} [34], since $Kn \ll 1$ ($Kn \to 0$). Thus, it is acceptable to use the Euler or Navier–Stokes equations when calculating the flow of a gas medium. This conclusion will be relevant for the pressure range of air gas medium from 1 Pa to atmospheric pressure (if it is necessary to study aerodynamic processes in conditions of reduced pressure).

Influence of Annular Airfoil Effect of a Tunnel

The aerodynamic characteristics of tunnel transport should be analyzed within the context of movement inside the tunnel, as this environment involves more complex physical processes compared to open-space travel [29, 35, 36]. Several factors must be considered, including variations in the aerodynamic properties of rolling stock, the flow choking effect, pressure front propagation within the structure, the emergence of pulsating airflow, increased noise and vibration levels – all of which require additional energy consumption. When a route includes open sections, special attention must be given to tunnel entry and exit zones.

In the tunnel complex, uPods are expected to operate across the full range of speeds, necessitating an understanding of the tunnel's impact on vehicle aerodynamics. From an aerodynamic optimization perspective, increasing the tunnel's cross-sectional area is desirable [37–40]. However, this approach is associated with an increase in tunnel diameter, leading to higher material costs and construction expenses. Therefore, a rational balance must be maintained between initial capital investments and operational costs required to counteract increased aerodynamic drag.

The influence of the tunnel on the aerodynamic properties of high-speed uPods has been examined within an operational speed range of 10 to 175 m/s, where the upper limit represents the maximum feasible speed for rolling stock in atmospheric conditions. The optimal uPod body design adopts a shell with aerodynamically efficient contours (Figure 2). The midsection is circular, with a fuselage length of 20 m, while each fairing (nose and tail) extends 6 m.

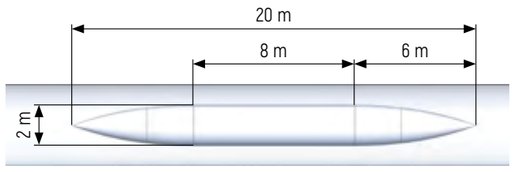

Figure 2 – uPod model used for assessing influence of annular airfoil effect of a tunnel

In calculations determining the ratio between the midsection area of the uPod and the cross-sectional area of the tunnel, the fuselage diameter was taken as a constant. The most relevant range of ratios extends from 0 to 0.5 in increments of 0.05. Values approaching zero were used to approximate movement in an open environment, where the airfoil effect is absent.

Based on computational data obtained through virtual testing, a graph was constructed to illustrate the influence of the airfoil effect on the aerodynamic characteristics of the uPod for the selected speed range, depending on the ratio between the midsection area of the vehicle and the cross-sectional area of the tunnel (Figure 3).

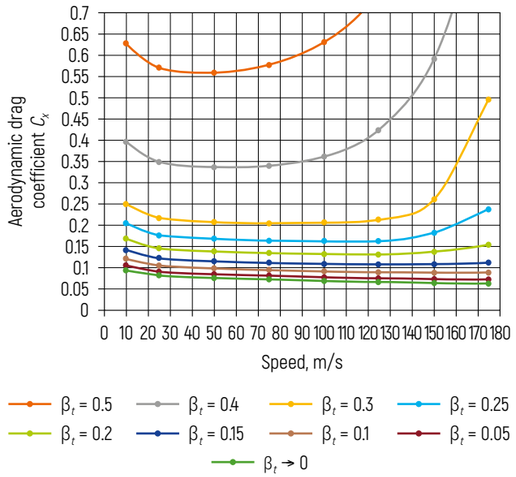

Figure 3 – Influence of airfoil effect on aerodynamic drag coefficient C_x

At β_t = 0.05, only a minimal increase in aerodynamic drag is observed compared to the uPod's movement in an open-air environment. However, further enhancing of this parameter lead to more significant changes in the aerodynamic drag coefficient C_x. It is worth noting that when transport moves in an open environment, the C_x curve tends to decrease as speed increases across the entire range under consideration. The obtained data correlate with full-scale aerodynamic experiments.

Conversely, with an increment of β_t, the opposite trend is observed. When the uPod exceeds a speed of 125 m/s (450 km/h), the values of C_x begin to rise. Additionally, the smaller the clearance between the uPod and the inner tunnel wall, the lower the speed at which this effect manifests, and the more dynamic the increase in C_x, as conditions approach the onset of the choked flow effect (Figure 4).

To achieve energy-efficient movement, it is necessary to maintain the lowest possible ratio values, ideally aiming for 0.05 or even lower. In this case, additional energy expenditures to overcome aerodynamic drag will not exceed 15 %.

However, it is important to consider the significant difference in dimensions between the tunnel and the uPod. The vehicle's design, particularly its midsection, determines the final cross-sectional dimensions of the tunnel. Reducing the midsection below the necessary size for comfortable passenger accommodation is impractical. For this reason, the layout of the passenger cabin, taking into account all structural requirements, becomes the primary parameter in determining the final cross-sectional area of the tunnel.

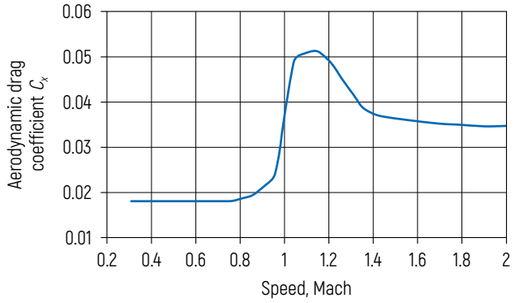

Figure 4 – Dependence of aerodynamic drag coefficient C_x on vehicle speed [41]

Figure 5 provides a scale illustration of the tunnel dimension changes for the full range of ratios considered.

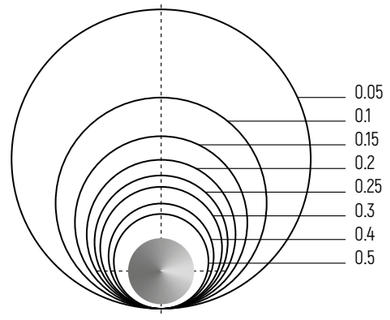

Figure 5 – Visualization of the range of ratios of uPod's midsection area and tunnel's cross-sectional area

Thus, the effort to minimize the influence of the annular airfoil effect leads to a significant increase in tunnel size. For example, for a uPod with a circular fuselage diameter of 2 m, the equivalent internal tunnel diameter at a ratio of 0.05 would be 9 m. Constructing such a structure presents various challenges. First and foremost, material consumption will increase. A larger diameter negatively affects the tunnel's ability to withstand wind and snow loads, necessitating substantial reinforcement of its framework and supporting towers. Therefore, when selecting the design dimensions of the transport overpass, a comprehensive analysis of the aerodynamic efficiency improvements must be conducted in comparison with the additional financial investments required for increasing the tunnel diameter.

Numerical evaluation of changes in the aerodynamic characteristics of the uPod within the tunnel across the entire speed range can be obtained from aerodynamic calculations (Table 2).

Table 2 – Multiplicity of growth of aerodynamic drag coefficient C_x of uPod in the tunnel compared to open-space movement

uPod speed, m/s (km/h)	Multiplicity of growth of C_x relative to open-space movement for different β_t							
	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5
10 (36)	1.1	1.3	1.5	1.8	2.2	2.6	4.2	6.6
25 (90)	1.1	1.3	1.5	1.8	2.1	2.6	4.2	6.9
50 (180)	1.1	1.3	1.5	1.8	2.2	2.7	4.4	7.3
75 (270)	1.1	1.3	1.5	1.8	2.2	2.8	4.6	7.8
100 (360)	1.1	1.3	1.5	1.9	2.3	2.9	5.1	9
125 (450)	1.1	1.3	1.6	2	2.4	3.2	6.3	11
150 (540)	1.1	1.4	1.7	2.1	2.8	4	9.1	14.9
175 (630)	1.2	1.4	1.8	2.4	3.8	7.9	15.5	19.6

The acceptable range for aerodynamic degradation (no more than twice the original value) lies between 0.05 and 0.2, which should be applied for speeds up to 900 km/h.

The conditionally acceptable degradation range is 0.25 to 0.3, suitable for speeds up to 500 km/h. This range may be used in areas where station distances are minimal, and the vehicle operates at maximum speed for no more than 50 % of the acceleration–braking cycle. Additionally, this range may be optimal in cases of design constraints, such as dense urban environments where high-speed travel is not expected or mountainous tunnels with significant longitudinal slopes.

A ratio of 0.4 and above leads to significant aerodynamic degradation, making it unsuitable for high-speed travel. If necessary, operational speeds must be reduced in such sections. However, this range may be applicable for large, low-speed transport with a working speed of no more than 100 km/h. In this case, overall aerodynamic losses will be significantly lower than in high-speed movement, and the degradation of aerodynamic characteristics will be comparable to rolling resistance losses of the uPod's steel wheels.

The overall assessment must also consider traffic intensity. For transport systems with intervals of 1 min or less, a larger tunnel size should be used, whereas lower traffic loads allow for a smaller diameter.

The data in Table 2 demonstrate a significant change in the aerodynamic characteristics of vehicles, particularly in the ratio of the uPod's midsection area to the tunnel's cross-sectional area close to 0.5. Therefore, proper attention must be given to the vehicle's contours. The aerodynamic shape of the rolling stock should ensure minimal possible values of the aerodynamic drag coefficient C_x. In this regard future research should explore the structural features of rail uPods, identifying the best aerodynamic solutions for tunnel transportation.

Conclusion

The authors conducted an analysis of the application of a tunnel-based transportation system within the framework of the GPV equatorial overpass, focusing on energy efficiency and safety. The distinguishing characteristics of movement in an open environment versus a tunnel were identified. The study examined how the tunnel modifies the aerodynamic properties of a vehicle. A significant influence of the tunnel's cross-sectional area on aerodynamic drag was established. To quantify performance indicators, the ratio of the uPod's midsection area to the tunnel's cross-sectional area was selected as a defining parameter. The findings indicate that as this parameter increases, resistance to movement in the tunnel also intensifies due to the annular airfoil effect.

Based on calculations, recommendations were developed regarding the applicability of these ratios. Values of 0.4 and above may be used for transport vehicles at speeds up to 150 km/h or up to 250 km/h with a large interval between vehicles. For high-speed or intensive transport operations, a ratio range of 0 to 0.25 is recommended. In this case it is possible to obtain a compact tunnel size with acceptable aerodynamic losses. Further increase in speed within this ratio range may lead flow choking, resulting in a sharp increase in the power required to overcome aerodynamic drag. Consequently, for speed exceeding 500 km/h, a ratio range of 0.05–0.15 should be considered.

Additionally, this study determined the critical transport speeds across the entire range of ratios. For example, for a ratio of 0.5, the calculated uPod's speed at which choked flow effect occurs is 376.5 km/h, whereas for a ratio of 0.1, the critical speed is 838.2 km/h.

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Aerodynamics of Rolling Stock in Tunnel Structures of General Planetary Vehicle Overpass

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This study examines the technical pecularities of rail vehicles on steel wheels (uPods), emphasizing the need for their optimization to achieve maximum energy efficiency during high-speed travel along the tunnel structures of the General Planetary Vehicle equatorial overpass.

The analysis highlights that significant differences in design approaches for uPods are essential, particularly regarding the aerodynamic phenomena encountered during tunnel movement, such as the annular airfoil effect. Energy-efficient forms of nose and tail fairings, optimal ratio of their length and diameter of the circular-section fuselage, preferable fuselage shapes, peculiarities of the structural arrangement of the chassis have been determined. In the future it will allow already at the stage of preparation for preliminary design of high-speed and ultrahigh-speed uPods to reasonably use the obtained data for drawing up the upper level requirements.

Keywords:
aerodynamics, chassis, equatorial overpass, fuselage, General Planetary Vehicle (GPV), high-speed uPod, tunnel, tunnel transport.

Introduction

The General Planetary Vehicle (GPV) is a new generation of geocosmic transport infrastructure [1]. It is designed for non-rocket industrialization of near space [2] and is capable of delivering up to 10 mln passengers and 10 mln tons of cargo into orbit in a single launch to support geocosmic industry operations [3]. Since the GPV has a ring-shaped structure encircling the Earth along the equator – over 40,000 km in length – it requires even distribution of passengers and cargo along its entire length before ascent into space begins. Therefore, uninterrupted transportation must be organized along the GPV equatorial overpass at a speed no less than that of a long-haul airliner. This will not only ensure continuous delivery of passengers and cargo, but will also reduce humanity's dependence on aviation, thereby lessening the environmental impact of burning aviation kerosene in the stratosphere.

Travel at airliner speeds demands an unprecedented level of safety. The use of tunnel structures within the GPV equatorial overpass enables the operation of high-speed (up to 360 km/h) and ultrahigh-speed (up to 600 km/h) transport. The tunnel design of the Unitsky String Transport complex ensures consistent performance of the rail electric vehicle on steel wheels – the uPod – by shielding it from environmental influences such as wind, precipitation, birds and others [4]. However, movement at such speeds necessitates overcoming aerodynamic drag forces, the power required for which depends on the uPod's speed, the aerodynamic contours of its body and a parasitic ring airfoil effect. Since the power needed to overcome aerodynamic drag has a cubic relationship with speed, for example, raising the uPod's speed from 300 to 900 km/h would require 27 times more drive power. This significant increase leads to greater mass and size of the rolling stock, as all components of the traction drive must store and deliver much more energy.

Reducing the energy cost of overcoming aerodynamic drag in atmospheric air is only possible by decreasing the frontal projection (midsection) area of the vehicle and optimizing the aerodynamic properties of its fuselage shape. However, changing the midsection area does not always produce the desired result, as it often leads to a decline in the vehicle's aerodynamic efficiency. For this reason, special attention must be given to selecting a combination of solutions that together ensure the lowest possible aerodynamic drag coefficient C_x [5–14], which ultimately results in a significant reduction of power required to overcome aerodynamic drag in the gas medium.

The aim of this study is to determine the optimal configuration of tunnel-based transport and identify its structural features that provide the best aerodynamic performance for the uPod, based on experimental tests. The findings may serve as a foundation for key design decisions to ensure maximum energy efficiency of the transportation process within the tunnel-based transport and infrastructure complex of the GPV equatorial takeoff and landing overpass.

Impact of Wheel Propulsion Design and Configuration on Aerodynamic Characteristics of uPod

Virtually all land-based vehicles are equipped with wheels. Even in aviation, no viable alternative has been found to eliminate wheels from the configuration of an aircraft. A wheel protruding beyond the vehicle body contributes negatively to the overall aerodynamic profile [15]. This is precisely why, shortly after takeoff, an aircraft's landing gear retracts into a technical compartment that is sealed, ensuring smooth airflow along the fuselage. Another example comes from motorsports: Formula 1 race cars are known not only for their aerodynamic fuselage design but also for the streamlined shape of their suspension arms [16] (Figure 1).

Figure 1 – Aerodynamically optimized chassis components of a Formula 1 car

To assess the impact of the uPod's wheels on aerodynamics, wheel arrangement schemes were selected for operation on monorail, bi-rail and quad-rail track structures [17] (Figure 2).

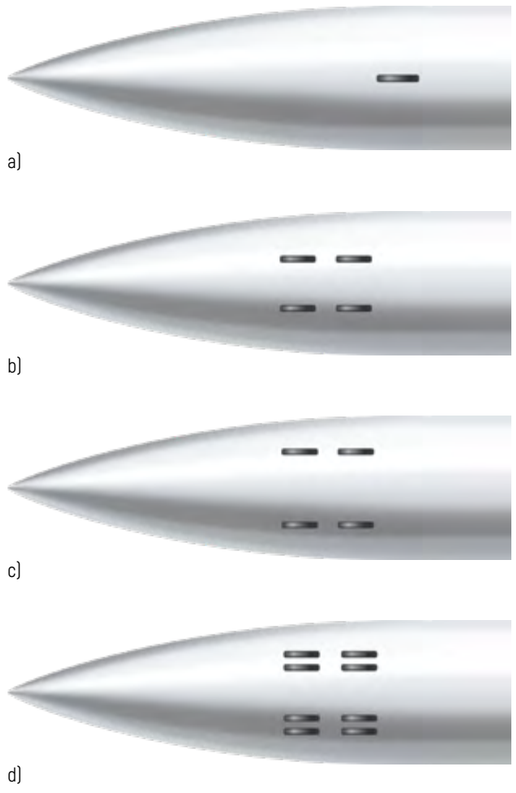


Figure 2 – uPod chassis configurations (bottom view):
a – monorail; b – bi-rail with narrow gauge;
c – bi-rail with wide gauge; d – quad-rail

The presence of wheels in a vehicle is, on the one hand, an objective necessity, but on the other hand, it also comes with drawbacks. The unsprung mass of the wheel negatively affects the dynamic running performance of the vehicle, while its protrusion beyond the fuselage degrades aerodynamic efficiency. Based on these considerations, efforts should be made to reduce the number of wheels. To evaluate their contribution to overall aerodynamics, calculations were carried out for various wheel propulsion configurations of high-speed uPods operating in a tunnel with a ratio between the uPod's midsection area and the tunnel's cross-sectional area (β_t) equal to 0.2. This value of β_t corresponds to the upper limit of the optimal range, which ensures acceptable aerodynamic performance related to the tunnel's cross-sectional dimensions. During tests of uPods under previously verified boundary conditions [18] in atmospheric air, numerical values of the resulting aerodynamic drag forces were obtained. These made it possible to calculate the shape aerodynamic influence coefficient and to visualize airflow speed distribution patterns (Figure 3). The resulting parameters were compared with data from wind tunnel tests of a circular-section fuselage without wheels (Figure 4).

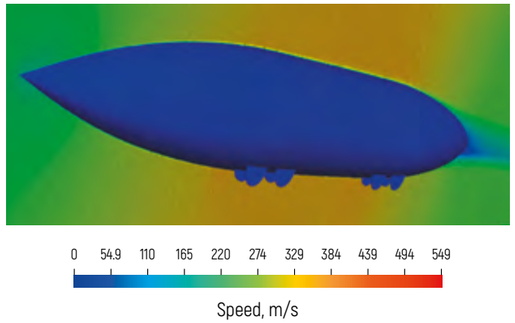


Figure 3 – Airflow speed distribution for the model used to assess impact of wheel configuration on uPod's aerodynamics

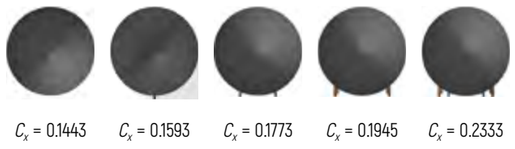


Figure 4 – Impact of wheels and their arched recesses on aerodynamic drag coefficient C_x of uPod during tunnel travel (β_t = 0.2)

As evident from the numerical values (Figure 4), even the inclusion of a single wheel in the design results in a degradation of the fuselage's aerodynamic performance by at least 10 %, which necessitates a corresponding increase in the power supplied to the wheel drive to maintain the desired speed. In the case of a quad-rail chassis configuration, the relative increase in C_x reaches 62 %. Additionally, a difference is observed between the results for bi-rail configurations with narrow and wide gauge, which is attributed to the greater protrusion of the wheel beyond the fuselage contour. This leads to the introduction of wheel fairings and an increase in the uPod's midsection area.

The use of a monorail vehicle configuration imposes a number of operational limitations: it requires mechanisms to prevent the uPod from tipping over while stationary and presents challenges in the event of an emergency stop inside the tunnel. Therefore, the optimal solution appears to be a bi-rail traction bogie with a narrow gauge. In this case, efforts should focus on minimizing the wheel's protrusion beyond the fuselage contour while maintaining the widest possible track gauge.

Since in actual vehicles the wheel is positioned within an arched recess in the fuselage, it is also necessary to assess the influence of this arched on aerodynamic characteristics. To this end, a model of the arched recess was created, with dimensions sufficient to accommodate the wheel's dynamic movement during uPod motion (Figure 5).

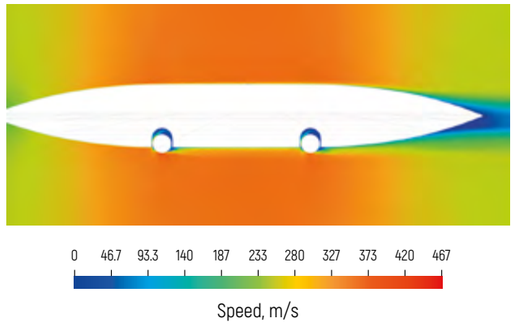


Figure 5 – Airflow speed distribution in the tunnel (β_t = 0.2)

The calculation results showed that the arch of the selected configuration did not degrade the vehicle's aerodynamic performance. On the contrary, it led to a slight reduction in the C_x to a value of 0.1591, which is 0.1 % lower. This can be attributed to improved airflow around the wheel due to the arched recess in the fuselage, which eliminates the flow choking zone at the wheel–fuselage junction.

Thus, once the traction bogie layout is determined, the geometry of the arched recess should be further optimized to enhance the aerodynamic performance of the uPod.

Optimization of Fairing Shape and Length

The fairings of a vehicle have a direct impact on its overall aerodynamic performance. These components receive particular attention when high-speed operation is anticipated. Measures to reduce the C_x allow for a proportional decrease in the power required to overcome aerodynamic drag. There are two primary shaping profiles used for fairings: bullet-shaped and S-shaped. A review of high-speed vehicle designs confirms that the S-shaped front fairing profile is used more frequently. Since modern ground-based transport vehicles spend most of their travel time in open environments and only occasionally pass through tunnels, this study aimed to determine which fairing profile delivers the best aerodynamic performance specifically for tunnel-based transport.

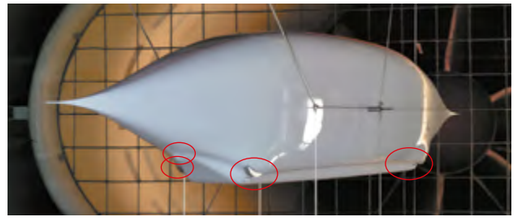
To evaluate the reliability of the calculated data, it was decided to verify the mathematical model using full-scale tests of a high-speed vehicle (HSV) model built at a 1:5 scale (see Table).

Table – Aerodynamic drag coefficient C_x values of HSV obtained from full-scale and virtual tests

Index	Test type	
	Full-scale	Virtual
Airflow speed, m/s	50	
Mach number	0.146	
Air pressure, Pa	101,325	
C_x	0.072	0.054
Relative change in C_x, %	–	25

The resulting C_x of the model in virtual tests was found to be 25 % lower than in full-scale tests [19, 20]. The primary reasons for this discrepancy are attributed to certain structural differences between the models (Figure 6).

The computational model used for virtual testing lacks wheels, wheel arches, ventilation openings and other details. As shown in Figure 4, the presence of wheels worsened the C_x by at least 23 %. It can be concluded that after aligning the computational model fully with the real design, the relative error will decrease to 2–3 %. Based on these findings, we accept the equivalence of virtual test results to full-scale ones.



a)

b)

Figure 6 – Test models: a – full-scale; b – virtual

With a validated methodology for conducting virtual tests, comparative aerodynamic calculations will be performed for uPod models featuring a cylindrical central section but differing in fairing geometry (Figure 7).

a) b)

Figure 7 – Body fairing shapes of uPod:
a – bullet-shaped; b – S-shaped

The results of virtual tests for three different fuselage designs (Figures 6b, 7a, 7b) in an open atmospheric environment are shown in Figure 8.

The graph suggests that all three shapes exhibit a similar trend in the variation of the C_x. It is worth noting that the HSV has a midsection shape distinct from the other configurations and a significantly shorter fuselage length. For this reason, the resulting C_x value turned out to be somewhat lower. In the speed range from 50 to 310 m/s, all models show a gradual decrease in C_x. As the flow velocity approaches 310 m/s, a slight increase in this coefficient is observed, although its value does not exceed that at the initial flow speed of 50 m/s. With a further increase in airflow speed up to the speed of sound, there is a sharp spike in C_x, the numerical level of which far exceeds the results obtained over the entire previous speed range. The phenomenon of a sudden increase in the coefficient was established in [21] and is explained by the fact that, as the sonic barrier is approached, shock waves are formed, creating high-pressure zones in front of the vehicle.

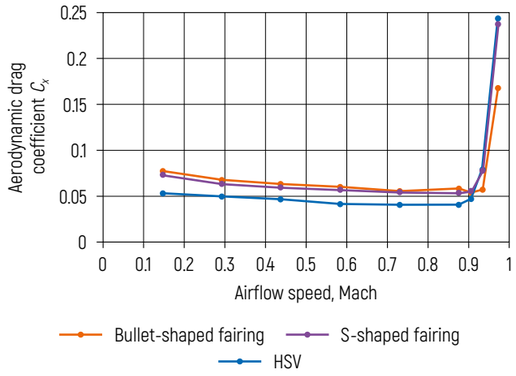


Figure 8 – Dependence of aerodynamic drag coefficient C_x of uPods with fairings of various shapes on airflow speed in open space

The behavior of the curves presented in Figure 8 corresponds to the data in the graphs shown in [21]. Based on the results of virtual tests, the lowest aerodynamic drag coefficient is observed in the HSV model at speeds up to 0.9 Mach. With a further increase in speed, the C_x value becomes nearly equal to that of the model with the S-shaped fairing. The low C_x in the HSV is explained by its fuselage length (9.5 m), which is shorter than that of the models with S-shaped and bullet-shaped fairings (16 m). As for the bullet-shaped configuration, it demonstrates better performance compared to other models in the 50 to 320 m/s speed range, but at 333 m/s it becomes 30 % more efficient. Consequently, it can be concluded that using S-shaped fairings is a rational solution for motion through open air at subsonic speeds.

It is necessary to verify whether the aforementioned patterns remain valid when the vehicle moves in the confined environment of a tunnel. To ensure comparability of the virtual test results, uPod models shown in Figure 7 will be used. Since the goal of the study is to obtain data for specific scenarios, calculations will be performed for a speed of 280 m/s, at which point the abrupt increase in aerodynamic drag has not yet occurred. The resulting values can be applied to a tunnel transport complex. To prevent flow choking, the diameter of the tunnel in the computational models must ensure that the β_t does not exceed 0.2. With a fuselage diameter of 2.6 m for the ultrahigh-speed uPod, whose layout allows for up to four seats per row, a tunnel with an internal diameter of 7 m meets this condition.

Since the key outcome of this work is to determine the optimal fuselage shape characteristics, it is necessary to conduct virtual tests of models with different fairing lengths (Figure 9). Rising the fairing length will undoubtedly have a positive effect on aerodynamic performance. However, it will also lead to an increase in the overall dimensions of the vehicle or, in the case of a fixed fuselage length, a reduction in the central section, which has the maximum usable volume.

The results of aerodynamic calculations for fuselages depending on their shape and length are presented in Figure 10. The graph shows that when the uPod moves through a tunnel, the bullet-shaped fairing becomes more effective in terms of aerodynamic drag, rather than the S-shaped one. It provides a smoother angle of attack in the near-wall region, resulting in faster and more stable airflow within the gap between the tunnel wall and the fuselage body.

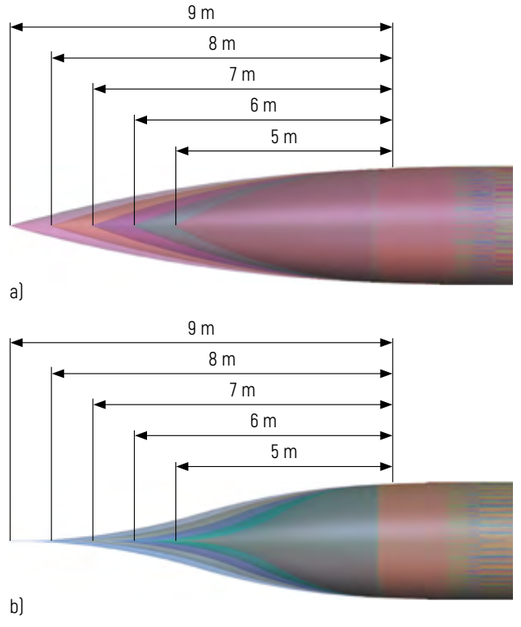


Figure 9 – Fuselage models of uPods with different fairing lengths:
a – bullet-shaped; b – S-shaped

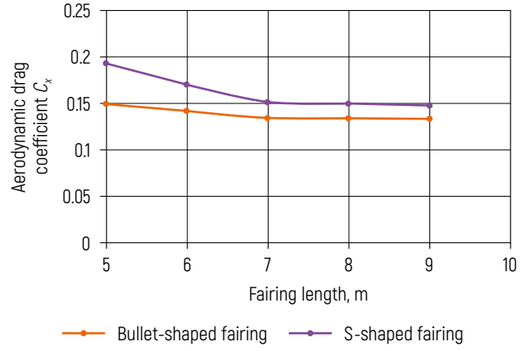


Figure 10 – Dependence of aerodynamic drag coefficient C_x of uPod moving in the tunnel on length and shape of fairings

The length of the fairings also has a significant impact on the aerodynamic characteristics of the fuselage. Increasing the length of the S-shaped fairing from 5 to 7 m reduces the overall aerodynamic drag by 28 %. In contrast, the same increase in the length of the bullet-shaped fairing results in only an 11 % reduction. Further elongation of the fairings does not lead to additional improvements. This is because the increase occurs at the expense of the overall dimensions of the fuselage. The aerodynamic advantages of smoother shapes are offset by the growth in the total wetted surface area. Therefore, for ultrahigh-speed tunnel transport systems, it is appropriate to use bullet-shaped fairings, with the optimal ratio of their length to the fuselage diameter being approximately 2.7.

Influence of Fuselage Central Part Shape on Aerodynamic Characteristics of uPod

From an aerodynamic standpoint, it is preferable for the fuselage's profile line to form a smooth contour along its entire length. Any change in shape should be made with the largest possible radius. In practice, this means that the central section of the vehicle's fuselage would take on a barrel-shaped form and, accordingly, have a unique midsection along the entire fuselage length. However, such a solution conflicts with commonly accepted requirements for manufacturability and design and production versatility. Therefore, a decision was made to explore the possibility of truncating the barrel-shaped form in order to create a cylindrical section that would provide sufficient length in the central part of the uPod fuselage. This approach allows for improved manufacturability of the fuselage and increases the flow cross section of the tunnel.

For virtual testing, a uPod model with a barrel-shaped fuselage was developed (Figure 11). The midsection area corresponds to the cross section of the central part of the uPod and amounts to 5.38 m^2, which is equivalent to a circle with a diameter of 2.6 m. Truncating the barrel-shaped part of the model resulted in a new fuselage design (Figure 12) with a midsection area of 5 m^2 in the central part of the uPod. The truncation reduced the maximum fuselage diameter by 10 cm and provided a cylindrical shape in the central cabin section with a length of 5.7 m.

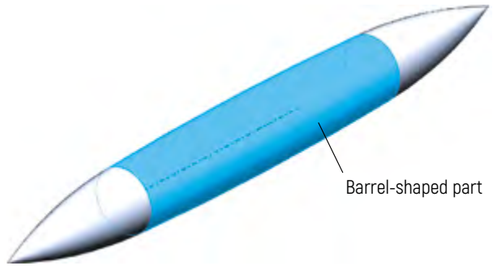


Figure 11 – uPod model with a barrel-shaped fuselage

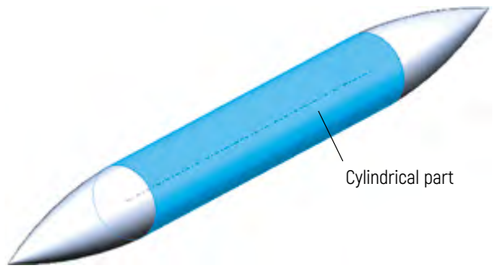


Figure 12 – uPod model with a cylindrical fuselage

Based on the uPod fuselage length of 17.6 m, the cylindrical section accounts for 32 % of its total length. The aerodynamic characteristics of the two fuselage shape variants were assessed in a tunnel with an internal diameter of 7 m. The results showed a 1.7 % increase in the C_x for the cylindrical fuselage. However, the frontal drag force in this case decreased by 5.1 %. Since the tunnel diameter remained unchanged, the reduction in the required power to overcome aerodynamic drag was due to a 5.8 % decrease in the uPod's midsection area, as well as a declined influence of the annular airfoil effect thanks to the increased flow cross-sectional area.

Thus, in some cases, achieving a fuselage shape with maximum aerodynamic performance is not necessary for high- and ultrahigh-speed transport. Optimizing the midsection area and increasing the flow cross section of the gas medium can yield better results when evaluating total energy expenditure.

Influence of Fuselage Length on Aerodynamic Characteristics of uPod

For efficient long-distance mass passenger transportation, it is essential to maximize the cabin capacity of the vehicle. Traditionally, engineers achieve this by designing rolling stock with greater length.

The need to increase the fuselage length should be evaluated based on the specific energy efficiency of transportation, i.e., the drive power per passenger.

As a baseline, a fuselage 12 m in length with a barrel-shaped central section is considered. Each subsequent model variant differs from the previous one by an increase in length due to the addition of a cylindrical section (L) in the central cabin area (Figure 13).

Virtual tests were conducted using airflow at a speed of 250 m/s. In the simulation model, the ratio of the uPod's midsection area to the tunnel's cross-sectional area was set at 0.11 to eliminate the risk of flow choking. Based on the obtained data, a graph was constructed showing the dependence of the aerodynamic drag coefficient C_x on the length of the uPod fuselage (Figure 14).

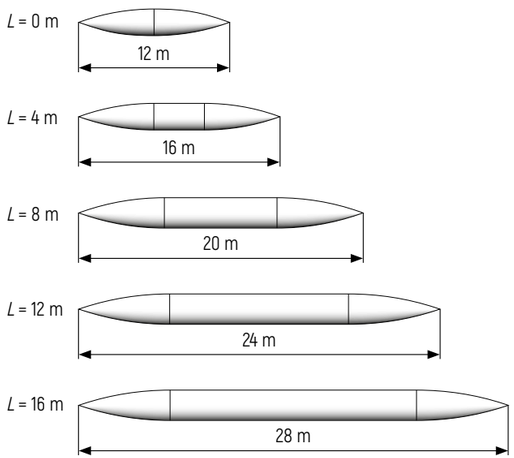


Figure 13 – Models of high-speed uPods

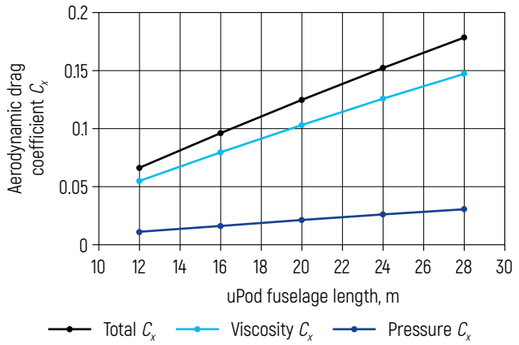


Figure 14 – Dependence of resulting aerodynamic drag coefficient C_x and its components on length of uPod fuselage

The graphs shown in Figure 14 have a linear pattern and a tendency for the total C_x to increase as the fuselage lengthens. In this case, the resulting aerodynamic drag coefficient should be considered as the sum of two components: one caused by frontal pressure, and the other resulting from viscous friction between the gas medium and the fuselage surface. When the central cylindrical section of the uPod is extended from 4 to 8 m, an increase in turbulence is observed in the near-wall layers of the fuselage (Figure 15).

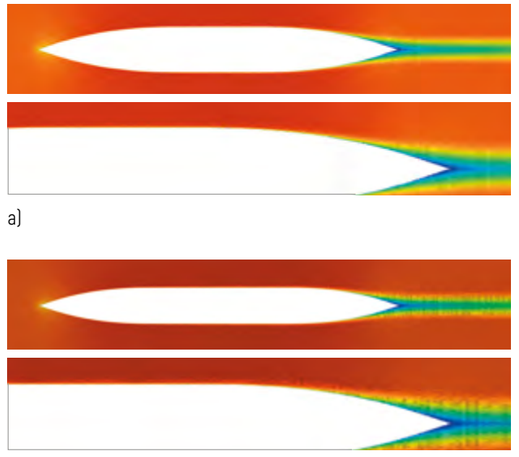


Figure 15 – Airflow speed distribution around a high-speed uPod with a cylindrical section length of: a – 4 m; b – 8 m

The airflow distribution patterns clearly show the formation of turbulence in the boundary layers of the longer fuselage, leading to a less smooth flow separation. The increase in turbulence causes a rise in the resulting C_x, and consequently, a higher power requirement to overcome aerodynamic drag. It was found that increasing the fuselage length of the uPod from 16 to 28 m – by a factor of 1.75 – resulted in an increase in the C_x by a factor of 1.85. At the same time, the added usable cabin space allowed the number of seating rows to increase from 8 to 23. This means that although the aerodynamic performance worsened by a factor of 1.85, the passenger capacity grew by a factor of 2.9, leading to a 1.57-fold improvement in specific energy efficiency of the rolling stock.

This positive outcome was primarily achieved thanks to the uPod being equipped with fairings up to 7 m long, which help form an aerodynamically optimized shape. The bullet-shaped fairing has a gradual taper along its entire length, which makes it unsuitable for comfortably accommodating passengers in that section of the fuselage. Therefore, the main volume of the fairings is best used for housing electrical, power and auxiliary equipment. In the case of further fuselage elongation, all the additional volume will be used solely for passenger seating.

Thus, it has been found that increasing the fuselage length leads to a linear rise in aerodynamic drag due to intensified viscous friction between the airflow and the surface of the high-speed uPod's fuselage. At the same time, this results in improved energy efficiency due to the nonlinear expansion in usable volume suitable for additional seating.

Conclusion

The authors conducted research on the aerodynamic optimization of a high-speed tunnel uPod. It was found that wheels protruding beyond the fuselage contour significantly impact the aerodynamic drag coefficient. Calculation results showed a direct relationship between C_x and both the number of wheels on a single axle and the extent of their protrusion beyond the fuselage. To improve aerodynamic performance, no more than two wheels should be used per axle, and their protrusion should be minimized. It is likely that the installation of special aerodynamic fairings with a streamlined shape will further reduce the C_x value. The challenge of implementing such a solution lies in the need for the wheel and fairing to move vertically together to accommodate suspension operation.

In addition, the aerodynamic characteristics of S-shaped and bullet-shaped fairings were studied in a length range of 5 to 9 m. The bullet-shaped fairing demonstrated better performance during tunnel motion tests. Its optimal length is 7 m, at which point air resistance is reduced by 28 % compared to a 5-meter fairing. Further lengthening of the fairing did not reveal any clear comparative advantage.

An analysis of the preferred shape for the central part of the fuselage did not confirm the necessity of a barrel-shaped design. Changing the shape to cylindrical slightly worsens the C_x, but it reduces the uPod's midsection area and increases the tunnel's flow cross section, making it the optimal solution overall.

Elongating the central part of the fuselage has a significant effect on the increase in aerodynamic drag. Tests showed a notable rise in viscous air friction due to the formation of turbulent boundary layers. Specifically, increasing the uPod's fuselage length from 16 to 28 m – by a factor of 1.75 – led to a 1.85-fold increase in the C_x. However, due to the expanded usable cabin volume, passenger capacity increased by a factor of 2.9, and specific energy efficiency improved by 1.57 times.

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Integrated Approach to Definition of Reliability Indicators of General Planetary Vehicle

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The issues of defining reliability as a key characteristic of the General Planetary Vehicle (GPV) designed for the non-rocket launch of spacecraft, equipment, materials and personnel as well as components of the Industrial Space Necklace "Orbit" (ISN "Orbit") into near space are analyzed. It is demonstrated that the reliability of the GPV, a massive geocosmic vehicle over 40,000 km in length and approximately 40 mln tons in mass, is a multifaceted property encompassing failure-free performance, maintainability, durability and sustainability. A comprehensive methodological approach is proposed for selecting, standardizing and evaluating critical failure-free performance indicators of the GPV and ISN "Orbit." These include the probability of failure-free operation, failure probability, gamma-percentage life, mean time to failure, failure rate and operational readiness coefficient.

The obtained values and results contribute to the development of a comprehensive plan for ensuring, evaluating and monitoring reliability at each stage of the GPV and ISN "Orbit" life cycle, with the objective of achieving the required failure-free performance indicators.

Based on established criteria for rational selection and optimization of reliability parameters both for critical components and the overall system, a structural reliability model for the geocosmic self-supporting dynamic object is proposed. This model is designed to enhance structural ways for ensuring reliability during the design and operational phases, including methodologies for these parameters' confirmation.

Keywords:
General Planetary Vehicle (GPV), Industrial Space Necklace "Orbit" (ISN "Orbit"), failure-free performance, mean time to failure, orbit, probability, reliability, spacecraft, survivability.

Introduction

Currently, Astroengineering Technologies LLC (Minsk, Belarus), under the leadership of General Designer A. Unitsky, is implementing an unparalleled project called the General Planetary Vehicle (GPV). This innovative system is intended for the non-rocket launch of spacecraft, materials and people into near-Earth orbit, contributing to the construction of the Industrial Space Necklace "Orbit" (ISN "Orbit"). The project represents a transformative step in transferring industrial production facilities from Earth to near space, establishing space-based residential and industrial infrastructure, and laying the groundwork for deep space exploration [1].

The GPV, as a modern spacecraft, represents a highly sophisticated space complex (SC) due to the significant number of integrated components connected with a variety of different links. These include autonomous navigation systems, thermal management, power supply, telemetry and mission-specific equipment, etc. Each subsystem, in turn, is composed of numerous technical elements such as instruments, sensors and actuators, each with a wide range of parameters, operational modes and input commands. Adding to this, complexity is the practical impossibility of accurately calculating or analytically predicting the spacecraft's behavior during flight [2]. Consequently, this difficulty often leads to failures arising from various causes.

Taking into account the labor intensity and cost of development, reliability is a crucial characteristic of space equipment. According to GOST 27.002-2015 [3], reliability encompasses failure-free performance, maintainability, durability and sustainability. The failure-free performance analysis model for spacecraft presented in this paper highlights the heightened operational demands placed on numerous components. For this reason, it is proposed to prioritize the core functions of the spacecraft, particularly those related to crew life support and structural protection against destruction, while integrating the additional property of survivability [4, 5].

Thus, determining the reliability indicators for the GPV and the ISN "Orbit" involves addressing a complex task that includes:

- eneral methodological approach to the selection, standardization and assessment of reliability (failure-free performance) indicators for the components of the GPV and the ISN "Orbit" as well as the systems as a whole;
- updating reliability indicators and associated requirements in line with the specific objectives and functional purpose of the GPV and the ISN "Orbit," framed within an analytical structural layout.

The values and results obtained can serve as a foundation for developing a comprehensive work plan and implementing measures to ensure, assess and monitor reliability at every phase of the GPV and the ISN "Orbit" lifecycle. These efforts aim to achieve a safety level that meets or exceeds required thresholds.

Ensuring Spacecraft Survivability

For traditional machines and mechanisms operated on Earth, serviceability is restored through diagnostics and repairs performed by specialized technicians. However, repairing spacecraft in orbit is usually impossible, with only a few exceptions, such as the Salyut 7 orbital space station, which was restored to working condition in 1985 by cosmonauts V. Dzhanibekov and V. Savinykh, and the Hubble Space Telescope, which was repaired by Space Shuttle crews. To guarantee failure-free performance in spacecraft, it is necessary to incorporate structural or functional redundancy in onboard equipment, as well as implement software diversification.

Additionally, throughout the spacecraft's operational lifetime, it is essential to establish a set of control actions to maintain the configuration of onboard systems required for fulfilling its designated functions. Ensuring survivability mandates the ability to compensate for the failure of a single device without compromising critical functions, though secondary functions may be affected. In cases where failures are diagnosed, hardware reconfiguration should occur, utilizing either "hot" or "cold" redundancy or transitioning the spacecraft into a special mode. These measures help prevent the development of emergency situations that could lead to catastrophic performance loss.

The onboard software plays a critical role in ensuring spacecraft survivability, performing essential functions such as control, diagnostics and handling abnormal situations when necessary.

When searching for control and diagnostic algorithms, a list of critical failures is compiled based on an engineering analysis of onboard equipment. This process considers available redundancies and prior operational experience with spacecraft. The importance of these failures is assessed, and state diagrams, as well as temporal cyclograms of control modes, are created [6, 7]. Historical cases exist where spacecraft performance, albeit with reduced quality, was restored by repurposing onboard equipment to perform tasks for which it was not initially intended. This often requires

updating onboard algorithms and programs and uploading modified software [6].

Traditionally, command telecontrol is widely used for this purpose. This approach involves the ground control complex (GCC), which monitors the spacecraft's condition, makes decisions regarding its operation and transmits the necessary coordination commands to the spacecraft in real time [8]. Throughout the spacecraft's operational lifetime, the GCC – comprising telemetry reception stations, command transmission systems and communication links with the flight control center – must maintain continuous interaction with the spacecraft. Additionally, personnel must remain on full alert, possessing in-depth knowledge of operational documentation and the ability to make prompt, responsible decisions when issuing commands. However, this control structure introduces latency, as reactions to changes in the spacecraft's status typically take several minutes. Even with advanced decision-making support systems, including knowledge-based tools, this delay persists.

The resolution of this issue lies in maximizing the implementation of autonomous control, where decision-making is handled by onboard control systems, leaving the GCC responsible only for setting general tasks, operational goals and subsequent monitoring.

In the case of automatic (unmanned) spacecraft, such as the GPV, autonomous control systems play a crucial role, ensuring operability and task execution without human intervention. The effectiveness of these systems depends on the accuracy and completeness of the onboard information required for rapid responses, as well as the efficiency of the decision-making mechanisms under the constraints of limited onboard computing resources.

Reliability Assessment of General Planetary Vehicle

In general, the requirements for spacecraft are defined by GOST R 56526-2015 [9], which standardizes the reliability (failure-free performance) indicators for the components and equipment included in spacecraft, as well as for the spacecraft as a whole. It also establishes a methodological approach for evaluating these indicators.

At the same time, the analysis of the operational survivability of modern spacecraft reveals an insufficient reliability level of their components [10]. Failures and malfunctions occur in orbital insertion systems, ground infrastructure equipment, GCC systems, and in spacecraft themselves, both partially and completely, during their active lifetime. Such failures hinder the deployment and replenishment of orbital constellations and negatively impact the reputation of space technology.

Therefore, spacecraft reliability is a critical operational and technical characteristic and an inherent property that must be embedded during the design phases. The findings from the reliability analysis of traditional spacecraft and the methodological approaches used to determine their reliability indicators should be reviewed and updated for application to the GPV.

A modern spacecraft consists of repairable and non-repairable elements designed to ensure successful launch, operation and control. Throughout the operational cycle of a single spacecraft launch, these elements function sequentially according to an operation cyclogram. At specific stages, some elements may be repairable (e.g., launch vehicles before the commencement of irreversible operations), while in other cases, they are classified as non-repairable (during flight phases).

Drawing an analogy with traditional spacecraft and considering the specifics and target functions of the GPV and the ISN "Orbit," it is reasonable to refine the indicators and corresponding reliability requirements by classifying them into generalized, basic and additional categories [11].

The analysis of reliability indicators regulated by standards [3, 9] confirmed the following:

- the most applicable integral indicators for assessing the reliability of the GPV and the ISN "Orbit" are the probability of failure-free performance (or failure probability) during the operating time t, and the gamma-percent mean time between failures;
- the mean time between failures and the failure rate of object-systems can be determined analytically based on system component data but pose challenges for direct statistical evaluation. This is due to the requirement for a large number of similar objects and extended observation periods, during which the assessment may lose relevance;
- the mean time between failures and the availability factor require an assumption of stationarity in the failure and recovery processes of the object. This assumption is often inadequate for the real-life cycle of spacecraft, particularly for the GPV and the ISN "Orbit."

At the SC level of constant long-term operation with an orbital constellation of n spacecraft, an example of which is the GPV and the ISN "Orbit" formed with its help around the planet in its equatorial plane, the generalized reliability indicator can be the probability of failure-free performance of the SC $P^{SC}(t)$ [12].

For promising SC with geostationary spacecraft, the fundamental conditions for component reliability are proposed as follows:

- probability of failure-free performance of the orbital constellation $P^{OC}(t)$ (the probability that the regular orbital constellation remains in a serviceable state for a specified time);
- probability of failure-free operation of the GCC $P^{GCC}(t)$ (the probability that the GCC performs the spacecraft control technological cycle);
- reliability indicator of the GPV $P^{GPV}_{prep}(t_{prep})$ (the probability that the GPV is prepared for launch based on the established technical readiness within the timeframes, not exceeding the specified t_{prep});
- reliability indicator of the GPV P^{GPV}_{reg} (the probability of launching the GPV into a given region of space);
- reliability indicator of the GPV $P^{GPV}_{in}(t_{in})$ (the probability of preserving maintainability of the GPV in the process of insertion);
- reliability indicators of the spacecraft (gamma-percent active lifetime T^{AL}_{γ} and gamma-percent preservation time T^{pres}_{γ}).

The reliability indicators of the GPV can be consolidated into a single, integral measure: the probability of a successful launch into the reference orbit and entry into a given region of space.

The structural reliability diagram for such a SC is given in Figure [10].

Taking into account the given reliability indicators of the GCC, the ISN "Orbit" and the GPV, real periods of SC operation, preservation of the GPV before launch, the total probability of failure-free performance of the orbital constellation takes the following form:

$$P^{OC}(t) = P^{GPV}_{pres}(t_1) \times \left[P^{GPV}_{prep}(t_{prep}) \times P^{GPV}_{in}(t_{in})\right]^n, \quad (1)$$

where $P^{GPV}_{pres}(t_1)$ – the probability of failure-free storage of the GPV during t_1 before the preparation and launch.

Reliability indicators $P^{GCC}(t)$ and $P^{OC}(t)$ are linked by the following expression:

$$P^{OC}(t) = \left[P^{spacecraft}(t)\right]^n \times P^{GCC}(t), \quad (2)$$

where $P^{GCC}(t)$ – the probability of failure-free performance of the GCC when operating with all n spacecraft of the ISN "Orbit" orbital constellation;

$P^{spacecraft}(t)$ – the probability of failure-free performance of a single spacecraft, defined as

$$P^{spacecraft}(t) = \sqrt[n]{\frac{P^{OC}(t)}{P^{GCC}(t)}}. \quad (3)$$

Analysis of expressions (1) and (2) shows that ensuring a high level of probability of failure-free performance of the SC (e.g., 0.99) requires significantly higher values of probability of failure-free operation of the SC components, which are unattainable in practice (0.99999). For this reason, among all the functions performed by the SC, it is reasonable to single out the main ones, which are responsible for crew life and health, protection against environmental disasters, protection against destruction of the GPV and other components. Along with the probability of failure-free performance it is proposed to use the probability of survivability assurance.

If the statistical quantitative value of the availability factor K^{OC}_A, is known based on the results of analogs operation, then expression (3) can be used to determine the correctness of the specified quantitative values of K^{OC}_A and K^{GCC}_A for the spacecraft under consideration.

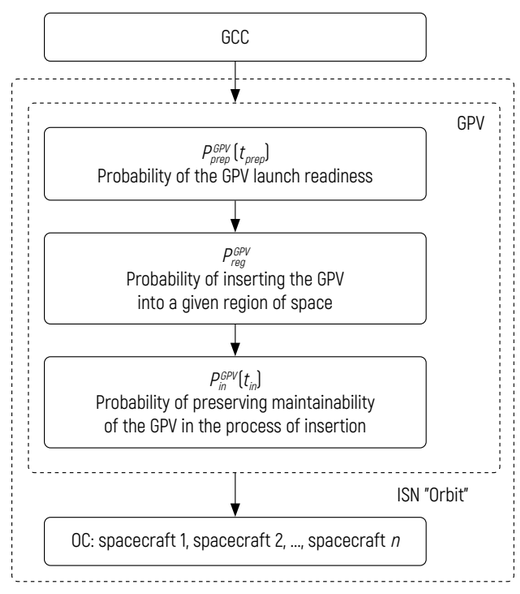

Figure – SC structural reliability model (the probability of successful launch and landing of the GPV)

The probability of failure-free performance of the GPV over the preservation period is calculated as follows:

$$P_{pres}^{GPV}(t_{pres}) = \exp(-\lambda_{pres} t_{pres}), \quad (4)$$

where λ_{pres} – the failure rate of the GPV over the preservation period.

The probability of preparation of the GPV for launch on the basis of the established technical readiness within the timeframes, not exceeding the standard specified t_{prep} is determined by the following expression:

$$P_{prep}^{GPV}(t_{prep}) = \exp(-\Delta_{GPV} t_{prep}) = \exp(-t_{prep} \Sigma_{i=1}^{k} \lambda_i), \quad (5)$$

where Δ_{GPV} – the total failure rate of the GPV elements;

k – the number of the GPV elements to be considered;

λ_i – the failure rate of the i-th element of the GPV at the launch preparation phase.

The probability of inserting the GPV into a given region of space P_{reg}^{GPV} and the probability of preserving the maintainability of the GPV during its insertion $P_{in}^{GPV}(t_{in})$ are determined by the reliability of the GPV elements that ensure its insertion.

Expressions (4) and (5) assume an exponential distribution law for the failure-free performance time of the evaluated objects. However, the failure rate of the objects vary significantly at different stages of operation. A key task is determining the relevant data for the phases of spacecraft launch and its operation in orbit.

The SC elements typically go through four main stages, each with significantly different failure rate (resource reduction rate):

- storage before launch: the failure rate is negligible;
- operation before launch: the failure rate is tens of times higher than during storage;
- launch: the failure rate is 1,000 times higher than during storage;
- in-orbit operation: the failure rate is 100 times higher than during storage.

The values of 10, 100 and 1,000 are expert estimates, based on the analysis of GOST RV 20.39.304-98 [13] and may need to be adjusted through the test results.

Recovery of a fully deployed ISN "Orbit" with n spacecraft, in the event of a sudden failure of a spacecraft, requires the launch of a replacement spacecraft. The recovery time for the ISN "Orbit" after deployment is determined by the total time of operational interruption of any spacecraft caused by the restoration of its functionality.

Interruptions of operation of some ISN "Orbit" spacecraft can be categorized into two types [14]:

- sudden failures of redundant equipment, compensated by onboard automation through an unscheduled transition to a backup set;
- sudden equipment failures, compensated only through the use of GCC units.

Scheduled transitions to a backup set of equipment for onboard systems or switching to a backup system in the event of a calculated abnormal situation do not result in operational interruptions.

Thus, the average recovery time for the ISN "Orbit" due to partial failures of its constituent spacecraft can be determined as follows:

$$T_{rec}^{ISN} = \frac{\Sigma_{i=1}^{n}\left(\Sigma_{j=1}^{m} T_{ij}\right)}{nm}, \quad (6)$$

where n – the regular number of spacecraft in the ISN "Orbit" orbital constellation;

m – the number of types of partial failures;

T_{ij} – the operational interruption of the i-th spacecraft by the j-th type of failure related to partial failures and methods of their elimination.

Conclusion

Taking into account the need for rational selection and optimization of the effective requirements and reliability parameters for the GPV and the ISN "Orbit" elements, as well as for these systems as a whole, in relation to their operating periods [15], it is possible to determine and develop the structural layout of SC reliability. This aims to improve the structural methods of ensuring these indicators during the design and operational phases, including methods for their validation.

Due to the lack of statistical data on the actual operating time and failures of the GPV and the ISN "Orbit" elements, as well as of these systems as a whole, the methodology for determining reliability indicators presented by the authors can be applied in mathematical modeling of complex technical objects.

This approach allows for virtual testing to verify the adequacy of the proposed methods, determine actual reliability parameters, and identify technological and operational factors that most significantly affect the reliability of the GPV and the ISN "Orbit."

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Section

ENERGY AND INFORMATION GEOCOSMIC SCIENCES, TECHNOLOGIES, MATERIALS AND RESOURCES

UDC 620.97+629.7

Application of General Planetary Vehicle as Element of Unified Energy System of Earth

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This article examines the structure of traditional unified energy systems that provide electric power to most consumers on Earth. Based on the gathered data and fundamental requirements for energy systems and facilities, the concept of a unified energy system is proposed. This system incorporates the General Planetary Vehicle (GPV) which can serve as a means for the accumulation and transmission of electric energy to consumers on a planetary scale. An important condition for the successful commercial efficiency of external energy systems during the GPV run is the low cost of their creation, operation and disposal.

An analysis of modern technologies used for primary energy production on Earth, including those for generating electricity, is also conducted. In light of fundamental requirements for energy facilities and systems, it is determined that for the efficient and sustainable operation of both the GPV and the Earth's energy system, technologies with minimal ecological impact are essential. The GPV is proposed as a powerful tool for balancing electric energy flow on Earth and as a means for intercontinental cargo transportation (at the initial stage of creation and operation).

Keywords:
accumulator, Earth, efficiency, energy, General Planetary Vehicle (GPV), intercontinental transportation, power industry.

Introduction

The General Planetary Vehicle (GPV), upon its implementation, will become the most energy-efficient and reliable aircraft for large-scale geocosmic cargo and passenger transportation along the Earth–Orbit–Earth route [1]. Typically, during acceleration and launch into orbit, the GPV will consume a significant amount of electrical energy, mainly to power the linear electric motors [2]. Some additional electricity will also be required to compensate for the inevitable irreversible losses during operation. In the case of a complete stop of the GPV, this energy should be stored for further application, highlighting the need for appropriate solutions. When the spacecraft returns from orbit, a vast amount of the kinetic and possibly potential energy it gained (from Earth or space) can be converted into electrical energy for use on Earth.

Apparently, to ensure efficiency (particularly achieving high energy efficiency with minimal irreversible losses during all stages of energy transformation) as well as the safety and stability of the GPV as an energy object and all other energy facilities working with the GPV, the following basic (generally accepted) requirements for energy facilities and systems must be met:

- effective functioning and interaction with the GPV and other consumers within the Earth's classical external energy system, including, first and foremost, power plants (external generation stations – EGS) with devices for transformation, protection, switching, distribution and accumulation (external accumulation stations – EAS) of electrical energy, as well as transmission lines;
- productive interaction of the GPV with external consumers (EC), where large amounts of stored kinetic and potential energy of the GPV (approximately 1.42×10^{18} J = 380 TW·h) during braking can be converted into electricity and efficiently (with minimal irreversible losses) transferred to EC or EAS. This is particularly crucial during scheduled repairs of the GPV or in emergency situations, when it is necessary to stop the GPV as quickly as possible. Reliable, fast transmission with minimal energy losses is required to handle the enormous amounts of energy released from the GPV;
- stable operation of the entire set of the above elements (unified energy system – UES) over an extended period;
- compliance with environmental and human security standards for UES;
- ensuring commercial efficiency of UES, based on the low cost of creation, operation and utilization of its individual elements.

According to the above, the GPV should be considered an important element of UES, which, in addition to its main purpose – geocosmic transportation – will determine energy efficiency and commercial success together with the balancing and reliability of both its own functioning and UES as a whole, with minimal impact on the Earth's biosphere.

Structure of Traditional Unified Energy Systems

The structure of energy distribution in both developed and developing countries serves as the basis for the future architecture of UES, with the GPV as a significant element (Figure 1).

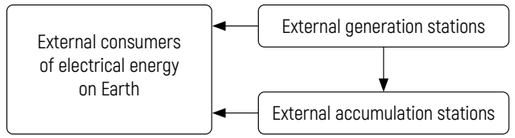

Figure 1 – Diagram of traditional UES

Each element of UES is interconnected by energy flows with other (external to it) elements.

External Consumers

In the considered structure, EC include industrial enterprises, agricultural facilities, public utilities, public service facilities, various institutions and organizations, life support and security systems, electric transport, public lighting, servers, mobile communication towers, household appliances, etc. At the same time, EC are net consumers of energy – all energy flows come from other elements of UES to EC.

External Generation Stations

EGS are net energy donors for all other elements of UES. They represent a set of different types of power plants that can use thermal energy from the combustion of organic raw materials (such as hard coal, natural gas, oil products, peat, etc.) as primary energy, the energy of falling water in hydroelectric power plants (HPP) or sea tides in tidal power plants (TPP), atomic energy from the nuclear fission of radioactive elements in nuclear power plants (NPP), wind energy in wind power plants (WPP), solar energy in solar power plants (SPP), the energy of sea wave oscillations or geothermal energy.

Today, about 30,000 TW·h of electrical energy is generated worldwide [3]. The percentage distribution of primary sources required for energy production on Earth is presented in Figure 2.

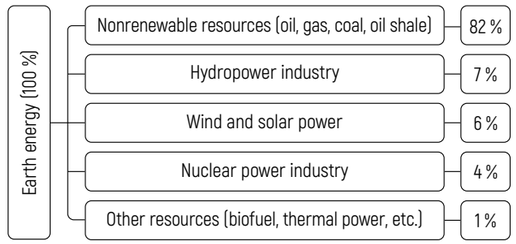

Figure 2 – Sources of primary energy production on Earth

EGS that use nonrenewable fossil fuels (gas, coal, oil products, peat, oil shale, etc.) as primary energy carriers do not meet the basic requirements, such as environmental friendliness and duration of use. According to many experts' estimates, the explored and prospective oil reserves will be sufficient for mankind for no more than 70 years. Moreover, as fossil organic fuels are depleted from the Earth's reserves (which will happen in the medium term), their price will rise rapidly, primarily due to the increased cost of production. Additionally, organic fuels, when burned with existing technologies, are environmentally harmful, as a large number of substances are emitted into the atmosphere, negatively impacting the Earth's biosphere. Installing various cleaning and capture devices for harmful emissions is very expensive. Finding efficient methods for generating and applying energy to EC (including the GPV) is an urgent task, not only for this study.

External Accumulation Stations

EAS consists the systems of accumulation stations of different types. Such stations, depending on the needs of other elements of UES (first of all, EC and EGS), function in two modes: accumulation and output of energy. The presence of EAS is conditioned by the fact that in certain periods EGS cannot fully meet the needs of EC: it is then that EAS give the previously accumulated energy to EC. In other cases, the energy produced by EGS will be surplus and sent to EAS for storage and subsequent use. At the same time, EAS interact with EC, whose energy consumption can be very uneven for various reasons (e.g., at night it is much less than during the day; in cold weather, more electrical energy is required for heating than in warm weather; in hot weather, air conditioners consume significant amounts of electrical energy). Thus, EAS are an important balancing element of UES, ensuring the stability of its operation and minimizing the loss of unnecessary energy. The physical principles on which EAS function are different.

In practice, pumped storage units are primarily used as high-capacity EAS. In the storage mode, external excess electrical energy powers by pumps to move water into large reservoirs, such as dams (upper basin). In the generation mode, the water stored in the dams flows downward (lower basin), transferring its energy to a hydroturbine connected to a generator to produce electrical energy. HPP are successfully used as both pumped storage units and hydroelectric generation stations. Depending on the demand for electricity, the accumulation or release of energy can be easily regulated by raising or lowering the water level in the dam through gate valves on the collectors feeding the hydroturbines. For relatively small amounts of energy storage, batteries operating on electrochemical principles are employed. Recently, EAS based on mechanical principles have gained momentum. In the accumulation mode, excess energy (in the form of electrical energy) is used to lift solid massive bodies to considerable heights. In the generation mode, the accumulated potential energy of these bodies is converted into electrical energy as they descend. In some cases, it is proposed to convert excess electrical energy into rotational energy by using a massive flywheel with a large moment of inertia.

Analysis of Advantages and Disadvantages of Using Different Types of Primary Energy on Earth

HPP and TPP use renewable energy from falling water. In addition, they are relatively environmentally friendly as they do not emit harmful substances, although large areas are often flooded during the construction of HPP dams. However, Earth's hydropower resources are already significantly utilized, and in the areas where the GPV are located, hydropower potential is very limited due to the small number and capacity of rivers and sea tides at the Earth's equator.

As for geothermal energy, including the energy from sea waves and currents, it should be noted that their reserves and prospects for use are also limited [4, 5] and cannot serve as the primary source for the GPV's energy supply due to their unpredictable impact on the marine and coastal environment [6].

The application of EGS based on renewable biofuels (such as plant raw materials like wood, rapeseed, sugar cane, etc.) requires vast agricultural areas and is currently economically costly [7].

EGS using wind and solar energy are relatively environmentally friendly, although the production of materials for WPP and SPP, as well as their subsequent disposal, are processes harmful to the biosphere and involve the consumption of large amounts of energy [8]. Serious disadvantages of WPP and SPP are high costs per unit of electricity produced, substantial resource intensity and the need for large territories and water areas due to the low volumetric densities of wind and solar energy.

The disadvantages of modern solar and wind generation include low overall efficiency factor and energy conversion rates into electrical energy [9]. There is a narrow range of optimal wind speeds for WPP (about 10–20 m/s). Additionally, the higher the ambient temperature, the lower the solar-to-electrical energy conversion efficiency for SPP. WPP and SPP are also prone to frequent failures due to environmental factors (hail and sandstorms can damage solar panels; strong storms, frost and collisions with blades cause bird deaths – one wind turbine can kill thousands of birds during its lifetime – and can lead to the breakdown of wind turbines; etc.).

The service life of SPP and WPP is much shorter than that of traditional power plants, requiring frequent and costly repairs and maintenance. WPP creates strong vibrations in large volumes of air, which means a significant portion of the surrounding area must be designated as sanitary zones. The installation of SPP also leads to shading of the Earth's surface and sharp local changes in ecosystems. The operation of wind turbines disrupts bird migration, and offshore WPP disrupt the migration of fish and marine animals. Moreover, the disposal of used SPP panels and WPP blades presents significant challenges [9].

The most significant disadvantage is the instability of generation. When the wind blows lightly or changes direction frequently, WPP loses their efficiency. If the sun shines weakly (due to clouds, fog, smog, precipitation) or if there is significant dust accumulation on the panels (which need to be periodically washed or cleaned), SPP does not provide maximum generation. In these cases, conventional power generation is vital.

This explains the low utilization rate of the installed capacity of SPP and WPP. Functioning in an unstable generation mode leads to significant wear and tear not only of WPP and SPP but also of traditional power sources, which results in a significant reduction in the overall efficiency factor of the energy system. Additionally, large problems arise in transmitting excess electricity generated by SPP and WPP during periods of low consumption by EC. Therefore, there is a need to deploy additional powerful and costly transmission lines between all regions where SPP, WPP and EC are located, as well as energy storage units.

It is both theoretically justified and practically confirmed that the greater the share of SPP and WPP in total electricity generation, the higher the cost of electrical energy [10]. In fact, the rapid growth of energy generation using WPP and SPP is largely driven by significant subsidies, primarily at the expense of traditional energy sources.

A good alternative, in addition to coal, oil shale and peat, is the use of fast neutron nuclear power plants (NPP), which can effectively provide energy to the GPV for many hundreds of years in the future [11]. The inclusion of such NPP into the UES cycle is a promising area of research.

Proposed Structure of Unified Energy System, Including GPV

The structure of UES, including the GPV as a significant component, should clearly be based on the diagram presented in Figure 1. However, the inclusion of the GPV introduces important adjustments (Figure 3).

In the flywheels acceleration mode, the GPV will consume and accumulate a substantial amount of electrical energy from EGS and EAS (Figure 3, yellow arrows). The GPV will also function as a consumer of electricity (as the most efficient form of its utilization and transmission to date) in the mode of compensating for irreversible energy losses during the repeated ascent to orbit without stopping the flywheels.

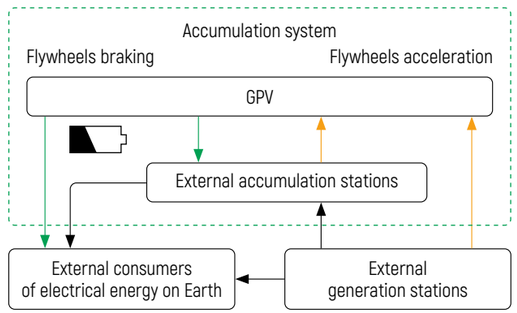

Figure 3 – Diagram of UES with GPV as a significant component

When braking the flywheels (if necessary), a large amount of excess energy (up to 400 TW·h) can be extracted from the GPV. This energy will be directed to EAS and EC (Figure 3, green arrows) for storage and consumption, respectively.

From this, an important conclusion is drawn: the operation of the GPV, from an energy perspective, is very similar to that of EAS. Therefore, the GPV can also serve as a crucial balancing element within UES.

It should be noted that the efficiency factor of the majority of applied EAS is relatively low. For example, in modern pumped storage units, the total efficiency (injection and generation) does not exceed 40 % [12]. This is due to the fact that when water is pumped from the lower basin to the upper basin during the accumulation mode, up to 40 % of the energy is irreversibly lost (efficiency factor is 60 %). Similarly, when water flows back from the upper basin to the lower basin during the generation mode, up to 40 % of the remaining energy is also lost (efficiency factor is 60 %). In contrast, energy losses in the GPV [13], operating in the accumulation mode, are lower than those in modern EAS due to the rotation of rotors in a vacuum, resulting in minimal friction losses. This makes the operation of the GPV, in conjunction with not only EGS and EAS but also EC, highly promising from the standpoint of rational energy transfer and utilization – especially when it is necessary to completely stop the flywheels.

Thus, for some countries within the GPV area, there is an opportunity to obtain energy independently of the availability of transmission lines to EGS (Figure 4).

Since the GPV can store up to 380 TW·h of energy, or up to 1.3 % of the total electrical energy produced on Earth in a year (28,000 TW·h in 2023), it will serve as a crucial balancing element in the flows of generated and consumed electrical energy in the Earth's equatorial and largely tropical zones.

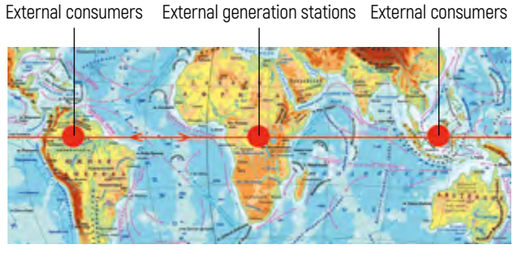

Figure 4 – An example of using GPV
as an intercontinental power transmitter

Adhering to this approach, the GPV, with appropriate optimization, can also be used for cargo transportation on the Earth's surface (Figure 5).

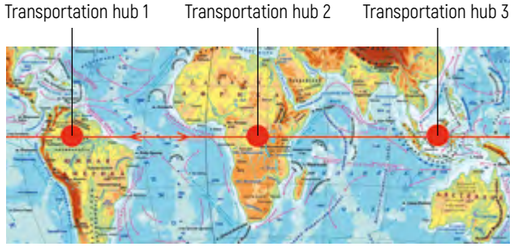

Figure 5 – Intercontinental cargo transportation using GPV

Thus, to ensure commercial efficiency, it is proposed to consider the GPV as an intercontinental vehicle located along the Earth's equator. Specifically, during the first stage of the GPV construction and launch, the authors envision its use (in conjunction with the overpass outlined in [14]) as a transportation link connecting continents and islands near the equator – not only through the GPV overpass designed for the movement of traditional and string rail vehicles. This approach will undoubtedly accelerate the exchange of goods between countries (compared to sea transport) and stimulate the development of the GPV as space transport. The technology for operating the entire GPV structure on Earth could become the subject of further research in this area.

Conclusion

To ensure efficiency – primarily, energy efficiency with minimal irreversible losses at all stages of its transformation – along with safety and sustainability of the GPV as an energy object of the Earth, the following basic requirements must be met:

- effective functioning and interaction with the GPV and other consumers within the classical external energy system;
- productive interaction of the GPV with external energy consumers on Earth;
- stable operation of all elements of UES over an extended period (both during launch and operation and during braking until the complete shutdown of the GPV);
- environmental and human safety of UES;
- commercial efficiency of UES.

Thus, the GPV is a vital element of UES. It can be used not only as a space and intercontinental vehicle but also as a massive accumulator of kinetic and potential energy with high efficiency factor (up to 97 %). The GPV is capable of competing with sea transportation, large-capacity storage stations and rocket-based space transport.

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Application of Closed Nuclear Fuel Cycle Technology for Operation of General Planetary Vehicle

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This article substantiates the use of closed nuclear fuel cycle (CNFC) technology with fast-neutron reactors in the electric power industry as a means to support the long-term, sustainable operation of the General Planetary Vehicle (GPV) with minimal impact on the Earth's ecosystem. The CNFC technology is explained, and current uranium-238 energy reserves, including nuclear waste, are assessed. The number of GPV launches possible with Earth's nuclear fuel resources is analyzed. The authors determined that nuclear power using CNFC and uranium-238 depending on the GPV overall energy efficiency alone could enable around 100,000 full GPV launches or over 2 mln times would compensate energy loss during GPV operations.

Additionally, each GPV launch and subsequent landing could transfer 1.4×10^{18} J of electrical energy to external consumers or storage stations. The GPV is proposed not only as a geocosmic vehicle but also as a large-capacity kinetic energy storage unit and an efficient balancing element in the unified energy system of Earth.

Keywords:
disposal, energy reserve, General Planetary Vehicle (GPV), fast neutrons, nuclear cycle, nuclear waste, number of GPV launches, uranium.

Introduction

According to the calculations performed [1], the General Planetary Vehicle (GPV) is a highly energy-intensive facility within Earth's energy system. The consumption of energy from nonrenewable sources for its operation will lead to a significant environmental burden on our planet, making such an approach unsustainable in the long term.

In order to ensure prolonged, sustainable and efficient operation of the GPV without significantly impacting Earth's ecosystem, it is proposed to use nuclear power technology based on the introduction of the so-called closed nuclear fuel cycle (CNFC). This technology involves the use of fast-neutron reactors [2] and is substantially different from the nuclear technology of uranium-235 heavy nucleus fission on slow neutrons, which is implemented in the vast majority of modern NPP.

The use of uranium-238 as a primary energy carrier has already been implemented at the pilot level by Rosatom State Atomic Energy Corporation in existing fast-neutron reactors (for example, the industrial fast-neutron reactor BN-800 has been operating safely for a long time at the Beloyarsk NPP). Additionally, the construction of the BN-1200 industrial-research fast-neutron reactor for the CNFC at the Beloyarsk NPP is underway to comprehensively study all technical, technological, environmental and economic indicators of the CNFC over a long period. In Seversk (Russia), the research reactor BREST (lead-cooled fast reactor) is being built [3]. In Dimitrovgrad (Russia), in 2028, it is planned to launch a multi-loop fast research reactor (sodium-cooled) – MBIR, which will be used to conduct a comprehensive analysis of technological solutions, study the behavior of various materials in intense fast-neutron fluxes, and master technologies for producing valuable radioisotopes.

Similar developments are being carried out in China and India. At the same time, there are practically no such studies in Western countries that have focused on green energy.

Considering the above, it raises the question of the need to assess nuclear fuel reserves for the operation of the GPV as a high-energy capacity facility.

Description of CNFC Technology in Nuclear Energy

It is assumed that the establishment of external generating stations (EGS) using natural uranium-238 as the primary energy carrier with large proven reserves on Earth will meet the basic requirements, ensuring the effective functioning of the GPV and the Earth's energy system.

The essence of using uranium-238 as a nuclear source of primary energy with the organization of the CNFC is as follows. Initially, a fuel assembly of heat-generating elements made of a mixture of plutonium-239 (an alternative option is uranium-235) and uranium-238 is loaded into a fast-neutron reactor. Plutonium-239 undergoes fission under the influence of an intense flux of fast neutrons, resulting in the formation of two fission fragments (fragment 1 and fragment 2) with the main amount of kinetic energy and two to three fast neutrons per fissioned nucleus (Figure 1, left side). Some of these neutrons are captured by other (non-reacting) plutonium-239 nuclei, causing their fission – a self-sustaining regulated chain nuclear reaction occurs. The fission fragments are radioactive: their decay releases a large amount of energy in the form of alpha, beta particles and various electromagnetic radiation – from gamma rays to radio waves. Ultimately, all of the released energy is converted into heat, which is also used for electricity generation.

The fission fragments (Figure 1) can vary, but are smaller in mass and charge number than the plutonium-239 nucleus. The specific type of fission fragments is determined by statistical laws.

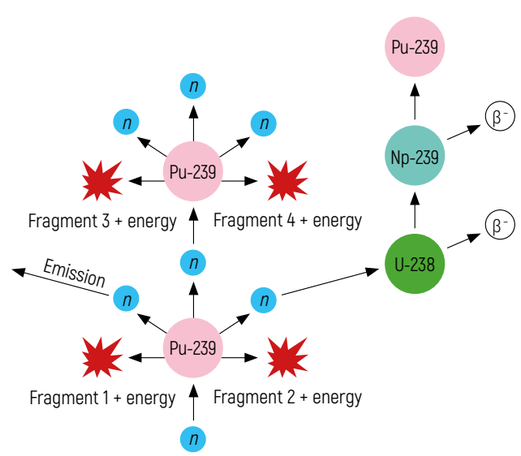

Figure 1 – Set of nuclear reactions on fast neutrons

This reaction, from an energy and functional perspective, is similar to the fission reaction of uranium-235, which occurs under the influence of slow neutrons in the reactors

of most modern NPP (Figure 2). In such a reaction, the absorption of a slowed neutron by a uranium-235 nucleus can result in the formation of, for example, two radioactive fragments: barium-141 and krypton-92 nuclei with high kinetic energies, as well as three fast neutrons.

Uranium-238, which constitutes at least 80 % of the assembly, undergoes weak fission under the influence of fast neutrons but captures them effectively (Figure 1, right side; more details in Figure 3).

Upon capturing a fast neutron, a β-decay nuclear reaction occurs, resulting in the formation of the neptunium-239 isotope:

$$U_{92}^{238} + n_0^1 \longrightarrow Np_{93}^{239} + e_{-1}^0,$$

subsequently, a rapid β-decay reaction of the neptunium-239 nucleus occurs, leading to the formation of the plutonium-239 nucleus:

$$Np_{93}^{239} \longrightarrow Pu_{94}^{239} + e_{-1}^0.$$

The total energy output of these two reactions is relatively small (compared to the reaction shown on the left side of Figure 1). However, at the end of the operating cycle of a fast-neutron reactor, a significant amount of energetic plutonium-239 is produced in the uranium-238 fuel assemblies (Figure 1, right side), and its quantity may even slightly exceed the initial load.

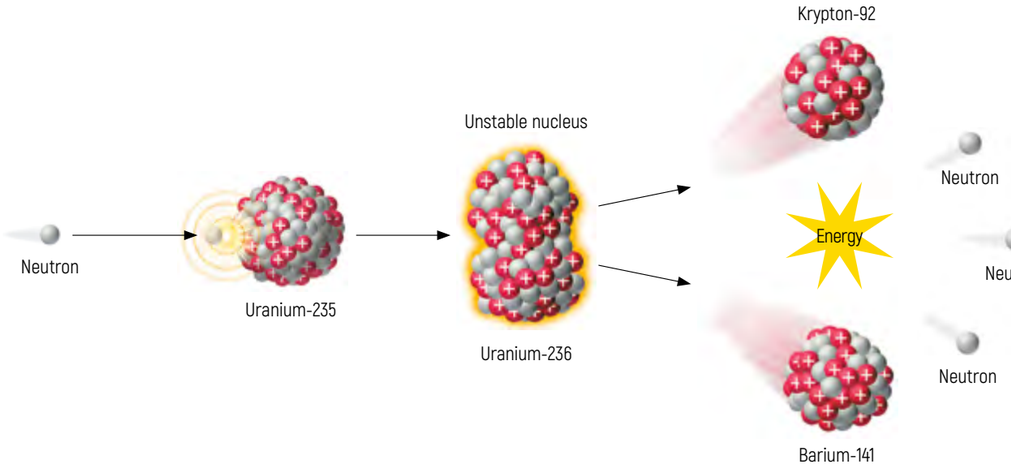

Figure 2 – Nuclear reaction on slow neutrons

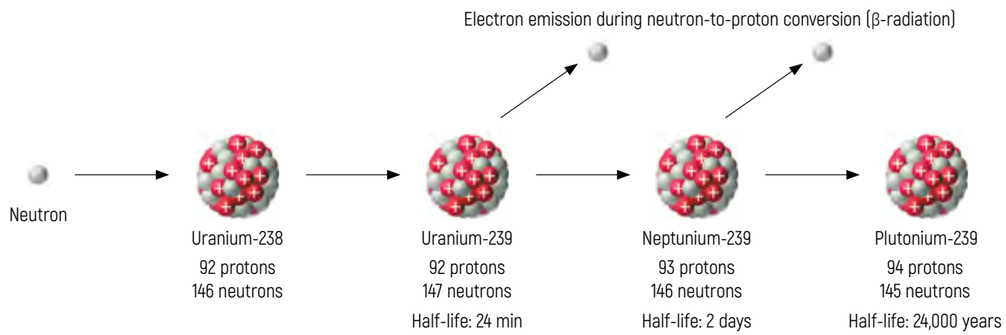

Figure 3 – Nuclear reactions on fast neutrons with the production of energy plutonium-239

After the reactor is shut down, unloaded and held in a spent fuel pool (where short-lived isotopes decay), the produced plutonium-239 and remaining uranium-238 are separated from the spent nuclear fuel (SNF) obtained after the reactor's operational cycle using relatively simple chemical methods. New fuel assemblies (plutonium-239 + + uranium-238) will be manufactured from uranium-238 and plutonium-239 for subsequent use in these same fast reactors. Fast-neutron reactors, SNF holding and separation complexes and fuel assembly manufacturing facilities are planned to be located in one place (Figure 4). This approach will reduce logistics costs, enhance overall safety and enable the organization of the CNFC.

As the weakly radioactive uranium-238 is consumed, its supply to the described CNFC zone can be ensured.

It is important that the use of the CNFC contributes to the complete utilization of radioactive waste, resulting in valuable radioisotopes that find wide application in various technologies (e.g., in medicine, experimental physics and the creation of nuclear batteries). Herewith, radioactive waste will account for no more than 5 % of the original nuclear fuel, which will practically eliminate the need for its disposal, thus increasing radiation safety and significantly reducing overall costs. The CNFC technology will allow the reprocessing of already accumulated hazardous radioactive waste from repositories in fast-neutron reactors (by decaying into nonradioactive elements with the release and use of energy), thereby increasing the radiation safety of the Earth.

It is also worth mentioning the additional possibility of utilizing the heat generated in the spent fuel pools. Since a significant amount of heat is released during the decay of short-lived isotopes in SNF, it is advisable to use it for heating various buildings and structures (greenhouses, houses), making this technology promising, especially in regions with cold climates. Furthermore, it should be emphasized that the implementation of the CNFC, unlike thermal generation, is practically not accompanied by the release of chemically harmful substances into the environment.

Assessment of Uranium-238 Energy Reserves, Including Nuclear Energy Waste

Proven reserves of uranium-238 (in deposits in the form of solid loose oxides, silicates, phosphates and complex compounds with vanadium) amount to between 5 and 11 mln tons in terms of pure uranium [4]. At the same time, according to experts, the total amount of uranium-238 isotopes on Earth is much higher [5]. However, since the majority of it is found in soluble compounds at very low concentrations, industrial development is economically unfeasible. Therefore, we will base our calculations on uranium-238 from deposits, using the lower mass limit: $m = 5$ mln tons $= 5 \times 10^9$ kg.

When one nucleus of plutonium-239, obtained from uranium-238, undergoes fission and subsequent decay of fission fragments, thermal energy is released: $e = 207$ MeV = $= 3.318 \times 10^{-11}$ J, or in terms of 1 kg of substance $E_0 = 8.361 \times$ $\times 10^{13}$ J/kg. With the full involvement of 5 mln tons of uranium-238 in the CNFC, the energy produced would be:

$$E = E_0 m = 8.361 \times 10^{13} \times 5 \times 10^9 = 4.18 \times 10^{23} \text{ J}.$$

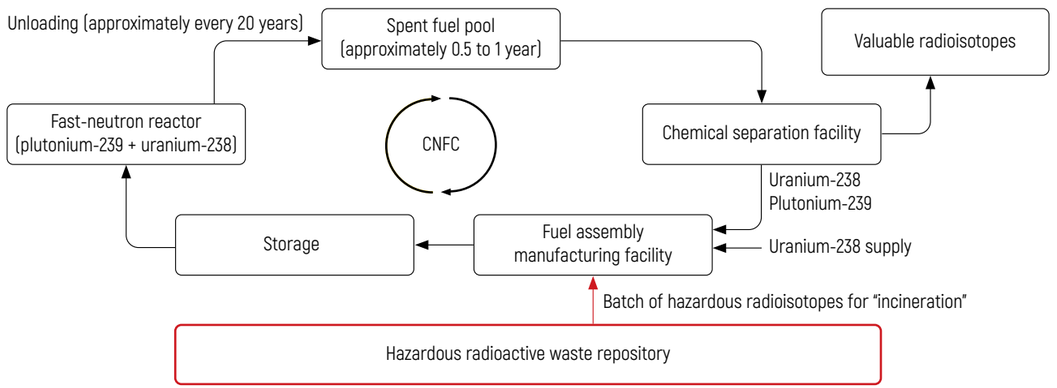

Figure 4 – CNFC scheme

The efficiency factor of modern NPP is approximately 33 % [6], therefore the electrical energy will be:

$$E_{el} = 4.18 \times 10^{23} \times 0.33 = 1.38 \times 10^{23} \text{ J}.$$

This calculation does not consider depleted uranium-238 in the spent pools resulting from the enrichment of natural uranium. More than 2 mln tons of depleted uranium hexafluoride (DUHF) have accumulated worldwide [7]. In the Russian Federation alone, more than 1 mln tons of DUHF are stored in special steel cylindrical containers [7]. In terms of pure uranium-238, global reserves in the form of uranium hexafluoride can be estimated at 1–1.5 mln tons. Some of the depleted uranium is located in radioactive waste repositories as part of SNF and waste. Thousands of tons (if not more) of depleted uranium have been used and are stored in the form of various finished high-penetration artillery ammunition. It is also advisable to involve highly-enriched plutonium-239 from accumulated nuclear weapons in the CNFC.

It should be emphasized that the CNFC can be organized using thorium-232 instead of uranium-238, the reserves of which in the Russian deposits are at least twice as large (Table) [8].

Table – Assessment of potential reserves of nonrenewable energy

Resource	Percentage, %
Fission energy of thorium-232	43
Fission energy of uranium-238	16
Energy of thermonuclear reaction of tritium produced from lithium-6	39
Fission energy of uranium-235	0.1
Energy from modern hydrocarbon sources Including: • oil • gas • coal	1.9 0.2 0.4 1.3

It should be noted that EGS can be not only nuclear: if there is economic, technological or other justification for other types of electricity generation, they should be utilized, but always within the framework of a unified energy system, the basis of EGS of which will be the CNFC.

Assessment of Uranium-238 Energy Reserves for Launch and Operation of GPV

According to [1], an energy of 3.544×10^{10} J/lin m would be required to obtain flywheels with specific masses of 450 and 200 kg/lin m to give absolute launch velocities of 13.015 and 0.365 km/s, respectively. If the acceleration time is set to 20 days, then 21.6 kW of power will be required for each linear meter of the GPV. Therefore, to compensate for losses arising from movement, braking and acceleration of the flywheels, an additional 1.16 GJ/lin m of energy (0.116×10^{10} J/lin m) is needed, i.e., the GPV can be conditionally considered as a kinetic energy accumulator (Figure 5).

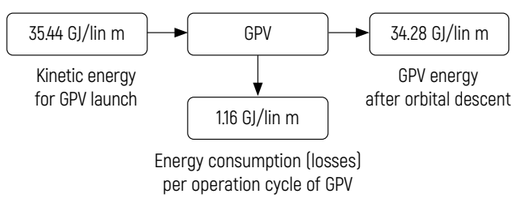

Figure 5 – Energy balance of GPV operation

Provision of electrical energy for the GPV to operate the linear electric motors of the belt flywheels and their magnetic suspension systems is proposed to be achieved through the use of nuclear energy based on the CNFC, which allows for the production of the required amount of energy over a long period without significantly impacting the environment. Thus, with an initial length of the GPV of 40,076 km ≈ ≈ 4.008×10^7 m (along the Earth's equator) for its initial launch from the state of complete rest it is necessary to expend electrical energy in the amount of:

$$E_{i.l} = 35.44 \times 10^9 \times 4.008 \times 10^7 = 1.42 \times 10^{18} \text{ J}.$$

If the initial launch of the flywheels to the starting velocities (spinning around the planet) is carried out over t = 20 days = 20 × 24 × 3,600 = 1.728×10^6 s (soft launch conditions), then the average consumed electrical power will be:

$$P_{av} = E_{i.l} / t = 1.42 \times 10^{18} / (1.728 \times 10^6) = 8.218 \times 10^{11} \text{ W} = 821.8 \text{ GW}.$$

Therefore, it is possible to approximately estimate the number of full launches of the GPV using only the energy from the CNFC, which utilizes depleted uranium-238 from undeveloped terrestrial deposits as fuel:

$$N_{f.l} = E_{el} / E_{i.l} = 1.38 \times 10^{23} / (1.42 \times 10^{18}) = 9.71 \times 10^4.$$

Thus, only nuclear energy based on the CNFC will allow for more than 90,000 launches of the GPV, although the flywheels will need to be stopped approximately every 100 full geocosmic cycles (i.e., once every few years) for scheduled inspections and repairs.

Let us calculate the energy required to replenish the energy expenditure for the subsequent launch:

$$E_{r.e} = 1.16 \times 10^9 \times 4.008 \times 10^7 = 4.65 \times 10^{16} \text{ J}.$$

Then the number of launches requiring only the replenishment of irreversibly lost energy will be:

$$N_{r.e} = E_{el} / E_{r.e} = 1.38 \times 10^{23} / (4.65 \times 10^{16}) = 2.97 \times 10^6.$$

After the takeoff and landing of the GPV, it is possible to extract electrical energy from it for the needs of the Earth's energy system and transfer it to external consumers and/or external accumulating stations:

$$E_{i.l} - E_{r.e} = 1.42 \times 10^{18} - 4.65 \times 10^{16} = 1.374 \times 10^{18} \text{ J}.$$

These calculations show that the existing reserves of nuclear fuel are sufficient for the successful and sustainable operation of the GPV for millennia without detriment to the primary energy consumers on the planet Earth.

Conclusion

Several conclusions can be drawn as a result of the conducted research.

1. The use of uranium-238 in the fuel nuclear assemblies of fast-neutron reactors will allow the production of an optimal amount of energetic plutonium-239 for its subsequent use as a primary energy carrier in these reactors. This approach will enable the implementation of a CNFC and ensure long-term sustainable operation of the GPV without significant impact on the planet's ecosystem.

2. The CNFC technology will minimize logistical costs, allow the utilization of already accumulated radioactive waste from repositories, and enhance the overall radiation safety of Earth. Additionally, unlike thermal generation, the CNFC is practically free from the emission of chemically harmful substances into the environment.

3. The reprocessing of SNF within the CNFC will enable the production of numerous valuable radioactive isotopes and eliminate the need for SNF burial in repositories.

4. The reserves of uranium-238 extractable from Earth's deposits amount to at least 5 mln tons. In the case of CNFC implementation, this quantity is sufficient to produce at least 1.38×10^{23} J of electrical energy. This amount is enough to ensure more than 90,000 full launches of the GPV or more than 2 mln launches requiring only the replenishment of irreversibly lost energy.

5. Currently, DUHF with a high content of uranium-238 is stored in special containers. In terms of pure uranium-238, its global reserves are estimated at 1–1.5 mln tons. Some reserves of depleted uranium are located in radioactive repositories as part of SNF and waste. Thousands of tons of depleted uranium are available in the form of various high-penetration artillery munitions. It is also advisable to use highly-enriched plutonium-239 from accumulated nuclear weapons in the CNFC.

6. The CNFC can be organized using thorium-232 instead of uranium-238, the reserves of which in the Russian deposits are at least twice as large as those of uranium-238.

7. EGS can be not only nuclear. If there is economic, technological and other justification for other types of electrical generation, they should be utilized, but within the framework of a unified energy system of the Earth, the basis of EGS of which will be the CNFC.

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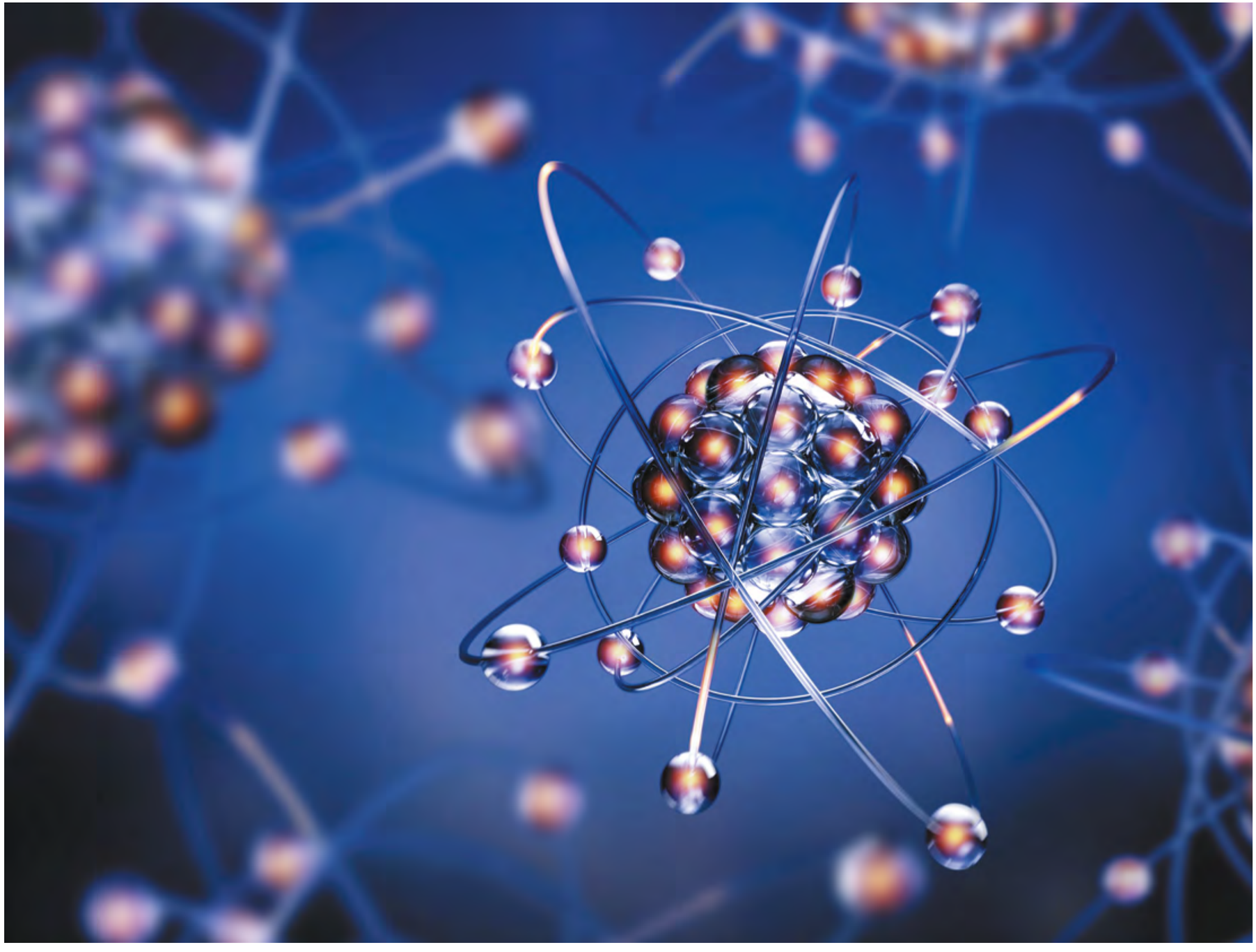

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Electrohydraulic Discharge Equipment for Coal-Water Fuel Production

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The results of using the UniThorr 2 electrohydraulic discharge equipment, designed by Unitsky String Technologies Inc. (Minsk, Belarus), to produce coal-water fuel (CWF) are provided. The impact of various parameters (solids content, granulometric composition) on the rheological properties and sedimentation stability of coal-water suspensions has been studied, that made it possible to select the formulation of CWF. The process flow of its obtaining with the use of electrohydraulic discharge equipment is proposed on the basis of experimental evidence; patterns between the process parameters of CWF are distilled; the optimal fuel composition is determined. It is demonstrated that by adjusting the granulometric composition of CWF it has been possible to reduce the dynamic viscosity of the samples by six times.

The developments in this area are an important component of the implementation of the EcoSpace program, in particular in the energy (heat and electricity) and biohumus production in the Equatorial Linear City for the needs of the General Planetary Vehicle and the Industrial Space Necklace "Orbit."

Keywords:
brown coal,
coal-water fuel (CWF),
coal-water suspension (CWS),
dispersion, dynamic viscosity,
electrohydraulic discharge equipment (EHDE),
electrohydraulic effect,
Industrial Space Necklace "Orbit" (ISN "Orbit"),
sedimentation stability, UniThorr.

Introduction

The Industrial Space Necklace "Orbit" (ISN "Orbit") is a multi-orbital industrial-residential complex with a developed transport infrastructure, built according to the model of the Equatorial Linear City and encircling the planet in the equator plane. It will supply the Earth's population with space products, act as a buffer in the event of threats to the Earth's civilization from space (in particular meteorites) and serve as a technological platform for deep space exploration [1–6].

The structure of ISN "Orbit" includes EcoCosmoHouses (ECH), which are orbital facilities with habitable internal spaces protected from the harsh external conditions of space [3, 4]. In such an environment, there is a pressing need to create enclosed biosphere-type ecosystems that provide a full cycle of self-sufficiency for people.

When developing these ecosystems, preference should be given to equipment and technologies that operate on electricity. This is due to the inexhaustible source of solar energy in space, which can be converted into electricity [4]. Accordingly, the use of an electrohydraulic discharge equipment (EHDE) in Earth's orbit will be a good alternative to traditional methods applied in various industrial technologies.

The principle of EHDE operation is based on the electrohydraulic effect: an electric discharge occurs within a volume of liquid, creating ultrahigh impulse pressures around the discharge zone capable of performing mechanical work and accompanied by a complex of physical and chemical phenomena [7]. The main advantages of implementing electrohydraulic technology in space life are its environmental friendliness and safety.

The application of EHDE in industry is quite diverse. There are many directions for the use of electrohydraulic shock: in mechanical engineering, construction, mining, medicine, agriculture, energy and more. Since one of the goals of building the ISN "Orbit" is to transfer harmful industries from Earth to it, replacing traditional technologies with EHDE in the new environment will be a reasonable solution.

In the implementation of the EcoSpace program, particularly for the purpose of obtaining energy and biohumus in the Equatorial Linear City (firstly, for the needs of ECH), the use of EHDE is proposed. The possibility of producing biohumus from crushed brown coal with such a unit is demonstrated in [8]. The electrohydraulic effect can also be used in fuel production technology (in this case, we are talking about coal-water fuel – CWF) [9], as confirmed by experimental results presented in this study.

Prospects for Using Coal as Fuel

Electric and thermal energy are obtained by burning various types of fuel, such as wood, peat, coal, gas, oil and others. The main fuel resources include oil, natural gas and coal (Table 1), which produce more than 80 % of the energy generated on the planet [10].

Global geological fuel reserves are estimated at approximately 13 tln tons, meaning that humanity's supply of mineral fuel is about 1,000 years at the current level of consumption. Of these reserves, coal accounts for 60 % (by calorific value), while oil and gas account for 27 %. However, the structure of global consumption of primary energy sources is different: in 2022, coal accounted for 27 %, oil – for 30 % and gas – for 23 %.

Table 1 – List of countries (first eight) by natural hydrocarbon reserves, 2022

Country	Coal, bln tons	Country	Oil, bln bbls	Country	Natural gas, tln m^3
USA	249	Venezuela	298	Russia	39
Russia	162	Saudi Arabia	266	Iran	32
Australia	149	Iran	157	Qatar	25
China	141	Iraq	148	Turkmenistan	20
India	105	Kuwait	100	USA	13
Indonesia	40	UAE	97	China	8
Germany	36	Russia	94	Venezuela	6
Ukraine	34	Canada	80	Saudi Arabia	6

Proven coal reserves in 2022 are estimated at 1,069 bln tons, with 70 % of them being hard coal and anthracite, and the rest being brown coal. The planet's coal supply is sufficient for 400 years at the 2022 extraction and consumption rates [11]. Global reserves of oil shale amount to 650 tln tons. With an average annual per capita energy consumption of 5 kW·h, these reserves can fully supply a global population of 10 bln people for approximately 5,400 years [12].

The countries richest in coal are the USA (28 %), Russia (over 18 %), Australia (13 %) and China (11 %). These states account for about 70 % of the world's proven coal reserves.

Today, coal is mined in about 80 countries. Hard coal production is around 3.5 bln t/year, and brown coal production is 1.2 bln t/year. Currently, China leads in coal production with 4.4 bln tons in 2022 [13]. The largest producers remain India (937 mln t/year), Indonesia (690 mln t/year) and the USA (540 mln t/year).

Proven oil reserves in the world are estimated at 245 bln tons, with a resource availability of 55 years at the current consumption level. In 2022, global crude oil production increased by a record 5.4 %, significantly higher than in 2021 (+1.6 %) and the average for 2010–2019 (+1.3 % per year).

Proven natural gas reserves in the world are increasing rapidly and are estimated at 199 tln m^3. According to forecasts by the multinational oil and gas company British Petroleum, at the 2018 production level, global natural gas reserves should last for approximately 151 years [11]. Therefore, the planet's supply of coal as a fuel resource is significantly higher, making the transition to its use in the implementation of the EcoSpace program more feasible.

Coal-Water Fuel and Its Features

CWF is a composite dispersed system consisting of fine coal, water and a plasticizing agent.

The technology for producing and burning CWF emerged in the 1970s in Russia and gained widespread use in China and Japan. Currently, mass production and use of CWF are carried out in China, where coal consumption as a fuel is increasing every year.

The application of coal in the form of CWF has several advantages [14]:

- fire and explosion safety (during production, storage, transportation and use);
- reduction of pollutant emissions into the atmosphere (dust, ash, nitrogen and sulfur oxides) and the amount of ash produced due to increased combustion efficiency of the fuel mass up to 97 %;
- full mechanization of technological processes;
- various transportation methods.

In the technology of producing and burning CWF, the following properties are decisive: the content of the solid phase (in this case, coal), the granulometric composition of the suspension, dynamic viscosity, static stability (i.e., sedimentation stability), ash content, lower heating value and others (Table 2) [9, 14].

Table 2 – Technological parameters of CWF

Parameter	Permissible range of values
Mass fraction of solid phase, %	45–70
Granulometric composition, μm	Less than 250
Density, kg/m^3	About 1,200
Coal ash content, %	5–50
Lower heating value, kcal/kg	2,300–4,700
Dynamic viscosity (shear rate 13.5 s^{-1})	0.8–2
Ignition temperature, °C	450–650
Combustion temperature, °C	900–1,150
Freezing temperature (without additives), °C	0
Static stability, day: • without additives • with additives	 Up to 5 Not less than 30

All these parameters vary significantly depending on the raw material and are adjusted when it changes. However, if the influence of one or another factor, as well as their combination, on the nature of CWF properties is not taken into account, it is impossible to obtain fuel.

In developing CWF technology for its effective use, it is necessary to address several emerging challenges, such as ensuring sedimentation stability and optimal rheological characteristics with the maximum solid phase content. This can be achieved by selecting the raw materials for preparing CWF, its granulometric composition as well as plasticizing and stabilizing additives.

Accordingly, the aim of the study was to investigate the influence of various parameters (granulometric composition, solid fraction content) on the sedimentation and rheological properties of CWF obtained using an EHDE and to select the optimal components. Based on experimental data, a technological scheme for the production of CWF is proposed.

Materials and Methods of Research

Coal grinding and CWF production were carried out using the modernized UniThorr 2 EHDE (Figure 1) designed by the employees of Unitsky String Technologies Inc. (Minsk, Belarus). Previously, the authors studied the influence of various parameters (initial fraction size, chamber design, properties of the working medium, working gap size, loading volume) on the quality of coal grinding in the UniThorr EHDE in discrete mode [9]. The main components of the UniThorr 2 EHDE are the pulse current generator, the working chamber, the coal feeding device, the water pump, the classifier and the particle fraction separation system.

Figure 1 – UniThorr 2 EHDE: working chamber and coal feeding device

The working chamber is a container made of polymer material, into which coal and water are fed, and where the electrohydraulic discharge occurs, leading to material grinding. Thanks to the circulation process created in the chamber, the ground particles are carried into the classifier and then into the clarification system, where the particles settle and are separated into fractions: coarse (20–200 μm) and fine (1–20 μm).

Brown coal of B1 grade was used for the research. The range of the initial fraction fed into the working chamber was 0–50 mm. Tap water was used as the working fluid. After separating the coal-water suspension (CWS) into fractions in the clarification system, CWF samples were prepared by mixing fractions of the required granulometric composition in different ratios. The uniform distribution of particles in the suspension volume was ensured by a ULAB US-2200D stirrer (1,500 rpm for 10 min). The solid phase content was determined according to GOST R 52911-2020 [15]. Dispersion analysis of CWF samples was conducted with a FRITSCH ANALYSETTE 22 NanoTec laser particle size analyzer. Rheological studies were carried out using a RheoTest 2 rotational viscometer.

The sedimentation stability of CWF samples was determined visually: at specified intervals, the thickness of the layer separated from the suspension during settling was assessed. An increase in its height indicated the destabilization of the dispersed system, leading to the gradual compaction of the solid phase. Sedimentation stability S was calculated using the formula [16]:

$$S = \frac{H_0 - H_l}{H_0} 100\ \%,$$

where H_0 – height of the initial sample layer;

H_l – height of the separated clarified layer.

Experimental Results

The critical characteristics of the suspension for obtaining CWF are the size of the coal particles and their quantity. Additionally, the grinding process is key and the most energy-intensive. Therefore, careful selection of equipment will reduce technological costs for fuel production. According to the main parameters of CWF (Table 2), the particle sizes of the dispersed phase should not exceed 250 μm. The influence of the dispersion composition on viscosity is crucial [17]. A properly selected granulometric composition of the solid phase helps reduce dynamic viscosity and increase suspension stability [14]. Herewith, to meet the required technological parameters of CWF, such as dynamic viscosity and sedimentation stability, a finer fraction (particle size less than 150 μm) should be used.

As a result of grinding brown coal in the UniThorr 2 EHDE, two types of CWS were obtained, differing in particle size: coarse and fine fractions.

Figure 2 shows the granulometric composition of the coarse fraction of CWS: 38 % – particles sized 50–100 μm, 30 % – 100–200 μm, 24 % – 20–50 μm, 8 % – less than 20 μm.

The fine fraction of CWS is mainly represented by particles sized 5–20 μm (48 %) and 20–50 μm (12 %). Particles sized 0.5–5 μm account for the remaining 40 % of their total quantity, with the distribution of such particles being almost uniform and ranging from 6 to 10 % (Figure 3).

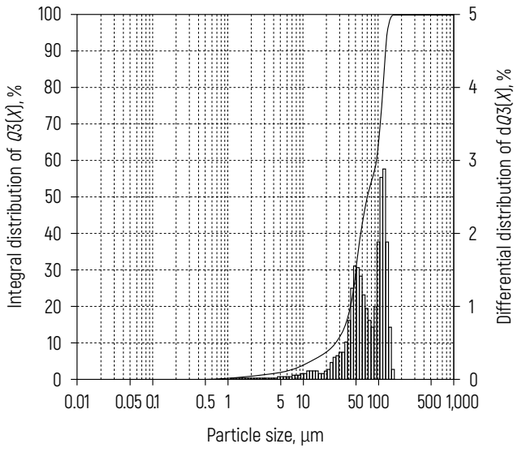

Figure 2 – Integral and differential particle size distribution of coarse fraction of CWS

Figure 3 – Integral and differential particle size distribution of fine fraction of CWS

It was experimentally established (Figure 4) that reducing the mass fraction of coal from 46 to 40 % allowed the dynamic viscosity of CWS to decrease from 10 to 5.5 Pa·s at a shear rate of 13.5 s^{-1}. This indicates that preparing CWF solely from the fine fraction is impractical, as achieving the required rheological characteristics (no more than 1–2 Pa·s at a shear rate of 13.5 s^{-1}) necessitates reducing the mass fraction of the solid phase to below 40 %.

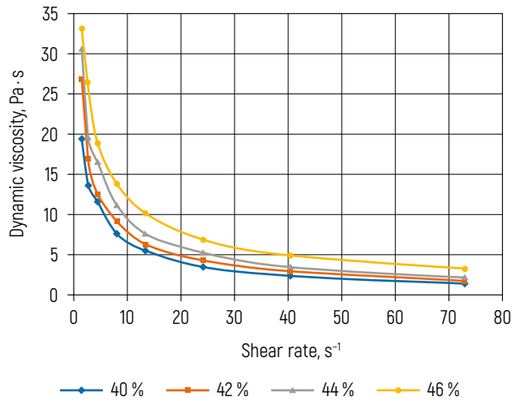

Figure 4 – Rheological curves of dynamic viscosity dependence on shear rate at changing mass fraction of fine fraction of CWS

Moreover, it is impractical to use only the coarse fraction separately from the fine fraction for preparing CWF, due to the following factors:

- low sedimentation stability (separation occurs within a few minutes);
- high dynamic viscosity (from 10 Pa·s at a shear rate of 13.5 s^{-1});
- insignificant content of the coal solid phase.

Incorporating a coarse fraction of CWS into a fine one in various ratios allows for a reduction in dynamic viscosity from 10 to 1.6 Pa·s at a shear rate of 13.5 s^{-1}, while simultaneously increasing the content of the coarse fraction in the solid phase to 70–80 % (Figure 5).

Experimental data revealed that the highest stability is exhibited by CWF samples without any addition or with up to 30 % of the coarse fraction (of the total solid phase mass). However, such samples are characterized by high dynamic viscosity (Figure 5). Introducing more than 30 % of the coarse fraction deteriorates stability indicators, and more than 80 % leads to the formation of a dense, hard-to-mix sediment within the first 12 h.

Figure 6 presents the results of the dependence of sedimentation stability of CWF samples on sedimentation time at various contents of the coarse fraction of CWS.

It has been established that the dynamic viscosity of the studied samples of CWF decreases with an increase in the number of particles sized 50–100 μm as well as with the expansion of the range of the smallest and largest

particles in the dispersed system. This is due to the more compact structure of the system, as the small particles fill the voids between the larger ones and displace the liquid, leading to improved flowability of CWF and an increase in the solid phase content. Thus, by adjusting the granulometric composition of CWF, it was possible to reduce the dynamic viscosity of the samples by six times.

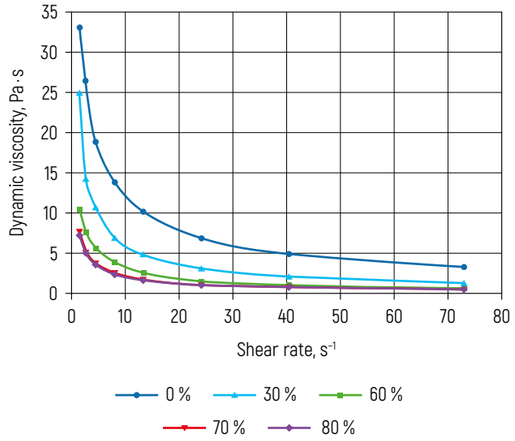

Figure 5 – Rheological curves of dynamic viscosity dependence on shear rate at changing mass fraction of coarse fraction of CWS

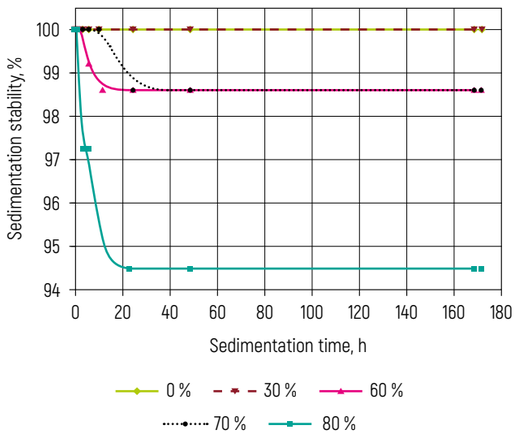

Figure 6 – Dependence of sedimentation stability of CWF samples on sedimentation time at various contents of coarse fraction of CWS

Experimentally, a formulation for the preparation of CWF was developed, meeting the requirements for the mass fraction of the solid phase (coal content 46 %), dispersion composition (70 % coarse (less than 200 μm) and 30 % fine (less than 50 μm) fractions), rheological properties (dynamic viscosity not more than 2 Pa·s) and sedimentation stability (more than five days). This information formed the basis for the development of the principal technological scheme for the production of CWF.

Technology of CWF Production Using EHDE

Main stages of CWF production (Figure 7):

- preliminary processing of the raw material (brown coal). At this stage, it is necessary to separate the raw material from coarse and metallic inclusions. Additionally, the raw material may be enriched, dried, etc.;
- one- or two-stage grinding of coal in an aqueous medium, resulting in the formation of CWS. The first stage involves coarse grinding in a mill, and the second stage involves fine grinding. This method optimizes the granulometric composition of CWS and positively affects the dynamic viscosity of CWF;
- final stage: obtaining CWF by introducing stabilizing or plasticizing additives.

Figure 7 – Main stages of CWF production

The principal technological scheme for CWF production using EHDE is presented in Figure 8.

From the raw material hopper 1, after passing through the magnetic separator, the coal is fed together with water into the EHDE discharge chamber 3 using the screw feeder 2, where it is ground, resulting in CWS. Then, CWS moves through the classifier 4 and the clarification system 5, where the suspension is separated into coarse and fine fractions. The fractions are then discharged into the storage tanks 6, from where, after checking the dispersion composition of CWS, they are directed in the required proportion to the reactor for CWF production 8. Water is added here if necessary. The circulation of liquid in EHDE is carried out by the centrifugal pump 7.

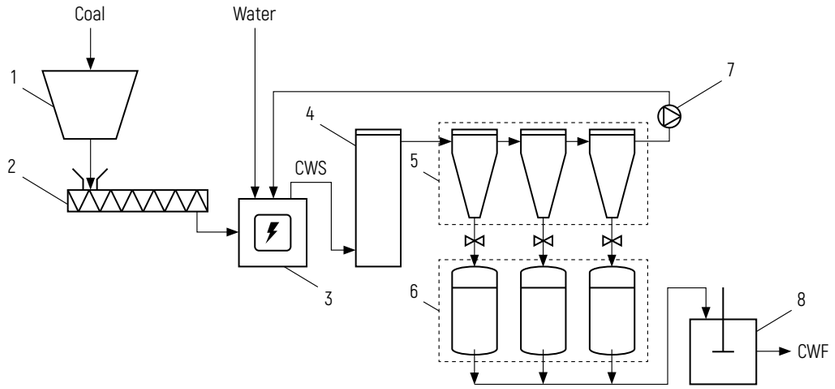

Figure 8 – Basic technological scheme for CWF production:
1 – raw material hopper; 2 – screw feeder; 3 – EHDE discharge chamber; 4 – classifier;
5 – clarification system; 6 – CWS storage tanks; 7 – centrifugal pump; 8 – reactor for CWF production

Conclusion

To implement the EcoSpace program within the framework of obtaining energy and biohumus in the Equatorial Linear City for the needs of the General Planetary Vehicle and the ISN "Orbit" (in the future – up to a billion tons annually), it is proposed to use such natural raw material as coal, of which planetary reserves are sufficient.

The study demonstrates the possibility of using EHDE to obtain CWF, highlighting the main advantages of the electrohydraulic effect. The presented data have been confirmed by scientific research conducted in 2022–2024 on the experimental modernized UniThorr 2 unit designed by the employees of Unitsky String Technologies Inc.

A technological scheme for CWF production using the electrohydraulic effect was developed experimentally, revealing the relationships between the technological parameters of CWF and determining the optimal fuel composition.

Further research will focus on improving the CWF formulation and determining the impact of the natural characteristics of raw materials on its technological properties. Experiments with oil shale as an alternative to brown coal are planned.

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Optimization of Per Capita Energy Consumption by Technogenic Civilization in Planet Biosphere

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The industrial component of the energy capacity of the Earth's civilization is approximately 2.6 kW/person at the present time. Herewith, the biological component of human energy capacity, which comes from food and is solar energy (mainly through photosynthesis in the Earth's biosphere) is only about 0.15 kW/person and has remained relatively stable over millions of years of evolution. This is almost 20 times less than the actual industrial component of the specific energy capacity of modern humanity.

The authors have proposed a system of recommendations for optimizing per capita energy consumption on planet Earth based on available technologies. The tools used in the development of these recommendations and presented in the article are as follows:

- **features of the use of energy-saving technologies and renewable energy sources in urbanism, transport, power industry, agriculture, particularly, natural solar energy for the biosphere and its relict hydrocarbon storage;**
- **phased removal of the most dangerous part of the Earth's industry into equatorial orbits through the large-scale introduction of near-Earth space exploration technology based on a geocosmic aircraft – the General Planetary Vehicle;**
- **improving the level and quality of life of each person by the implementation of the living standards of a new generation, formed not on the cult of consumption but on new philosophical, spiritual and moral aspects and a thrifty attitude to the use of limited earthly resources, including energy.**

Keywords:
biohumus, biosphere, ecology, energy consumption, limited resources, specific energy capacity of humankind, technosphere, Unitsky String Transport (uST).

Introduction

The survival and progress of human civilization are inseparable from energy consumption, which serves as a fundamental driver of life and development for individuals and societies. Today, the global average energy consumption per capita is approximately 2.6 kW/person [1, 2], and this figure continues to rise, which has an adverse impact on the Earth's ecology. For instance, the combined energy consumption of the five leading global economies (USA, China, Russia, India and Japan), which contributed 53 % to global GDP in 2022 [3], grew significantly over the past decades. In 1990, their energy consumption totaled 4,384 mln tons of oil equivalent, increasing to 8,210 mln tons in 2022 [4] – an 87.3 % rise.

During the same period, the population of these countries increased from 2,554.5 mln in 1990 to 3,466.8 mln in 2022 [5], representing a growth of 35.7 %. This indicates that the growth rate of specific energy consumption in these nations has outpaced population growth by nearly 2.5 times over the past 32 years.

These figures underscore the connection between rising energy consumption and improvements in living standards of each person.

Some of the key energy challenges facing humanity, contributing to this trend, include [6]:

- depletion of primary energy resources due to their exhaustibility and uneven distribution across the planet;
- environmental degradation;
- persistent conflicts over limited resources.

The current specific energy consumption (approximately 2.6 kW/person) is directed toward:

- improving the quality, comfort and safety of civilization's functioning, including the production of food for humans and animals; heating, cooling, ventilation and lighting of dwellings; powering household and service equipment; etc.;
- supporting the industrial production of Earth's technocratic civilization on an ever-growing scale, such as metallurgy, chemical and petrochemical production, engineering, construction, etc.;
- catering to excessive information demands, including illuminated advertising, nighttime urban and road lighting; cryptocurrency mining; production and consumption of excessive advertising content across the internet and mobile communications; etc.

At the same time, the biological component of human energy consumption derived from food – which is solar in origin, primarily through photosynthesis in the Earth's biosphere – is approximately 0.15 kW/person [1]. This figure is nearly 20 times lower than the current specific energy consumption of the global population. Consequently, the remaining 2.45 kW (a figure that reaches up to 10 kW in some highly developed countries) represents the energy each individual, on average, requires to sustain modern civilization. This includes the technosphere's exploitation of the biosphere. Thus, achieving a balance in energy consumption (quantitatively, structurally, etc.) that enables the harmonious development of humanity has become an urgent challenge.

Need for Energy Generation by Humanity to Develop Modern Civilization

The development of civilization today directly depends on the amount of energy consumed or the average annual per capita energy capacity. For people, reducing energy consumption while keeping existing technologies unchanged (η = const, Figure 1) would imply a rejection of ever-increasing living standards and consumer desires. Such a scenario is unlikely to be embraced by humanity in the near future.

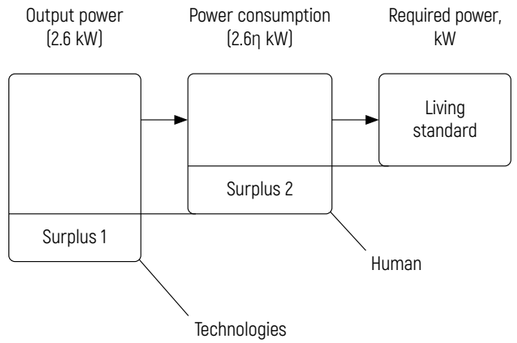

Figure 1 – Stages of reducing energy capacity for humans:
η – efficiency factor of energy conversion and delivery

For this reason, it is fundamentally important to improve efficiency – particularly in terms of environmental impact – and promote the rational consumption of generated power per person. This involves reducing surpluses in human energy consumption.

To minimize the excessive environmental impact of our civilization, it is crucial to identify ways to reduce these surpluses.

This can be achieved through advancements in energy production and delivery technologies (surplus 1) and changes in human consumption patterns (surplus 2). Such efforts would undoubtedly contribute to enhancing the average per capita energy efficiency on Earth.

Ultimately, the focus is on reducing overall energy consumption (Figure 1) as a result of the following:

- energy-efficient technologies in energy generation (left rectangle): enhancing power plant efficiency factor, minimizing transportation costs for fuel and raw materials, transitioning to alternative fuels and other measures;
- energy-efficient technologies for energy consumption (center rectangle): reducing energy transportation costs by promoting rational settlement patterns and locating energy-intensive industries near energy sources, among other strategies;
- new standards of living based on the efficient use of energy by individuals (right rectangle): ensuring that energy consumption is driven by creativity and purposeful activity, not the other way around.

To date, certain prerequisites and progress in this direction have already been noted [7], driven by the development of innovative technologies in energy generation, transportation and use. However, further improvement is needed. One of the key tools for achieving this goal is the gradual relocation of the most hazardous components of Earth's industry beyond the planet, as emphasized in this paper.

The proposed tools should be applied alongside efforts to simultaneously improve the level and quality of life for each individual, through the achievement of new-generation living standards. These standards should be based not on the cult of consumption, but on new philosophical and spiritual-moral principles, with a careful attitude toward the Earth's limited resources.

Estimating Global Energy Consumption and Energy Resources

Currently, fossil hydrocarbon fuels (coal, oil and gas) dominate global energy consumption, accounting for 160,764 TW·h, or 20,227 kW·h per capita, by the end of 2022. These fuels make up more than 80 % of total global energy consumption. Besides, the share of renewable energy sources (RES), such as solar and wind energy, is less than 10 %.

The structure of global energy consumption sources by the end of 2022 is shown in Figure 2.

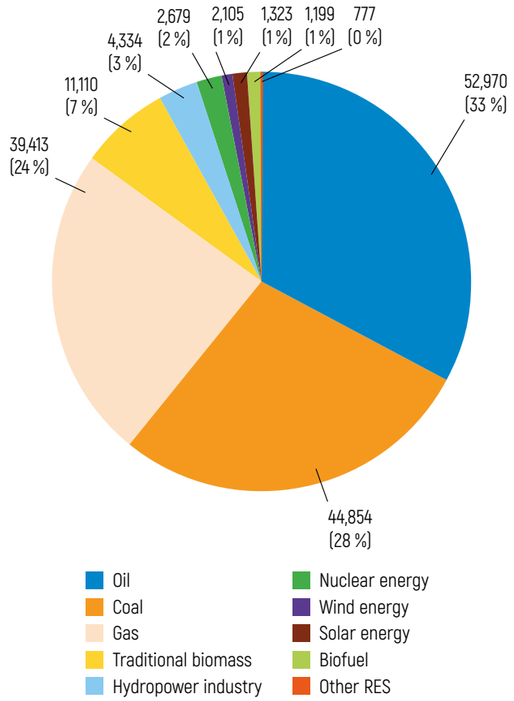

Figure 2 – Structure of sources of energy consumption by humanity by the end of 2022, TW·h (%) [7]

Finding a way to optimize global per capita energy consumption is inextricably linked to understanding the directions of energy use indicated in Figure 2. Let us represent energy production and main energy consumption as a diagram (Figure 3).

On the one hand, according to expert estimates [8], by 2050 the imbalance between fossil fuels and RES is projected to shift towards equilibrium. The article takes this assumption into account. However, the transition to RES on such a large scale is only possible with large-scale space exploration and the relocation of the environmentally harmful components of Earth's industry beyond the planet [9].

On the other hand, by 2050, in the baseline scenario, global energy consumption is expected to increase by more than 40 % [10]. Considering the global population forecast (about 10 bln people by 2050 [11, 12]), an average per capita energy consumption of approximately 24,000 kW·h/year is anticipated, which corresponds to an average per capita capacity of 2.74 kW/person.

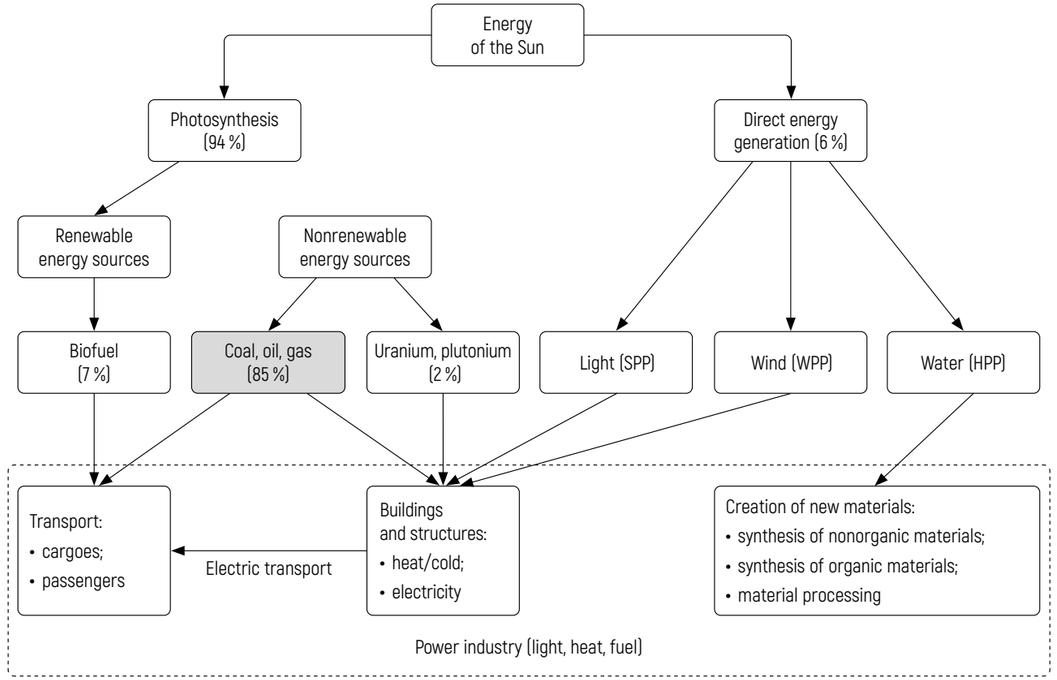

Figure 3 – Structure of the main energy production and distribution systems for the technosphere on Earth

In this regard, the first tool for optimizing global per capita energy consumption proposed and studied by the authors is the application of energy-saving technologies and RES in the key sectors of the global economy: urbanism, transport, power industry and agriculture.

Optimizing Global Per Capita Energy Consumption Based on Application of Energy Saving Technologies and RES

As a result of the analysis of the scientific sources listed in this paper, it was found that the most comprehensive, well-founded and thoroughly considered processes are presented in the doctrine of engineer A. Unitsky on rebooting the economy toward the biospheric path of the civilizational development. This approach primarily focuses on the deep transformation of the core sectors of the world economy [1, 9]. The mentioned global integrated approach includes biosphere engineering technologies, as shown in Figure 4.

As part of the research, each of these areas is not examined in detail, as they have already been studied, scientifically proven and presented in the works of A. Unitsky. However, it is important to highlight a number of aspects.

Improving Energy Efficiency in Fuel Choice

According to the data shown in Figure 2, one of the main sources of global energy generation is coal (about 28 %), primarily steam coal, which is less ashy and currently the most environmentally harmful type of fuel. Modern coal combustion technologies can be compared to using oil in internal combustion engines instead of gasoline or diesel, as this results in the emission of even more diverse chemical elements and toxic compounds in exhaust gases, further polluting the air, soil and water. In this context, it is crucial to develop planetary-scale technologies that allow coal to be processed into fuel whose combustion does not harm Earth's biosphere (similar to the transition from oil to biofuels). For example, coal can be processed into coal-water fuel (CWF) for widespread use, as reflected in [13].

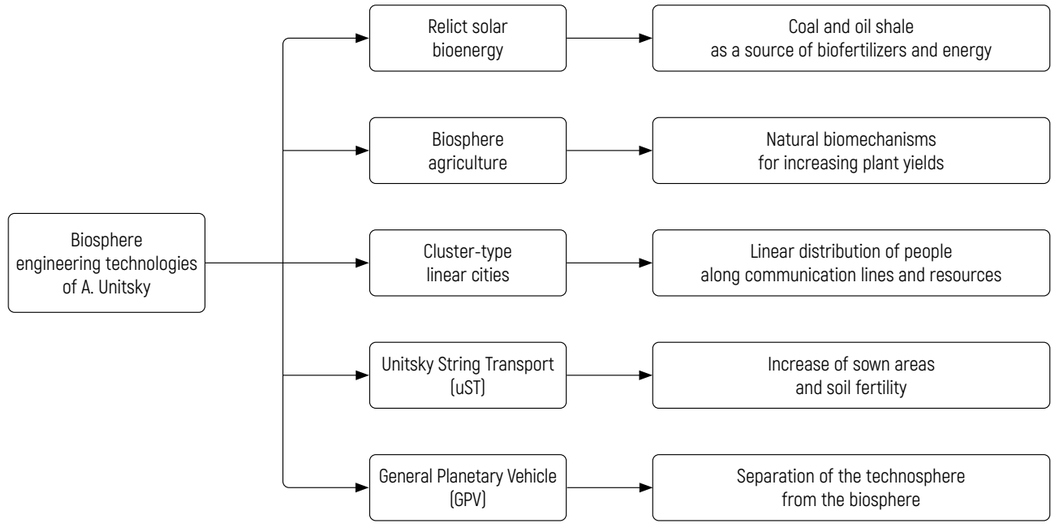

Figure 4 – Classification of biosphere engineering technologies of A. Unitsky

The most promising countries in this area are those with a high share of coal in their energy mix, such as Russia, China, Kazakhstan, Poland and India. The combustion technology for CWF can be applied both independently in new power plants and in conjunction with other fuels during the reconstruction and modernization of existing ones.

Table 1 provides information on the most widespread energy sources for transport on Earth.

As seen, kerosene and diesel fuel have the highest calorific value by volume, which explains their widespread use in the transport sector. However, these fuels are derived from a nonrenewable resource – oil – which makes them unsuitable as a promising energy source. The same applies to gas fuel, the storage of which in liquid form entails additional costs.

The use of charcoal and ethyl alcohol (biofuels) from various plant materials appears highly promising. Although they are slightly inferior to kerosene in terms of specific energy content, they are produced from RES, including the processing of various biological waste materials [14].

The comparative analysis suggests that Earth itself has determined the most suitable element for energy accumulation under biosphere conditions, which is carbon. It also serves as a biological building material, forming the strongest mineral on Earth – diamond. This conclusion is supported by the data in Table 1: butane has a higher energy content than methane and ethane, with a lower carbon content in its composition.

Despite the fact that most electricity is still produced by burning fossil fuels (primarily coal and natural gas), the share of RES has been steadily increasing in recent decades. Since 2007, there has been a downward trend in electricity generation from fossil fuels – from 68.32 % in 2007 to 60.65 % in 2023 – and from nuclear power – from 13.71 % in 2007 to 9.11 % in 2023 (it is worth noting that a similar trend in nuclear power industry has been observed since 2002). Meanwhile, the share of RES generation has risen from 17.96 % in 2007 to 30.24 % in 2023, reflecting an upward trend [15], largely due to developed European countries moving away from using nonrenewable energy sources, such as inexpensive Russian gas and African uranium. As a result, green energy has transitioned from a state-subsidized initiative to combat global warming into a profitable business with clear and acceptable payback periods for the investments made.

Today, RES are proposed as local energy generation sources for regions where this type of energy is most abundant (solar, wind, river, marine, geothermal). This will reduce the cost of transporting energy from RES, as increasing their share involves several challenges related to the significant negative environmental impacts of the technosphere (mining of iron, copper, aluminum, nickel, cobalt, lithium, rare earth metals as well as the disposal of various wastes) [16]. These challenges still need to be tackled.

Table 1 – Comparative analysis of widespread energy sources for transport

Energy storage for transport	Calorific value		Transportation conditions on Earth
	MJ/kg	MJ/m^3	
Butane (C_4H_{10}), μ = 58.1 g/mole	47.29[1]	114.27[2]	Normal conditions
		118.53[3]	Liquid phase (–0.5 °C)
		23,940	Under 20 MPa pressure
Propane (C_3H_8), μ = 44.1 g/mole	47.2[1]	86.53[2]	Normal conditions
		91.14[3]	Liquid phase (–42.1 °C)
		18,500	Under 20 MPa pressure
Ethane (C_2H_6), μ = 30.1 g/mole	47.87[1]	59.85[2]	Normal conditions
		63.35[3]	Liquid phase (–88.6 °C)
		16,730	Under 20 MPa pressure
Methane (CH_4), μ = 16 g/mole	50.09[1]	33.41[2]	Normal conditions
		35.76[3]	Liquid phase (–161 °C)
		7,400	Under 20 MPa pressure
Hydrogen (H_2), μ = 2 g/mole	128.87[1]	10.8[4]	Normal conditions
		10,070	Liquid phase (–273 °C)
		8,100	Under 70 MPa pressure
For comparison			
Gasoline	43.6[5]	32,625[8]	Normal conditions
Diesel fuel	43.4[5]	36,022[9]	
Kerosene	43.7[5]	36,576[10]	
Hard coal	>24[6]	>19,200[11]	
Wood pellets	>16.5[7]	>9,900[12]	
Charcoal	33.8[5]	27,040[11]	
Ethanol (C_2H_5OH)	30.5[5]	24,705[13]	According to GOST 31369-2021
Lithium	4.5	2,412	Solid phase
Li-ion batteries	0.63	1,714	Solid phase

Notes.

1. Recalculation by density (GOST 30319.2-2015).
2. GOST 31369-2021, Table 2.
3. Artikhovich, V.V. Szhizhennyye uglevodorodnyye gazy [Liquefied Hydrocarbon Gases]: Study and Methodical Manual / V.V. Artikhovich, M.G. Pshonik. – Minsk: BNTU, 2010. – 220 p.
4. GOST 3022-80.
5. TCP 130-2008, Tables B1, C1.
6. GOST 25543-2013.
7. GOST 33103.2-2017.
8. Recalculation by density (TU BY 400051902.022-2019).
9. Recalculation by density (STB 1658-2015).
10. Recalculation by density (TU BY 400091131.005-2009).
11. Density of bulk coal is 800 kg/m^3.
12. Recalculation by bulk density (GOST 33103.2-2017).
13. Recalculation by density at 98 % (FS.2.1.0036.15).

Improving Energy Efficiency in Transport

The use of pipeline transport will significantly reduce the transportation costs of CWF compared to rail and road transport. This, in turn, will contribute to a substantial reduction in energy delivery expenses, particularly for coal. For instance, transportation costs account for 60 % of the price of Kuzbass coal in China.

Moreover, approximately 30 % of all energy consumption is attributed to transport [17]. For over 100 years, oil has been the primary energy source for this sector, accounting for 79 % of energy consumption [18]. Its share in the total energy consumption of the technosphere stands at 1/3 [19, 20].

Considering that motor transport fuels (gasoline and diesel) constitute an average yield of 75 % from oil refining, and with global oil production reaching 5.95 tln l annually in 2023, land transport plays a significant role in energy consumption. According to [21], land transport accounts for 28 % of global cargo transportation (110 bln tons annually) and 82 % of passenger transportation (1 tln passengers annually). Consequently, the annual fuel consumption for land transport can be estimated as follows:

$$V = 5.95 \times 10^{12} \times 0.75 \times 0.79 \times (0.28 \times 110 + 0.82 \times 100) / / (110 + 100) = 1.9 \text{ tln l, or 238 l/person a year.}$$

According to the methodology outlined in [22], the specific energy required for passenger and cargo transportation varies from 0.06 to 0.7 kW·h/(t·km), depending on the mode of transport. The implementation of advanced transportation technologies, such as uST solutions (including applications in outer space), could significantly enhance the energy efficiency of both terrestrial and geocosmic logistics [23]. For example, reducing this specific energy capacity by half – through minimizing motion resistance, improving fuel-to-mechanical energy conversion efficiency and enhancing fuel quality – could save up to 1 tln l of motor fuel. This is equivalent to 10×10^{12} kW·h of energy, which corresponds to an average annual power reduction of 1.14×10^{9} kW, or 0.14 kW/person.

Improving Energy Efficiency in Operation of Buildings and Structures

Reducing energy consumption in building operations primarily involves minimizing the energy required for heating, air-conditioning and lighting (both indoor and outdoor).

Currently, numerous concepts have been proposed by scientists to enhance energy efficiency in buildings and structures [24]. An analysis of these concepts suggests that structuring the proposed solutions into blocks, as shown in Figure 5, can improve clarity.

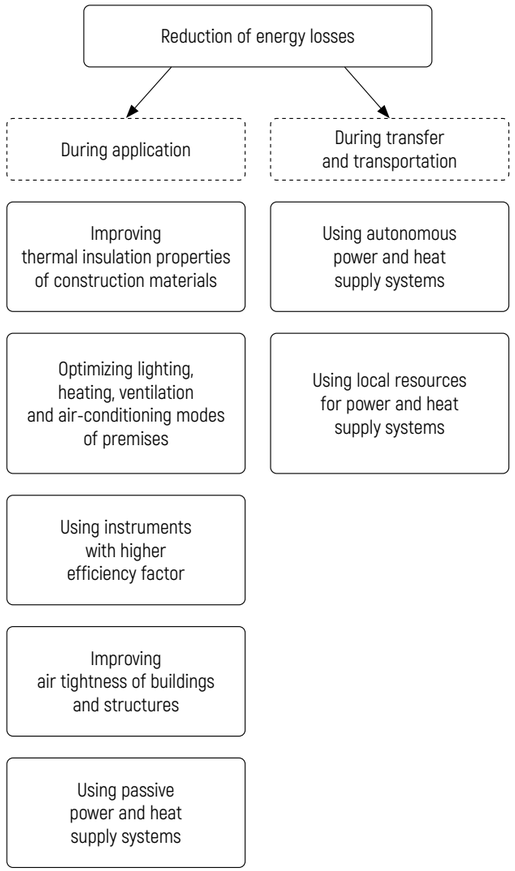

Figure 5 – Energy-saving solutions for operation of buildings and structures

The approaches to reducing energy losses in buildings and structures, as illustrated in Figure 5, are being actively developed in many countries worldwide. However, a general observation suggests that these efforts often lead to indirect savings. Energy savings typically involve the use of more energy-intensive materials (e.g., aluminum and copper), which may not result in a net reduction in overall energy consumption.

It is proposed to explore biospheric mechanisms of energy efficiency – such as studying the natural energy-saving behaviors of bees, ants and other organisms – which could serve as a foundation for future research.

Improving Energy Efficiency in Materials Creation

The development of the technosphere is inherently tied to the production, processing and utilization of materials, including artificial ones. By 2050, the annual per capita resource consumption is projected to reach approximately 13.6 tons [10]. In 2010, material production accounted for an average of about 25 % of the Earth's total energy consumption [2]. If this proportion remains constant, up to 0.68 kW out of the projected 2.74 kW per capita energy capacity by 2050 will be allocated to this process.

Table 2 provides a summary of energy consumption associated with the production of structural materials, based on data from [25].

Table 2 – Energy costs for materials creation

Material	Energy, GJ/t
Wood:	
• raw	0.5
• planed	3.5
• laminated	5–12
Chipboard	3–7
Plywood	7–15
Natural stone	0.5–2
Cement	3.5
Glass	7
Steel:	
• from ore	26
• from scrap metal	6
Aluminum	175
Plastic:	
• from standard raw materials	50–116
• from waste	25–45

According to Table 2, we can conclude that recycling minimizes energy consumption for obtaining materials because the raw materials already contain a portion of the previously spent energy. At the same time, it is possible to reduce the energy intensity of creating materials and structures through the following measures:

- recycling;
- improvement of production technologies;
- reducing the share of energy-intensive materials (aluminum, PET, etc.) and increasing the use of natural materials produced by biospheric "factories" rather than artificially created energy-intensive enterprises of the technosphere;
- decrease of the consumption of structural materials by optimizing the designs of buildings and structures, roads, vehicles, equipment, units and parts across all sectors of the global economy.

For instance, the use of prestressing and string rails in transport overpass designs has reduced material consumption (steel, reinforced concrete and concrete) by approximately 7–10 times compared to conventional overpasses. Simultaneously, the optimization of uST rolling stock – unpiloted rail electric vehicles on steel wheels – has increased transportation energy efficiency by 3–5 times.

In material production, priority should be given to leveraging the "enterprises" and mechanisms of the biosphere, which use natural processes to create basic semifinished products for further applications. For example, Scandinavian countries demonstrate effective practices by maximizing the use of local raw materials (wood) in construction and energy production. In contrast, adhering to universal construction standards across the Earth will inevitably lead to excessive energy consumption for material production and transportation.

Optimizing Per Capita Energy Consumption by Phasing Out the Most Hazardous Part of the Earth's Industry Outside the Biosphere

Engineers and humanity as a whole should focus on utilizing biospheric "factories" on Earth, while purely technospheric (anti-biospheric) enterprises should be located outside the biosphere, in near space, forming a space technosphere. To some extent, in addition to relocating harmful (technospheric) industries, there should be a transfer of these industries deep underground (underground technosphere). Considering the global practice of creating underground bunkers, mini-cities and mining industry developments, this approach can be viable.

The biosphere–technosphere mechanism on the example of uST is presented in Figure 6.

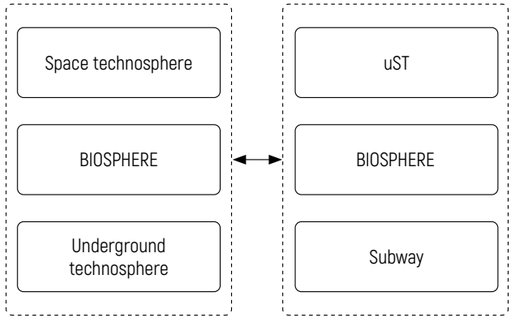

Figure 6 – Biosphere–technosphere mechanism on the example of uST

Thus, the technosphere can be divided into space-based and environmentally safe terrestrial (including underground) components. As technologies advance (in raw material processing, goods and services production, transportation, infrastructure solutions, etc.), the share of the space technosphere will increase. At the same time, the underground technosphere will only partially solve technological challenges, as there are no large cavities underground suitable for industrial use. Excavating significant volumes of soil to create such caves and moving it to the Earth's surface will cause damage to the biosphere.

Furthermore, underground facilities lack the highly efficient technological resources available in near space, such as weightlessness and deep vacuum, which are accessible in unlimited volumes. Underground facilities will also be more material-intensive and costly due to significant stresses from soil and groundwater. It is easier and more efficient to place such production facilities on the Earth's surface. These can be banked with soil, and soil from beneath the foundations of the workshops can be transferred to the second level (for example, on a flat roof) and enriched with biohumus (at least 2 %) created from coal and sewage effluents. Gardens will be planted there, even in areas surrounded by desert. Industries isolated from the biosphere will not only increase the amount of farmland on the planet but also its productivity. Areas currently classified as deserts, which are not involved in biosphere processes or organic food production, will be sufficient to accommodate the terrestrial part of the technosphere, even if the Earth's population reaches 20–30 bln people [1, 9].

This information is depicted in Figure 7, which shows that transporting resources requires energy for the movement of goods and raw materials, both within the technosphere and between the technosphere and the biosphere of Earth.

As part of this study, the main focus is placed on optimizing per capita energy consumption by relocating the most dangerous part of industry outside the Earth through the introduction of space exploration technology using the GPV.

According to [26] and the methodology proposed by the author, the metallurgical industry, chemical production and electrical equipment manufacturing are priority sectors for space industry creation. In the extractive industry, the extraction of metal ores is the most relevant.

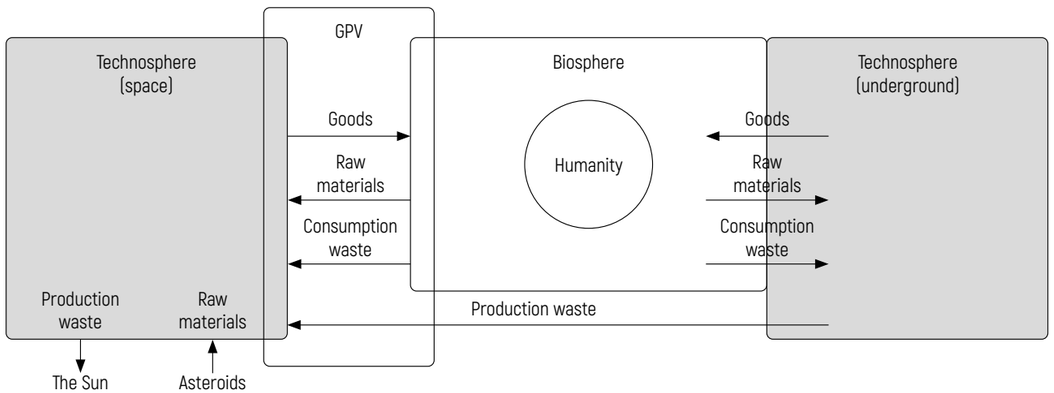

Figure 7 – Resource exchange diagram between Earth's technosphere and biosphere

Thus, the most expedient and logical engineering and technical solution for realizing such a large-scale creation (transfer) of industries outside the Earth and ensuring their subsequent operation is the construction and launch of the GPV [27].

Stages of near-Earth space exploration based on the use of the GPV [28]:

- preparatory stage (from 2025 to 2045–2050);
- basic space industrialization (from 2050 to 2060–2065);
- large-scale space industrialization (from 2065).

As a result, the energy capacities required for producing the most energy-intensive industrial products (metallurgy, chemical production, mechanical engineering, etc.), which are continuously increasing on Earth due to the growth of the industrial (technocratic) part of civilization and population, will gradually be created outside the planet. The portion of Earth's industry that poses the greatest danger to the biosphere will eventually be transferred to space.

The authors of this study do not aim to reduce per capita energy consumption by *n* percent or by *n* times for all of humanity. Similarly, as part of the gradual transfer of the most hazardous industries (manufacturing and extractive production) to space using the GPV, overall human consumption of energy and earthly goods (e.g., by 2065, during the large-scale space industrialization) may not decrease compared to the current value of 2.6 kW/person. However, most importantly, energy production, the manufacture of corresponding energy-intensive products, the emission of harmful substances and their disposal will occur outside Earth, rather than on the planet.

Optimizing Human Energy Consumption Based on Implementation of New Generation Living Standards

Is the human consumer capable of space exploration?

In the global capitalist world, humans are primarily seen as consumers [6], constantly striving to improve their living standard (Figure 1). This leads to an increase in energy consumption by individuals, regardless of the technologies used for energy generation and distribution.

However, this model can function successfully for extended periods if production and utilization cycles in the technosphere are enclosed, i.e., by employing waste-free or low-waste technologies that the biosphere can handle independently. As this approach is not well implemented today, the consumption of technosphere products results in the accumulation of waste and the destruction of the biosphere, which we are currently witnessing. For example, up to 35 % of products purchased by people end up in landfills [29].

The behavior of modern humans is driven by a desire to acquire more goods and services than are necessary. Additionally, this includes the mechanism of self-assertion in society ("He who has more desirable resources is superior!"), which ultimately feeds into the cult of consumption. Consequently, we must ask ourselves the fundamental question: do we want humanity to become merely a tool for the technosphere, consuming and depleting the Earth's biosphere?

At present, Earth appears to be following a clearly negative developmental trajectory (Figure 8).

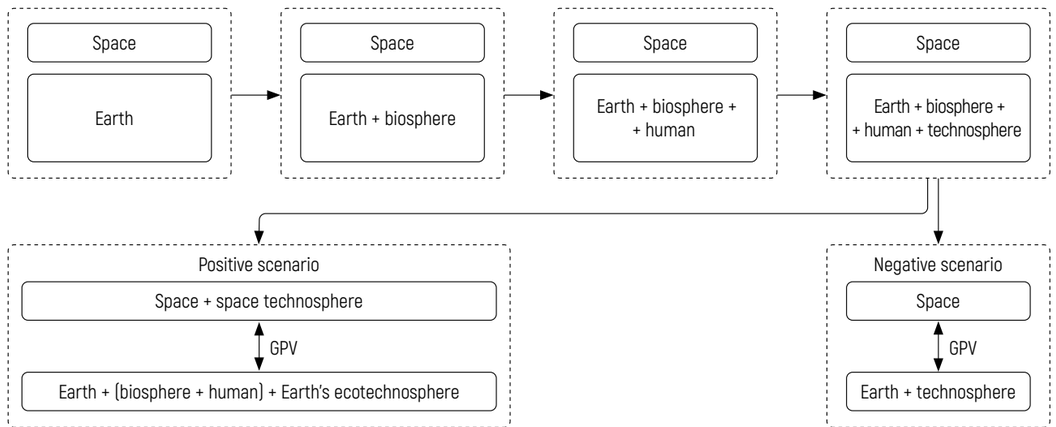

Figure 8 – Stages of Earth's transformation

The technosphere has provided humanity with benefits that have enabled us to rise above nature – allowing us to live longer, move faster, communicate more effectively and receive a wide variety of goods and services in the shortest possible time, often with just the press of a button on advanced smartphones. The technosphere has earned humanity's trust. However, we must not allow it to turn humans into its slaves and, ultimately, destroy civilizational society (the negative scenario).

A positive civilizational scenario is necessary: humans must remain the masters of the technosphere as its creators, not the other way around. This requires that humanity adopt new living standards and take on greater responsibility toward the biosphere. Every individual must become socially responsible and not revert to animal instincts, as is often emphasized in consumer society today.

The Earth's biosphere is already home to natural "factories" that do not need to be built; we only need to learn how to use them. This is one of the primary directions for the development of modern science and human lifestyles. To reduce average per capita energy consumption, we propose transitioning to a new approach to human consumption (Figure 9).

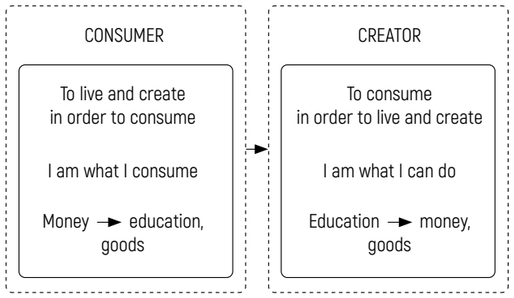

Figure 9 – Concept of a new approach to human consumption

The solutions proposed by the authors as part of implementing the concept of improving the level and quality of life of each person are as follows:

• development of creativity first of all, not consumption. In other words, the center of attraction for people should be schools that enhance an individual's creative abilities, around which retail establishments can be formed, not the other way around. It is necessary to highlight those who have made, organized or created something new and progressive, not a retail product behind which the consumer is visible, not the creator. This will also stimulate the growth of the quality of goods and services and, as a result, help develop the cult of the creator (thereby granting them freedom) rather than the consumer (which leads to slavery), reflected in the reduction of surplus consumed energy capacity;

• maximum use of biospheric "factories" for the production and delivery of goods to consumers. This involves developing key sectors of the economy primarily through the use of biosphere technologies that minimize interference in natural processes and avoid polluting the environment (for example, large-scale use of brown coal in the energy sector, with its processing and waste converted into fertile humus [30]; transforming sewage into biohumus; gradual transition of transport systems to the second level);

• creation of technologies (including transportation) that promote more even settlement across the Earth, redistributing transport, infrastructure and other flows, increasing the efficiency of energy, product and resource delivery, and improving the resource potential of individual regions;

• development and implementation of advanced technologies for an enclosed-cycle consumer goods system;

• innovative and large-scale solutions for the utilization of Li-ion batteries, nuclear waste and waste from mining and heavy industry;

• introduction of educational programs in schools and kindergartens on competent handling of resources and waste, with mass development at the state level of stimulating and administrative-ideological activities as well as educational methods in this area (for example, Sweden, a world leader in processing solid domestic waste into energy, where garbage disposal has been taught in kindergartens for many years) [31];

• formation of a conscious consumption culture in each individual (control over the production and consumption of food, clothing, electricity and water; waste reduction; sorting and recycling of garbage; etc.) [32].

Conclusion

The authors of this study propose the following scientifically developed complex measures to optimize the current global per capita energy consumption (approximately 2.6 kW/person):

• increasing the efficiency of energy use by further mass application of CWF (primarily in countries with a high share of coal in the fuel and energy sector, including Russia), charcoal and ethyl alcohol as biofuels, as well as RES;

• improving the transportation sector through the widespread introduction of second level transport technologies (primarily based on uST), along with the use of pipeline transport for the delivery of CWF due to its economic feasibility;

• increasing the efficiency of energy use in buildings and structures as well as in material production (by recycling, reducing the share of energy-intensive materials, such as aluminum and PET, and increasing the use of natural materials);

• phased removal of the most dangerous part of Earth's industry beyond the planet by 2065 through the construction of geocosmic transport (GPV) and the necessary infrastructure;

• improving the level and quality of life for each person based on the realization of new generation living standards, where the technosphere is subordinated to humans (not the other way around), including training in the rational use of biosphere resources and the transformation of the human consumer into a human creator.

The elements of scientific novelty in this research are as follows:

• argumentation for the necessity not only to apply technologies to increase the efficiency of energy use by humanity but also to change the behavior of the person responsible for their activity (in particular, when positioning goods and services, information about the main developer should be specified first);

• justification for using fuel as an energy storage;

• results of the analysis of energy demand reduction through innovative transport and infrastructure solutions and the production of energy-efficient materials;

• division of the technosphere into two components: space and underground (with their rational use for the benefit of humanity);

• development of technologies to maximize the use of biospheric "factories" in the creation of goods and services by humans.

Thus, the authors of this study propose that the optimization of per capita energy consumption on Earth is not narrowed down to attempts to significantly reduce the current level of consumption on a global scale but is based on more rational energy production and use (including through production and utilization outside the planet) due to a combination of the measures suggested.

The issues considered are global and extremely relevant to the current challenges of humanity; therefore, they will be developed, researched and presented in subsequent scientific works by the authors.

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Prospects of Using Electrical Discharge Technologies in Creation of Enclosed Ecosystems

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The reduction of human civilization's impact on the planet's ecology is impossible without decreasing the amount of chemical compounds used to meet human needs. Electrical discharge technologies can and should become one of the alternatives to harmful substances in various sectors.

This article explores the prospects of these technologies in food production, ranging from the obtaining of environmentally friendly fertilizers, preparation of seeds and processing of agricultural raw materials into final food products to the disposal of liquid and solid household waste, as well as their subsequent inclusion in a closed cycle of eco-friendly fertilizers production in "horizontal skyscrapers" of linear cities on Earth and in the EcoCosmoHouses in orbit.

Keywords:
EcoCosmoHouse (ECH), electrical discharge technologies, electrohydraulic discharge equipment, electrohydraulic effect, electrohydraulic shock, environmentally friendly technologies, Equatorial Linear City (ELC), Industrial Space Necklace "Orbit" (ISN "Orbit"), ozone, ozone technologies.

Introduction

Engineer A. Unitsky has developed the concept of constructing the Industrial Space Necklace "Orbit" (ISN "Orbit") – a multi-orbital transport, infrastructure and industrial-residential complex encircling the planet along the equatorial plane at an altitude of 400–500 km. This facility is designed to serve humanity on Earth from outer space. It will act as a functional equivalent of the Equatorial Linear City (ELC), a platform for countering space threats, including meteorite impacts, and a technological base for the expansion of Earth's civilization into deep space [1–3].

The structure of ISN "Orbit" is planned to include EcoCosmoHouses (ECH), which represent enclosed biosphere-type ecosystems providing all residents with balanced nutrition and clean drinking water [4–7]. In such conditions, there is a pressing need to create systems with complete life-support cycles – supplying people with food, water, oxygen and more.

At the current stage of technological development, many challenges are addressed using various chemical compounds, whose reaction by-products pollute the environment and pose health risks. Electrical discharge technologies allow for either eliminating the use of such substances or significantly minimizing the harmful consequences of their application.

The concept of "horizontal skyscrapers" in linear cities on Earth (including in the ELC) and the ECH in orbit implies a significant decentralization of many production processes and the creation of closed-loop ecosystems. In this context, environmentally clean technologies become a priority.

Electrical discharge technologies can and should find wide application in various industries, medicine, agriculture and environmental protection. This is due to the possibility of developing relatively compact, highly efficient units that support decentralized production processes.

These technologies are based on the transformation of low-temperature, nonequilibrium discharge plasma in various dielectrics or semiconductors, enabling the conversion of energy into phase transitions, chemical reactions, mechanical work and other forms. A key feature is the directed delivery of high-density energy to the object processed in a pulsed mode, ensuring rapid changes in the thermodynamic and physical properties of matter. The impact of electrical discharge technologies on materials is complex: it includes intense electromagnetic radiation ranging from ultraviolet to radio frequencies, electric fields fluctuating up to 10^{10}–10^{11} V/ms, high-energy atoms, charged particles (electrons, ions), as well as shock and acoustic waves. Due to the nonequilibrium nature of the processes, the effect is synergistic – the interaction energy exceeds the sum of individual contributing factors [8].

The development of electrical discharge technologies is of great interest to specialists across multiple fields. This article does not aim to cover all possible applications and trends. Its objective is to examine the most promising directions for applying these technologies in the "horizontal skyscrapers" of linear cities on Earth (including in the ELC) and the ECH in orbit. In the authors' view, particular attention should be paid to technologies involving electrohydraulic discharge equipment (EHDE) and ozone.

Figure 1 illustrates the potential of electrical discharge technologies in developing enclosed systems with full life-support cycles – including the production of eco-friendly fertilizers, cultivation of crops and livestock, storage and processing into food products, and neutralization of organic household and industrial waste, followed by its reuse in fertilizer production within a closed cycle.

Technologies Involving EHDE

The use of EHDE in industry is highly diverse [9]. More than 35 applications are known across various fields, including mechanical engineering, mineral extraction, construction, mining, medicine, agriculture, energy and environmental protection. Other applications include material fragmentation (nonmetallic materials, cullet, ferromagnets, plant waste, peat, gemstones), ore beneficiation, extraction of residual valuable minerals from waste dumps, demolition of various structures (rock masses during road construction, reinforced concrete structures, foundations, ice, permafrost), mechanical activation of construction materials, solution mixing, surface cleaning, water disinfection, soil fertility enhancement and more.

EHDE can be a promising alternative to traditional methods of grinding and disinfection in the creation of closed-loop systems intended for implementation in ECH. A simplified electrical diagram is presented in Figure 2.

The operating principle of the unit is based on the electrohydraulic effect (Yutkin effect), which involves converting electrical energy into mechanical energy with high efficiency factor. This occurs when a specially formed pulsed electrical discharge passes through a volume of liquid, generating extremely high impulse pressures around the discharge zone. These pressures are capable of performing mechanical work and are accompanied by a complex of physical and chemical phenomena [9].

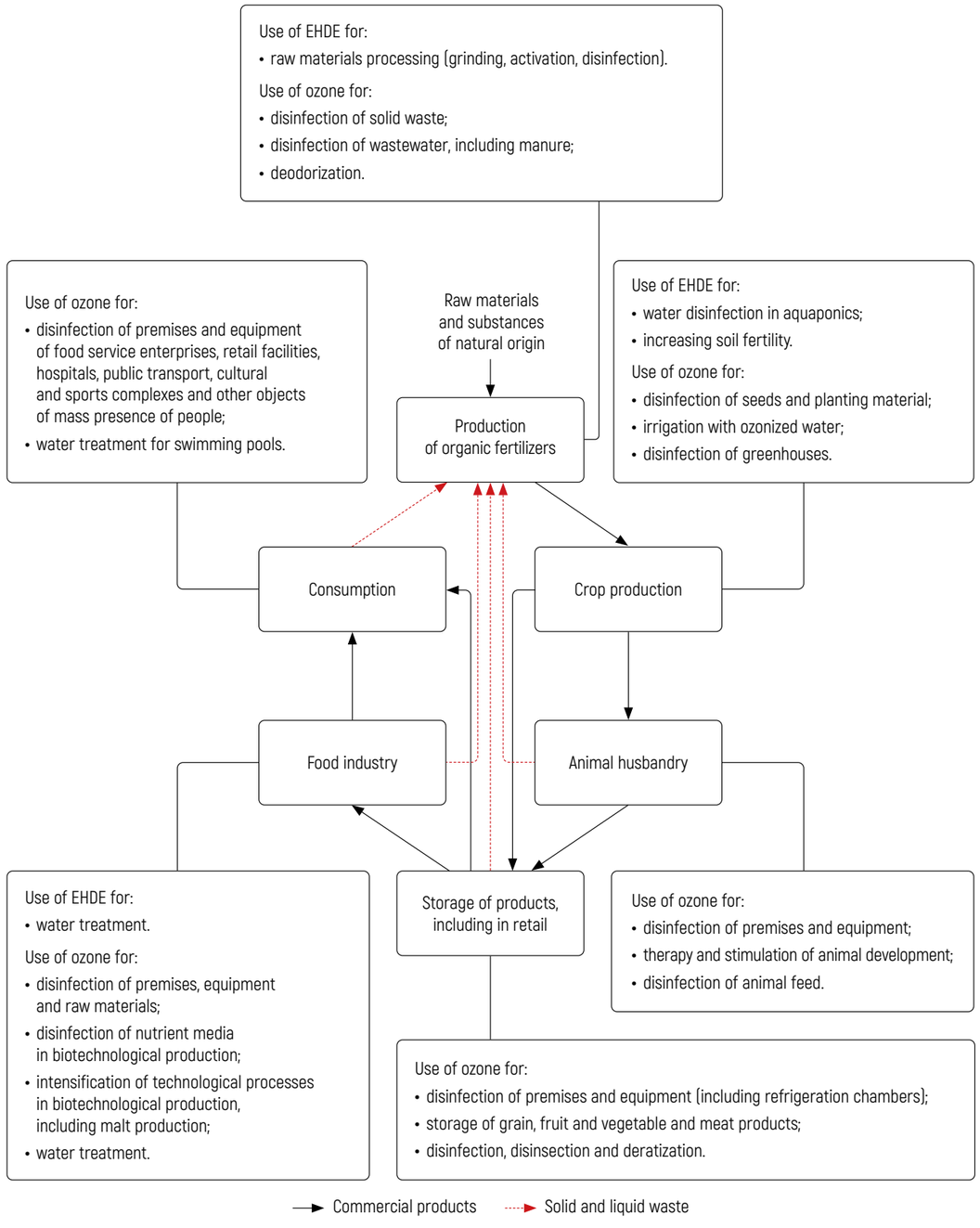

Figure 1 – Organic matter cycling within a closed system

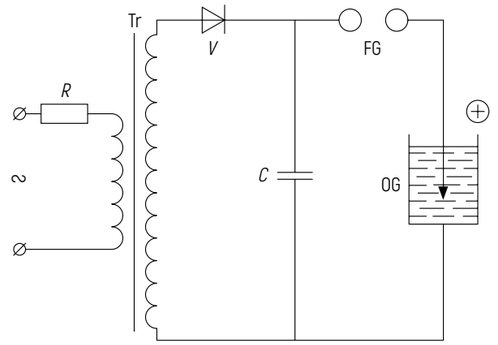

Figure 2 – Simplified electrical diagram of the EHDE:
R – charging resistance; Tr – transformer; *V* – rectifier;
FG – forming spark gap; OG – operating spark gap;
C – operating capacitance of condenser

One of the key advantages of using electrohydraulic shock technology in space development is its environmental friendliness, due to the absence of additional chemical substances and by-products.

In exploring possible applications of EHDE within the enclosed ecosystem of ECH, the authors have examined three directions related to providing people with food and water [10]:

- using EHDE to grind natural materials, particularly brown coal, as a component of lightweight soil substrates for plant cultivation;
- disinfecting water after wastewater treatment, which, depending on quality, can be used for domestic and industrial needs, irrigation and more;
- use in closed-loop systems for aquaculture, such as fish farming.

The studies were conducted using the UniThorr EHDE (Figure 3), developed by staff at Unitsky String Technologies Inc. (Minsk, Belarus). Based on the results obtained, modifications to traditional schemes for producing soil substrates, treating wastewater and managing aquaculture water were proposed [10].

Ozone-Based Technologies

A wide range of ozone-based technologies is implemented using electrical discharge units that generate ozone from air or pure oxygen. One of the possible basic circuit diagrams of an electrical discharge ozone generator is shown in Figure 4.

Figure 3 – The UniThorr EHDE

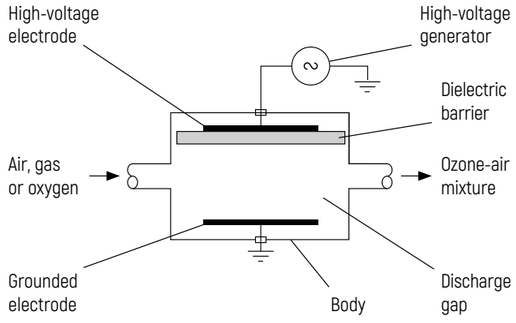

Figure 4 – Schematic diagram
of an electrical discharge ozone generator

Ozonation is one of the methods of electrical discharge technologies that enables various types of treatment – such as deodorization, disinfection, sanitation and sterilization – of materials, equipment and spaces. Ozone, an allotropic form

of oxygen, is widely used across many sectors: medicine, food and chemical industries, agriculture, utilities, cosmetology and others.

This substance holds a special place among oxidizers due to its high reactivity and rapid decomposition. In terms of oxidative activity, ozone is second only to fluorine and offers several additional advantages:

- environmental safety: the reactions result in stable oxides (and any unused ozone decomposes into atomic and molecular oxygen), which do not pollute the environment or form carcinogenic by-products;
- high effectiveness: compared to traditional agents, such as formaldehyde, chlorine or ethylene oxide, ozone is more efficient in inactivating bacteria, spores, fungi and viruses; it requires shorter contact time and does not lead to bacterial resistance;
- accessibility: ozone generation requires only air or oxygen and electricity, eliminating the need for transporting or storing chemical reagents;
- simple concentration control methods.

The use of ozone for sanitary purposes has been known since the late 19th century, when it was first applied for disinfecting drinking water. In 1886, French electrical engineer A. de Méritens made such an attempt, and 12 years later a water ozonation system was constructed in Paris. In 1906, a larger-scale industrial ozone water treatment project was implemented in Nice. From that point on, this gas began to be actively used in sanitation.

Interest in such technologies remains relevant. This is evidenced by the existence of the International Ozone Association – a nonprofit organization that promotes educational and scientific activities to best meet the needs of industry and the research community in the field of ozone application. Every two years, the association hosts the Ozone World Congress. The 26th Congress was held in July 2023 in Italy [11].

A distinguishing feature of ozone is its rapid action. Due to its high oxidative potential, ozone affects the membrane structures of bacterial, fungal and viral cells, disrupting their barrier functions and ultimately leading to the death of these microorganisms. Ozone causes the destruction of phospholipids in the plasma membrane. The products of ozonolysis formed in this process act as additional agents that damage intracellular structures involved in metabolic processes. The final stage of cytolysis is marked by the release of intracellular stores of autolytic enzymes.

At low ozone concentrations, bacterial growth stimulation may occur.

Given the numerous application areas of ozone technologies, the most significant ones have been selected for potential integration into the life support systems of the ECH and linear cities on Earth, including the ELC.

Ozonation for Waste Disinfection Aimed at Processing into Organic Fertilizers

Today, specialists show significant interest in ozonation both as a standalone method and in combination with other pre- and posttreatment techniques for wastewater. In the food industry and public utilities, such wastewater usually contains organic impurities and can be treated using biological methods, including in combination with domestic sewage.

Numerous studies on the oxidation of various organic pollutants with ozone have demonstrated its effectiveness in treating aqueous solutions containing phenols, formaldehydes, cyclopentane, cyclohexane, tetraethyl lead, naphthenic and sulfonaphthenic acids, cyanides, cresols, nonionic and anionic surfactants, oil, etc. Ozone has a significantly stronger disinfecting capability than chlorine – approximately 15–20 times more effective against common bacteria and 300–600 times more effective against spore-forming organisms. According to [12], the required ozone dose for disinfecting wastewater and treating manure ranges from 500 to 1,000 mg/m^3.

Ozonation for Reducing Microbial Contamination of Premises and Equipment

The bactericidal activity of ozone (averaging 99 %) was confirmed by JSC Yeast Plant (Minsk, Belarus), where tests were conducted on disinfecting tank equipment using ozonation [13]. The experiments showed that treating a 40 m^3 mash tank with an ozone-air mixture for 1 h resulted in the elimination of 100 % of foreign bacteria typical for yeast production. Economic efficiency calculations demonstrated that this technology is 20–30 times cheaper than traditional steam treatment for tank equipment.

Sealed production units used for manufacturing dry products (such as cereals, flour, powdered milk, infant formula, animal feed and others) are difficult to regularly wash, clean and disinfect. Mold quickly grows in areas where moisture or condensation accumulates, forming spore clusters that contaminate products [14]. When microbial counts increase significantly, the equipment must be thoroughly inspected, partially disassembled, mechanically cleaned and disinfected – a labor-intensive process that requires lengthy production downtime.

Sterilization with gases like ethylene oxide or propylene is possible, but afterward, the equipment must be carefully cleaned due to the risk of toxic by-products. Moreover, the effectiveness of such treatment lasts for only about five days, after which microbial contamination gradually increases.

Using a disinfectant like ozone helps avoid these challenges. Thanks to its gaseous form, the ozone-air mixture easily fills treated spaces, evenly distributing throughout volumes of any configuration. Ozone's high penetrating ability enables it to reach pores, capillaries, gaps and cracks.

Ozonation for Pre-Sowing Treatment of Seeds and Planting Material

The use of ozone in agriculture to destroy pathogens and stimulate biological processes during the seed germination stage shows great promise, as it significantly reduces the need for growth stimulants, pesticides, antibiotics and other chemicals harmful to humans [15, 16].

One of the main ways to increase crop yields is through the protection of plants from diseases, particularly from phytopathogens whose spores are localized on the surface of seeds. The most harmful among them are the pathogens of covered smut and root rot, which can cause crop losses of grain crops up to 20–35 %.

Research results show that seed treatment with ozone is effective as a method for reducing surface seed infection and even for the complete elimination of pathogens, such as those causing covered smut. Moreover, ozonation enhances seed germination, increases the length and fresh mass of seedlings and positively impacts several other indicators that ultimately contribute to higher crop yields [17, 18].

Compared to other methods of combating surface seed infection, pre-sowing ozonation of seeds has advantages such as high technological efficiency, sufficient effectiveness against disease pathogens and environmental safety. Additionally, as an oxidizing agent, ozone is capable of destroying mycotoxins. Treating agricultural products with gaseous ozone or ozonated water during storage improves their biological value by breaking down toxins.

Ozonation for Control of Stored Bread Pests

Preserving the harvest of grain crops is a serious challenge, especially in the context of global environmental changes. One of the key issues is the fight against stored bread pests.

According to current data, more than 100 species of storage pests are known, including 34 species of mites, 51 species of beetles, nine species of moths and six species of rodent-like mammals. These pests are highly fertile and capable of rapid reproduction under favorable conditions, quickly reaching significant numbers. Grain damaged by pests can lose up to 50 % of its weight and becomes unsuitable for both sowing and consumption.

Phytosanitary monitoring has revealed that after grain elevators are filled, more than 70 % of seed storage areas and over 73 % of forage product storage areas are infested with storage pests [19].

Numerous studies confirm that ozone is lethal to various species of harmful insects and mites inhabiting grain masses. Its biological activity depends on several factors, including the type of pest, its developmental stage, ozone concentration, exposure time, as well as the temperature and moisture content of the grain.

Some species, such as the rice weevil and the sawtoothed grain beetle, die immediately after treatment. A significant portion of the granary weevil and the confused flour beetle populations also perish instantly, while the rest enter deep paralysis and die by the fifth day [20].

Ozone has a lethal effect on all preimaginal developmental stages of pests (eggs, larvae, pupae), with pupae being the most resistant stage. Since the eggs, larvae and pupae of the lesser grain borer develop inside the grain, where ozone penetration is limited, exposure time must be increased to ensure their complete elimination [21].

Studies assessing the reproductive ability of insects that survived sublethal doses of ozone found that pests in a latent stage of ozone damage do not produce offspring. Observations also show that insects are more vulnerable to the lethal effects of ozone in dry grain compared to moist grain.

Thus, ozonation of grain is an effective and environmentally friendly method for controlling a wide range of pests during grain storage.

Ozonation for Preservation of Fruit and Vegetable Raw Materials

Initial studies on the effect of ozone on fruit preservation focused on its action primarily on the surface, which often contains compounds that are difficult to oxidize. The use of ozone to extend shelf life, especially under low-temperature conditions, was proposed and implemented in specialized refrigeration units as early as 1909. However, further research was needed to better understand the mechanisms of storing fruits and vegetables in ozone-cooled chambers, as all crops require different concentrations of the matter.

Ozone not only prevents the development of mold colonies on storage walls, wooden crates and other packaging materials – which can impart an unpleasant odor to fruits – but also slows down ripening and aging processes by oxidizing ethylene and other metabolites. For example, ozone treatment at a concentration of 4–6 mg/m^3 can double the shelf life of strawberries, raspberries and grapes without compromising their quality.

In addition, ozonation significantly inhibits the development of phytopathogenic microflora on vegetable crops. For instance, contamination of potato surfaces is reduced by 1.5–2 times, and microbial levels in storage air are reduced by 10–12 times, allowing a 5–7 % increase in the yield of standard-grade products without affecting their biochemical and organoleptic properties.

When applying ozone in the food industry, it is essential to consider the characteristics of the products being treated, as raw materials react differently to ozonation. For example, oranges are almost insensitive to relatively high ozone concentrations (up to 80 mg/m^3), while for other crops, such as potatoes, the optimal concentration ranges from 4 to 20 mg/m^3. Exceeding acceptable doses can deteriorate organoleptic qualities. Other factors, such as temperature, humidity, microbial composition and technological specifics, also influence the effectiveness of ozonation.

Thus, the approach to treating fruits and vegetables must be comprehensive and tailored to the specific needs of each crop [22].

Ozonation for Intensification of Drying Processes

The use of an ozone-air mixture during grain drying reduces the duration of the process by 1.2–2 times. At the same time, it provides surface decontamination of the grain (disinfection and disinsection), alters metabolic processes and leads to a slower rate of mass loss throughout the subsequent storage period [23].

Moreover, during the postharvest preparation stage, drying with an ozone-air mixture has a sanitizing effect, improves the quality characteristics of the material, prevents self-heating, ensures a state of deep dormancy, preserves the dry matter mass and enhances germination rates. This, in turn, increases plants' resistance to adverse environmental conditions.

Drying plant raw materials, including medicinal plants, is aimed at slowing down the physicochemical, biochemical and other processes that cause spoilage. However, thermal exposure to raw material components (vitamins, proteins, fats) can cause irreversible changes. To preserve the biological value of medicinal plant raw materials, it is essential to minimize the biochemical drying period characterized by intensified oxidative processes.

The challenges of intensifying heat and mass transfer during drying while preserving biological value can be addressed by replacing traditional drying agents with an ozone-air mixture, which directly influences chemical and biochemical reactions within the material. Ozone triggers adaptive biochemical reactions, changes cell membrane permeability and induces structural transformations of surface tissues. As a result, membrane compression creates a pressure gradient even at room temperature, weakening the moisture bond with the plant raw materials and shifting the process to a lower energy level. The amount of heat required to separate a water molecule is reduced by 20–60 %. Drying in an ozone-air environment also provides decontamination and improves the quality characteristics of the material.

Laboratory and industrial tests have shown that using an ozone-air mixture as a drying agent intensifies the drying process of medicinal plant raw materials by 15–20 %, reducing the time to reach conditioning moisture from 5 to 4 h. This increases dryer productivity and reduces losses of biologically active substances [24].

Ozonation of Meat, Fish and Cheese Products

Modern research confirms the importance of using ozone to extend the shelf life of various food products. As early as 1909, it was discovered that installing an ozonator in a specialized cold storage chamber helped reduce the microbial load on meat. Ozone exhibits a bactericidal effect only on the surface of the product, penetrating only to a limited depth. In a normal atmosphere, significant microbial contamination develops within seven days, whereas in an ozone-rich environment, it appears only after 14 days. To achieve the desired result, daily ozonation for 2 h at a gas concentration of 6 mg/m^3 is recommended. Under these conditions, fresh meat can be stored for up to 40–45 days at a temperature of 20 °C and 85 % humidity [25, 26].

Ozone treatment has also proven effective for frozen beef, where shelf life can be extended by 30–40 % with the concentrations of 10–20 mg/m^3.

Treating freshly caught fish with ozonated water and using ice made from ozone-containing water significantly prolongs its storage life.

Experiments on the application of ozone during the production and storage of cheese have also yielded positive results. Using it at a concentration of 0.04 mg/m^3 at 15 °C and 80–85 % humidity effectively eliminated spores on the surface of the cheese during ripening and extended its shelf life to 11 weeks.

Thus, the use of ozone shows high effectiveness in extending the shelf life of a wide range of food products.

Ozonation in Animal Husbandry

Farm animals often suffer from diseases caused by spore-forming microorganisms, such as salmonellosis, bronchitis and pneumonia. Studies show that air ozonation can be an effective method of prevention and treatment.

Experiments conducted in livestock facilities demonstrated that air ozonation almost completely eliminated bronchopulmonary diseases. Meanwhile, in conventional air environments, spontaneous pneumonia was observed in 40 % of the animals, leading to up to 20 % mortality. In tests where sublethal doses of *Staphylococcus aureus* were introduced, animals exposed to ozonated air did not develop pneumonia, whereas 50 % of those in the non-ozonated control group exhibited severe forms of the disease. It was also found that pulsed-mode air ozonation enchanced the animals' resistance to spore-forming microflora and reduced illnesses caused by feed mycotoxins, resulting in a 5–10 % increase in average daily weight gain [27].

Ozonation also has a positive effect on bee colonies. The best results were achieved at a concentration of 32 mg/m^3 with an exposure time of 24 days. Increasing the number of treatments to 24 sessions led to a 39 % improvement in colony development [12].

Additionally, ozone is highly effective for disinfecting and sanitizing livestock facilities. It destroys microorganisms in the air and on surfaces, including viruses such as African swine fever virus, unlike bactericidal lamps, which cannot guarantee full microbiological safety [28].

Ozonation at Food Industry Enterprises

Decontamination of Nutrient Media for Fermentation Production. In the food industry, the main sources of contamination of nutrient media for fermentation production are raw materials (malt wort or molasses), water and equipment. Due to the high concentration of sugars and solids in malt wort and molasses, microorganisms often exist in a near-anabiotic state. During preparation of the nutrient medium, the solids and sugars content is reduced by half, creating favorable conditions for the development of unwanted microflora. In industrial settings, this issue is usually addressed by adding large amounts of disinfectants (i.e., bleaching powder) or antibiotics to the nutrient medium.

The Belarusian Research Institute of Food Products proposed an environmentally friendly, comprehensive method for preparing nutrient media for fermentation production, based on the disinfectant properties that water acquires through ozonation [29].

The microbiological indicators of nutrient media prepared using this technology are one to two orders of magnitude better than those prepared using bleaching powder solutions. For example, when molasses is decontaminated with ozonated water, the bactericidal effect is observed not only immediately after treatment but also in the nutrient wort after it passes through the production pipelines. Compared to traditional methods, the total yeast count is 52 % lower, wild yeast is reduced by 86 %, lactic acid bacteria by 91.4 % and *Leuconostoc* bacteria by 96 %, with no detection of putrefactive bacteria or molds. Additionally, the acidity of the fermentations did not increase during the process [29].

This technology has been tested at several Belarusian enterprises, including the Yeast Plant, Malinovshchiznensky Distillery – "Akvadiv" and the Berezino Distillery (a branch of Minsk Kristall).

At the Malinovshchiznensky Distillery – "Akvadiv," ozonated water, which retains its aseptic properties, helps reduce contamination of the mash, wort and wash by acid-producing bacteria. The initially set acidity (pH = 6.4) remains stable throughout the technological process for three days, and antibiotic (for example, fricont) consumption is reduced by 50 %.

Decontamination of Food Concentrate Components. According to regulatory acts of the U.S. Food and Drug Administration (FDA), ozone is certified as a disinfectant and sanitizing agent for the agricultural sector. This status was granted because the use of ozone in food products does not lead to the formation of compounds with carcinogenic or mutagenic properties. On this basis, ozone has been recognized as "generally recognized as safe" (GRAS) [30].

The microbiological quality of food concentrates largely depends on the contamination level of their main components. Despite preliminary treatment of the ingredients, the microbial contamination of food concentrates tends to increase significantly during storage. Although spices contain natural antimicrobial substances, they can still be contaminated with high amounts of microorganisms. Sources of raw materials microflora vary. In some cases, such as with ginger, onion, garlic and other products, microbes enter from the soil. Additionally, drying, storage and processing can contribute to contamination, and the degree of hygiene maintained at all stages of production directly influences microbial counts in raw materials. Therefore, additional decontamination of raw materials is necessary to ensure

high product quality. The most effective solution is the treatment of food concentrate components with an ozone-air mixture.

Tests conducted by the authors of this article at OJSC "Lidapischekontsentraty" showed that treating ground food concentrate components with an ozone-air mixture reduced their overall microbial contamination by 41–86 % without altering the organoleptic properties of the products [31].

Water Treatment. Ozone treatment combined with filtration enables the oxidation and removal of complex organomineral compounds and metals (Fe^{2+}, Mn^{2+}, Ag^{2+}, Co^{2+}) from water. At the same time, the mineral composition, alkalinity and acidity of the water remain unchanged. Unlike chlorine, excess ozone does not denature water; on the contrary, it enriches it with oxygen, giving it the taste of spring water. This makes ozone suitable not only for disinfection but also for deodorizing drinking water and removing toxic organic substances [32].

From the perspective of preventing epidemic diseases, the most crucial aspect of improving drinking water quality is its disinfection. Ozone shows high virucidal activity at concentrations of 0.5–0.8 mg/l, which are realistic for water supply processes, with a contact time of 12 min [33].

More than 95 % of bottled water worldwide undergoes treatment with ozone which is approved as a disinfectant by the International Bottled Water Association (IBWA). The experience of its using for disinfecting, decontaminating and deodorizing water in both domestic and international practices highlights its promising application in the liquor, spirits, winemaking and brewing industries, as well as in municipal water supply systems [32].

Decontamination of Molding Starch in Confectionery Production. Using molding starch is one of the most common methods for shaping confectionery products. To maintain its technological properties and prevent contamination of finished goods by microorganisms, spent molding starch must undergo decontamination by thermal treatment in special dryers, which are highly energy-intensive. The use of chemical disinfectants is not permitted, as molding starch directly contacts the confectionery mass during production. At the same time, it is technically difficult to disinfect it with antimicrobial agents.

The best solution to this problem is the use of an ozone-air mixture, which reduces the overall microbial contamination of spent molding starch by 75 %, with a penetration depth of 3 cm. Its techno-chemical properties as a molding material change only slightly: moisture content varies within 1 %, and acidity increases by an average of 1.1 °T [34].

Ozone in Malt Production. Malt is widely used in the food industry not only for the production of strong alcoholic beverages, beer and kvass but also in baking to enrich food products with essential nutrients.

It has been proven that the impact of ozone on the biochemical processes occurring in malt is similar to those taking place in grain. Experimental studies have shown that the use of ozone reduces the germination time of grain by 4–15 h. Additionally, the drying duration of malt using an ozonated drying agent decreases by 4–6 h [35–37].

Test results indicate that applying ozone at various stages of malt production improves its quality characteristics. Short-term ozonation at a concentration of 10 mg/m^3 during sieving increases the germination energy of the grain by 7–8 %. This ensures proper quality of the finished malt, reduces saccharification time and increases extractivity, which reflects the higher activity of its hydrolytic enzymes [35–37].

Ozonation for Air Disinfection and Virus Control

Ozone is widely used in medicine for disinfecting air and surfaces indoors. Research results have shown that the effectiveness of disinfection depends on the materials of the treated objects. After 30 min of ozonation, complete destruction of microorganisms was observed on ceramic, glass, metal and plastic surfaces, while a few colonies remained on porous surfaces such as wood and linoleum. Extending the exposure time to 60 min ensured full microbial decontamination of surfaces made from any material [38].

It has also been established that bacteria are more susceptible to ozone exposure compared to mold.

Specifics of Using Ozone Technologies

When developing and implementing ozone-based technologies, it is important to consider several key aspects.

First, occupational safety regulations must be strictly observed, as current sanitary standards stipulate that the maximum allowable concentration of ozone in the workplace air should not exceed 0.1 mg/m^3.

Second, precise dosing of ozone is critical because low concentrations can have a biostimulatory effect. Therefore, when designing disinfection technologies, it is necessary to prevent the formation of such concentrations in certain areas of the treated objects.

Third, the rate of ozone decomposition varies significantly depending on the surface being treated. For example, the presence of cardboard packaging or molding starch in a room can increase duration the ozonation process by 3–10 times compared to an empty space.

Other important factors to consider when using ozone technologies include temperature, humidity, the configuration of the facility and the species composition of the microbial flora. Additionally, ozone can have a destructive effect on certain materials, such as rubber products, which requires an initial inspection of the facility and possibly the replacement of parts with ozone-resistant alternatives.

Thus, for each specific case, despite the abundance of publicly available technical and technological information on the use of ozone, the development of an ozonation technology must include a series of theoretical and practical activities. These should involve trial disinfection procedures and corresponding microbiological analyses to determine the optimal operating modes (duration and frequency) for each individual facility (Figure 5).

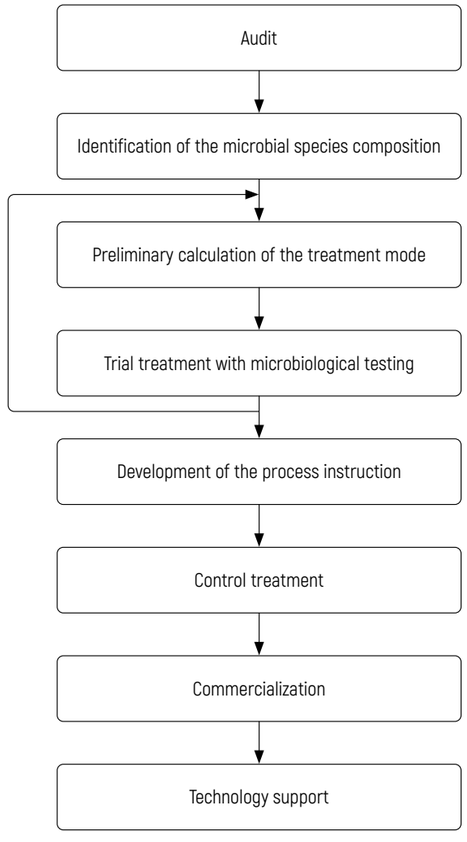

Figure 5 – Algorithm for developing ozonation technology

Conclusion

Based on literature sources and the authors' practical experience, an analysis was conducted on the application of electrical discharge technologies, which can be utilized in enclosed ecosystems as part of the development of linear cities on Earth (including the ELC) and ECH. The main advantages of these technologies are their environmental friendliness and the ability to generate the required electricity using solar panels in space conditions.

This study examines a small portion of possible applications of electrical discharge technologies to meet human needs (food, water, clean air and more), ranging from the manufacturing of eco-friendly fertilizers, crop and livestock production, storage and processing of agricultural products into final food products, to the neutralization of liquid and solid organic household and industrial waste, followed by its use in a closed-cycle production of eco-friendly fertilizers in linear cities on Earth (including the ELC) and in orbital ECH.

Further exploration of the applications of electrical discharge technologies, both independently and in synergy with other methods, is fully aligned with the ECH and linear city concepts and may open up new technological approaches to solving the challenges facing humanity.

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Prospects of Using an Additional Oxygen Source in Internal Combustion Engine

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Problems of environmental pollution caused by modern transport as well as types of harmful and dangerous chemical compounds in exhaust gases and their impact on the Earth's biosphere have been considered. Prospects for regulating ecological issues related to fuel use by optimizing combustion processes have been revealed. Possible solutions for implementing this technology have been analyzed. The efficiency of built-in oxygen sources and their potential impact on the environment by minimizing the level of pollutants in exhaust gases have been investigated. The advantages of pure oxidizer (oxygen) as well as the ways to increase engine lifespan by means of special additives and reducing combustion chamber temperature have been outlined.

Reducing the toxicity of internal combustion engines due to the use of an additional oxygen source will allow their employment in high-speed, ultrahigh-speed and hypervelocity complexes of the Unitsky String Transport (uST) integrated into the takeoff and landing overpass of the General Planetary Vehicle, since efficient passenger and cargo transportation along the equator will be required to ensure geocosmic logistics. The uST complex with its onboard energy reserve (especially relevant for long oceanic sections) could, for example, replace environmentally dangerous long-haul flights which intensively destroy the planet's ozone layer.

Keywords:
bioethanol, emission reduction, environmental safety, General Planetary Vehicle (GPV), internal combustion engine, liquid oxygen.

Introduction

One of the most pressing challenges facing humanity today is the need to reduce pollution from toxic substances emitted by industrial facilities and transport, both road and air.

Exhaust gases, particularly those from long-haul aircraft, have a profoundly detrimental impact on the environment. The combustion of fuel releases harmful by-products into the atmosphere, posing risks not only to human health but also to all forms of flora and fauna. The complex mixture of exhaust gases, which are also greenhouse gases, contributes to the depletion of the ozone layer, resulting in global warming and the greenhouse effect [1]. Smog produced by human activities can cause inflammation of mucous membranes as well as lead to respiratory distress and neurological disorders. Additionally, soils adjacent to roadways become degraded and contaminated with carcinogens from exhaust emissions and wear products from tires, brake pads and asphalt [2].

Exhaust gases contain approximately 300 different components, which can be categorized into several groups: nontoxic substances (nitrogen, hydrogen, oxygen, water vapor and carbon dioxide), toxic substances (carbon monoxide, nitrogen oxides, various hydrocarbons like paraffins, olefins, aromatic compounds, aldehydes, ketones, phenols, soot, sulfur dioxide and hydrogen sulfide), heavy metals and carcinogenic polycyclic aromatic hydrocarbons (PAH), with benzo[*a*]pyrene being among the most potent, etc. [3].

To mitigate the pollution caused by transport exhaust gases, the World Health Organization (WHO) advocates for a transition to environmentally friendly energy production methods, the development of rapid urban transport, the manufacture of low-emission vehicles, the use of cleaner fuels, etc. [4].

For this reason, the pursuit of technologies to minimize harmful emissions from internal combustion engines (ICE) has become an urgent priority and the central focus of this study. It is important to note that traditional electric vehicles, including string rail transport, are also equipped with an external (off-board) analogues of ICE – thermal power plants that burn fuel with atmospheric oxygen as an oxidizer. In conjunction with high-voltage power lines and power supply systems (transformer substations, catenary networks, charging stations, etc.), these can potentially pose greater environmental hazards than vehicles equipped with ICE and carrying eco-friendly fuels and onboard oxygen supplies.

This approach is particularly relevant for high-speed transport networks located along the General Planetary Vehicle (GPV) overpass, especially across oceanic sections spanning approximately 10,000 km, where the construction of high-voltage power lines and conventional power plants as well as the use of long-haul aviation, may be impractical or impossible [1, 2, 5].

Impact of Exhaust Gases on Human Health

Atmospheric pollution from emissions generated by ICE – such as carbon monoxide, dioxides, formaldehydes and heavy metals – contributes to approximately 7 mln premature deaths each year, according to WHO estimates. This pollution not only devastates Earth's ecosystems but also poses a threat of irreversible damage [6].

Carbon monoxide (CO) is produced during the incomplete combustion of gasoline. Inhaling this gas leads to a significant oxygen deficiency in the body, as CO binds irreversibly to hemoglobin. Symptoms of carbon monoxide poisoning include nausea, headaches, dizziness, migraines, loss of consciousness and, in severe cases, death.

Nitrogen dioxide (NO_2) is another harmful emission known for its respiratory toxicity. This brown gas, characterized by a pungent odor, irritates the mucous membranes of the respiratory system and can lead to both functional and pathological changes. Prolonged exposure to nitrogen dioxide increases the risk of mortality from heart disease and cancer.

Sulfur dioxide (SO_2), when present at concentrations exceeding permissible limits, can lead to various respiratory issues, including inflammation of the nasopharynx, bronchitis, etc. Individuals with chronic respiratory conditions, such as asthma, are particularly vulnerable to its effects.

Formaldehyde (CH_2O) is a toxic gas with a sharp odor that irritates the eyes, lungs and mucous membranes. It can trigger allergic reactions and negatively impact the central nervous system.

Lead (Pb), found in some fuel additives, accumulates in the body and adversely affects mental development, making it especially dangerous for children.

Hydrocarbons (CH_x) are a group of highly toxic compounds which occur in the exhaust gases after the fuel pyrolysis in ICE.

PAH are carcinogenic substances that tend to accumulate in the body, increasing the risk of malignant diseases.

Among these, benzo[*a*]pyrene ($C_{20}H_{12}$) is recognized as the most toxic carcinogen. Released in exhaust emissions, it settles along roadways and infiltrates soil and vegetation,

causing severe harm to flora and fauna. In urban areas, levels of benzo[*a*]pyrene pollution can exceed permissible limits by 10 to 20 times. At high concentrations, it poses risks to the circulatory system and exhibits mutagenic, hematotoxic and embryotoxic effects [7].

These emissions highlight the ICE-powered transport as dangerous and harmful for the environment, underscoring the urgent need for the global adoption of electric vehicles. However, this transition introduces its own set of complex challenges, including environmental ones. If the number of electric vehicles were to match the current fleet of approximately 1.5 bln ICE vehicles, the negative consequences for the planet could be even more severe.

Causes of Low Environmental Friendliness of ICE Vehicles

The primary cause of air pollution from ICE vehicles is the incomplete and uneven combustion of fuel. Only about 15 % of the fuel consumed is actually converted into usable energy for vehicle movement, while the remainder is released into the atmosphere as exhaust gases [8].

For the complete combustion of 1 kg of gasoline, approximately 14.7 kg of air is theoretically required, assuming the use of an ideal fuel, i.e., gasoline composed primarily of *n*-heptane and isooctane. However, many fuels contain a mix of heptane, octane, other alkanes, additives (such as detergents), oxygenates (like methyl tert-butyl ether or ethanol/methanol) as well as other components. This affects the composition of exhaust gases, shifting the stoichiometric balance towards increasing harmful emissions [9].

During engine operation, the quantity of air in the air-fuel mixture may vary, either exceeding or falling short of the required amount, as indicated by the excess air ratio (α), which is the ratio of the actual amount of air (L_A) involved in combustion to the theoretically required amount (L_T), i.e., $\alpha = L_A/L_T$.

Different operating conditions of an ICE require specific mixtures:

- for acceleration and high-load driving, an enriched mixture (α = 0.85... 0.95) is optimal, maximizing power output due to a higher combustion rate;
- at medium loads, a lean mixture (α = 1.05... 1.15) promotes complete combustion of fuel and efficient operation;
- during idling, a rich mixture (α = 0.7... 0.8) ensures stable ignition at low speeds, despite incomplete cylinder filling [10].

Complex and often poorly understood chemical reactions occur within the engine, contributing to the emission of pollutants into the atmosphere. Notably, the highest levels of emissions typically occur during idling when ICE operates on a rich mixture. In urban areas, this idling can account for one-third to one-half of a vehicle's operational time, particularly in traffic jams, at intersections and at traffic signals.

To optimize the air-fuel mixture, manufacturers equip vehicles with advanced systems that can even measure the temperature of ICE and the surrounding air, thereby adjusting fuel injection as needed.

The operational cycle of a four-stroke carburetor engine consists of several stages [11]: the inlet of working mixture, the compression of working mixture, the working stroke and the release of exhaust gases (Figure).

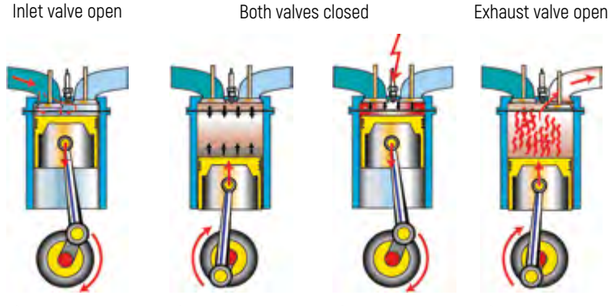

Figure – Operating cycle of a four-stroke carburetor engine:
a – inlet of working mixture; b – compression of working mixture; c – working stroke (expansion of gases); d – release of exhaust gases

Within this cycle, the working mixture undergoes rapid transformations, including:

- physical changes: the pressure increases from 0.08–0.09 MPa and temperature from 60 °C at the end of the first cycle to 4 MPa and 2,000 °C during the third cycle, where combustion energy is converted into mechanical work;
- chemical changes: these involve processes such as pyrolysis, synthesis of PAH, hydrogenation, dehydrogenation, polymerization, etc.

As a result, numerous by-products are generated, nearly all of which stem from incomplete and uneven oxidation, the primary contributor to air pollution. Increasing the oxygen concentration in the mixture can shift the balance of chemical reactions toward producing more complete oxidation products, thereby reducing toxicity.

The composition of harmful substances in exhaust gases is influenced by various factors, including the quality of fuel, the technical condition of ICE, its power, vehicle speed, fuel consumption and operating mode. A significant amount of pollutants is released during idling.

Burning 1 l of gasoline produces approximately 16 m^3 (16,000 l) of exhaust gases, which serves as a basis for estimating the quantity of harmful emissions released into the atmosphere. To accurately assess the pollution generated by a specific vehicle, one must consider its daily mileage, engine displacement, operating mode and other variables. However, average figures can often be misleading or inaccurate.

Table 1 illustrates the composition of predominant exhaust gases from two main types of engines: gasoline (spark ignition) and diesel (compression ignition) [3].

To evaluate the environmental impact of exhaust gases, various vehicle emission standards have been established. These legal requirements set limits on the release of pollutants into the atmosphere and define quantitative thresholds for specific air contaminants that can be emitted from designated sources within specified timeframes. While emission standards differ across regions and countries, their primary objective is to ensure high air quality and safeguard human health.

In Europe, the first European emission standard Euro was introduced in 1970 under Directive 70/220/EEC, which has since undergone multiple amendments. In the United States, Tier standards have been implemented, originating from early legislative efforts between 1955 and 1963 aimed at promoting clean air. In the former USSR, standardization efforts commenced in 1970 with GOST 16533-70.

Table 2 outlines the environmental standards for passenger vehicles with gasoline or diesel engines, as defined by the Euro regulations [12].

The standards presented in Table 2 account for the most common pollutants under standardized engine operating conditions. However, variations in atmospheric composition (i.e., gas makeup and particulate matter), temperature and other factors may lead to the formation of compounds not included in these regulations. Moreover, even if a vehicle complies with established standards, it is still possible for emissions of harmful and hazardous pollutants to exceed acceptable levels.

Table 1 – Composition of exhaust gases of ICE

Component	Concentration of components in exhaust gases	
	Gasoline engine	Diesel engine
Nitrogen (N_2), %	74–77	76–78
Oxygen (O_2), %	0.3–8	2–18
Water vapour (H_2O), %	3–5.5	0.5–9
Nitrogen oxides (NO_x), %	0.01–0.8	0.004–0.5
Carbon monoxide (CO), %	0.5–12	0.005–0.4
Hydrocarbons (CH_x), %	0.2–3	0.009–0.3
Benzo[*a*]pyrene ($C_{20}H_{12}$), mcg/m^3	0–20	0.05–1
Soot (C), g/m^3	0–0.04	0.01–1.1
Sulphur oxides (SO_x), %	0–0.008	0.002–0.02
Aldehydes (RCHO), %	0–0.2	0.0001–0.002

Table 2 – Requirements of environmental standards

Class	Introduction date	Harmful substances in exhaust gases, g/km					
		Carbon dioxide	Hydrocarbons	Volatile organic matter	Nitrogen oxides	Mixture of hydrocarbons and nitrogen oxides	Particulate matter
Diesel engine							
Euro 1	July 1992	2.72	–	–	–	0.97	0.14
Euro 2	January 1996	1	–	–	–	0.7	0.08
Euro 3	January 2000	0.64	–	–	0.5	0.56	0.05
Euro 4	January 2005	0.5	–	–	0.25	0.3	0.025
Euro 5	September 2009	0.5	–	–	0.18	0.23	0.005
Euro 6	September 2014	0.5	–	–	0.08	0.17	0.005
Gasoline engine							
Euro 1	July 1992	2.72	–	–	–	0.97	–
Euro 2	January 1996	2.2	–	–	–	0.5	–
Euro 3	January 2000	1.3	0.2	–	0.15	–	–
Euro 4	January 2005	1	0.1	–	0.08	–	–
Euro 5	September 2009	1	0.1	0.068	0.06	–	0.005
Euro 6	September 2014	1	0.1	0.068	0.06	–	0.005

Ways to Optimize Combustion Process

Various scientific organizations around the world propose several methods to enhance the combustion process, including:

- thermoforcing: this method involves preheating the fuel before it enters the engine cylinder, which improves fuel atomization and reduces the ignition delay time;
- additives: adding organic and organoelement compounds to the fuel can enhance the combustion process, decrease the likelihood of detonation and lower the toxicity of exhaust gases;
- electrostatic irradiation: this technique utilizes an electric field to accelerate the vaporization of fuel droplets and enhance the breakdown of fuel radicals and toxic oxide molecules, leading to more complete and efficient combustion. However, implementing this method in engines can be challenging;
- ozonization: introducing ozone into the engine's fuel supply system ensures complete combustion. However, this method has several drawbacks, including potential corrosion of fuel equipment and the breakdown of the combustible mixture;
- water-fuel emulsions: mixing water with diesel fuel can improve engine efficiency while reducing smoke, temperature and the toxicity of exhaust gases. However, poor water quality may lead to corrosion and significant wear on engine parts and fuel equipment;
- water vapor injection: injecting wet vapor or water into the intake manifold or cylinder can reduce emissions. The vapor partially dissociates into hydrogen and oxygen during combustion, helping to convert soot into fuel synthesis gas;
- catalytic fuel treatment (hydrogenation catalyst): using hydrogenation catalysts reduces the content of surfactants and increases the amount of paraffinic hydrocarbons, contributing to smoother combustion and significantly decreasing nitrogen oxide emissions;
- oxygen enrichment: increasing the concentration of molecular oxygen in the air-fuel mixture accelerates the combustion process. However, this also raises the temperature and maximum pressure within the combustion chamber, increasing the load on the engine;
- alternative fuels: utilizing methanol and natural gas, which produce no sulfur compounds or soot during combustion, represents another viable option;
- high-quality fuels: reducing the sulfur content and aromatic hydrocarbons in fuels can decrease the emission of harmful substances into the atmosphere [13].

One of the most promising alternatives is bioethanol, produced from agricultural raw materials such as potatoes, sugar cane, corn, sugar beet, fruit and by-products of the pulp and paper manufacturing process. Bioethanol effectively captures solar energy through photosynthesis. This is a renewable source of energy, derived from the sun. As early as 1927, L. Durey participated in the Indianapolis 500 race with an ethanol-powered vehicle [14]. In Germany, ethanol was blended with gasoline starting in 1930, with 5 % ethanol added initially and increasing to 10 % by 1932.

During the oil crisis of the 1970s, Brazil's government launched the Proálcool program, which spurred the development of alcohol-powered vehicles. By the late 1970s, gasoline contained 20–25 % alcohol, and by the 1980s, about 90 % of cars sold in Brazil ran on pure alcohol. The advantages of alcohol-powered engines are clear. Ethanol is more environmentally friendly than petroleum; growing sugar cane for ethanol production absorbs CO_2, a greenhouse gas, and burning ethanol emits less carbon monoxide, making it a cleaner process overall. Sugar cane is a natural renewable resource that harnesses solar energy, unlike oil.

The program has significantly transformed Brazil's air quality, reducing pollution in the urban areas of São Paulo and Rio de Janeiro. The country has also cut oil imports by 20 bln USD annually and emerged as the largest producer and exporter of ethanol. In the 1990s, Brazil began developing hybrid engines based on flex-fuel vehicle (FFV) technology, which can operate on both gasoline and alcohol-gasoline blends. Governments in several countries, including Australia, India, Canada, China, the USA, Thailand, Sweden and South Africa, are promoting FFV technology. By 2005, over 5 mln vehicles in the USA were equipped with FFV engines, and this number rose to 6 mln by the end of 2006. By 2008, the global fleet of vehicles with FFV technology exceeded 20 mln [15].

Methods for Neutralizing Exhaust Gases

Various methods have been developed to neutralize the exhaust gases from ICE, including catalytic, thermal, liquid, plasma and combined approaches.

Catalytic neutralization has one significant drawback that is the need for catalyst regeneration. Soot can clog the catalyst's active surface, while sulfuric anhydride reacts with the aluminum oxide carrier, forming aluminum sulfate, which further obstructs the pores and diminishes the neutralizer's efficiency [16].

Thermal neutralization involves full oxidation of toxic compounds using the heat from waste gases. The neutralizer consists of a thermally insulated container designed to direct the flow of exhaust gases, and it is integrated into the engine's exhaust system.

Liquid neutralization employs physical and chemical processes to treat exhaust gases. The gases are passed through a layer of liquid, cooling them to temperatures between 40 and 80 °C. Water-soluble compounds in the exhaust, such as sulfur oxides, nitrogen oxides and aldehydes, are neutralized, while dispersed particles (like soot and other substances) are captured by the liquid, reducing exhaust odor. To enhance efficiency, solutions of sodium sulfite, sodium carbonate and hydroquinone are often used, enabling the capture of substances like benzo[*a*]pyrene [17]. However, a major disadvantage of liquid neutralization is its higher cost compared to other methods, as it necessitates frequent disposal of solutions and sludge, along with system flushing and fluid replacement.

Plasma neutralization purifies toxic components emitted from the engine by using low-temperature plasma to convert them into less harmful or harmless compounds [18]. Low-temperature plasma can be generated through various electric discharges, including barrier, surface, corona and glow discharges.

In recent years, there has been a growing interest in developing vehicles with hybrid electromechanical propulsion systems [19], which are increasingly recognized as environmentally friendly and promising. For example, Toyota Prius was the world's first mass-produced hybrid car, combining both gasoline and electric engines. Additionally, the Toyota Mirai utilizes fuel cells to generate electric energy by oxidizing hydrogen with oxygen, producing only water as a by-product [20].

Methods for Increasing Oxygen Concentration in Fuel Mixture of ICE

Enriching the air-fuel mixture with oxygen is a viable method to enhance the combustion process. This approach accelerates oxidation, leading to higher temperatures and increased pressure in the engine's combustion chamber. Consequently, this results in reduced exhaust gas production and improved engine power. However, the trade-off is an increase in thermal stress on the cylinder-piston components

and the exhaust gas system, potentially shortening their lifespan.

There are several integrated oxygen supply systems, including:

• oxygen injection into the intake manifold. Here, O_2 is mixed with the air-fuel mixture before combustion occurs;

• oxygen injection into the exhaust manifold. In this method, O_2 is added to the exhaust gases prior to their passage through the catalytic converter;

• integrated oxygen sources. O_2 is generated within the engine or exhaust system through cerium oxide (CeO_2) oxidation [21].

Advantages of these methods include enhanced neutralization efficiency, reduced reliance on platinum and extended life for the neutralizer. However, disadvantages consist of increased system complexity, potentially higher operating costs (especially for oxygen injection systems) and limited applicability to direct injection engines (for intake manifold oxygen injection systems).

To maximize the efficiency of oxygen injection, several strategies can be employed:

• turbocharging or supercharging: this method forces more air into the engine, thereby increasing oxygen concentration in the working mixture;

• water or vapor injection: introducing water or vapor into the intake manifold promotes evaporation, cooling the incoming air and increasing its density, which raises the oxygen concentration in the fuel mixture;

• innovative combustion systems: utilizing stratified injection and spark plug ignition facilitates better mixing of fuel and air, leading to more complete combustion and a higher concentration of oxygen in the exhaust gases;

• exhaust gas recirculation (EGR): by redirecting a portion of the exhaust gases back into the intake manifold, this method can lower combustion temperatures and minimize nitrogen oxide formation. However, it may slightly reduce the oxygen concentration in the fuel mixture;

• addition of oxygen-containing compounds: introducing substances like hydrogen peroxide or sodium nitrate can effectively increase the oxygen concentration in the fuel mixture.

Herewith, built-in oxygen supply systems can directly inject O_2 into the exhaust gases to enhance catalytic converter efficiency. The choice of method depends on specific application requirements, including the type of ICE and the desired performance and emission standards.

To optimize engine conditions with an integrated oxygen source, the following recommendations can be implemented individually or in combination:

• adding ethanol (10–20 %) to gasoline: due to the more eco-friendly nature of biofuels this will lower the temperature of the engine and reduce harmful emissions [22];

• utilizing fuel combustion catalysts: products like ION-B, MPG-CAPS and MPG-BOOST can improve environmental performance [23, 24];

• replacing platinum catalysts with alternative options: this substitution can enhance efficiency while increasing oxygen concentration in the exhaust gases, potentially reducing the costs associated with the exhaust gas cleaning system [25].

It is proposed that liquefied oxygen, oxygen concentrators, hydrogen peroxide or water be considered as primary sources of oxygen.

A liquefied oxygen cryo-tank is designed with insulating materials that can withstand high pressure, allowing for extended vehicle range without frequent refueling. Liquefied oxygen offers a higher concentration of oxygen than ambient air, which promotes more complete fuel combustion and enhances both power and efficiency. This results in lower emissions of nitrogen oxides and carbon monoxide. However, a significant drawback is the need to store oxygen at extremely low temperatures (–183 °C), necessitating high-precision injection systems capable of withstanding these extreme temperature and pressure.

An oxygen generator [26] is a device that extracts oxygen from the surrounding environment. Its main advantages include the elimination of a complex fuel injection system, as the generator provides pure oxygen that can be mixed with fuel immediately before combustion. Nevertheless, these generators tend to be bulky and heavy, and they come with high maintenance costs.

Hydrogen peroxide (50 %), acting as an oxidizing agent, undergoes decomposition in the presence of catalysts, releasing substantial heat and water, which, during the process, transforms into steam. In combination with atomic oxygen, this steam gas reaches temperatures of 700–800 °C (an example of use is Walther engines).

Table 3 summarizes the various options for supplying vehicles with oxygen to facilitate complete fuel combustion.

Therefore, a significant enhancement in fuel combustion, leading to a reduction in harmful emissions in exhaust gases, can be achieved with a lower consumption of O_2 when it is used in conjunction with atmospheric oxygen.

Table 3 – Comparative characteristics of vehicle oxygen source options

Oxygen source	Advantages	Disadvantages
Cryo-tank with liquefied oxygen	No reagents	Use of liquefied gas
Oxygen generator	No need for refuelling	Electricity consumption
Hydrogen peroxide (50 %)	No overpressure	The ballast in the form of water (50 %) is needed

Utilizing an Integrated Oxygen Source for Exhaust Gas Cleaning

Intensive research is currently underway to explore the use of integrated oxygen sources for cleaning exhaust gases. The main areas of focus include:

• developing more efficient and cost-effective oxygen supply systems;

• investigating the impact of integrated oxygen sources on engine performance and emissions;

• creating integrated cleaning systems that combine embedded oxygen sources with other technologies, such as soot capture and exhaust gas recirculation.

Employing an integrated oxygen source for exhaust gas cleaning presents a promising solution for reducing vehicle emissions, offering several advantages:

• increased neutralization efficiency: the additional oxygen in the exhaust gases optimizes the performance of the catalytic converter, leading to more complete neutralization of harmful pollutants, including nitrogen oxides and hydrocarbons;

• reduced need for expensive metals: the introduction of oxygen lowers the operating temperature required for the catalytic converter, allowing for the use of less amount of costly platinum in its construction;

• extended lifespan of the neutralizer: enhanced neutralization efficiency contributes to a longer lifespan for the catalytic converter, which translates to lower maintenance costs over time.

Conclusion

Based on the analysis of factors that influence the chemical composition of fuel and its combustion conditions, the authors propose a concept for utilizing liquid oxygen to mitigate the environmental impact of exhaust gases from ICE. For a vehicle equipped with a 50-liter fuel tank, approximately 114 l of oxygen would be needed, resulting in a total weight of about 200 kg for the cryo-tank filled with oxygen. This is significantly lighter, its mass is 1.9 times less than that of the Tesla Model 3 electric car battery, which, including strapping, weighs 478 kg, while its energy capacity is 2.5 times greater compared to the Tesla battery capacity of 80.5 kW·h.

In addition, incorporating ethanol into gasoline can lower operating temperatures in the combustion chamber and extend the lifespan of the ICE. The use of additives that can reduce fuel consumption by 6 % and enhance engine longevity is also proposed. The ICE can operate on pure ethanol or methane; for instance, in hypervelocity forevacuum tunnel filled with rarefied methane, only an onboard oxygen source is needed while fuel is supplied from the tunnel via gas intake.

Implementing this operational scheme for ICE could reduce hazardous emissions by 40–60 % (and by 100 % in a forevacuum tunnel, as exhaust gases are contained within the tunnel and not released into the atmosphere) while potentially increasing engine lifespan by 3–5 %. Additionally, this approach would result in a lighter vehicle compared to electric cars.

Built-in oxygen sources for exhaust gas purification could significantly lower emissions from traditional ICE vehicles. The proposed technology offers several advantages: improved neutralization efficiency, reduced reliance on expensive metals for catalyst production and extended lifespan for the neutralizer. The availability of an integrated oxygen source would also help restore the functionality of platinum catalysts.

Continued research and development efforts in this field are focused on further enhancing and commercializing this promising technology, including its application in the high-speed logistics of the Equatorial Linear City, particularly in oceanic sections along the GPV takeoff and landing overpass.

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Section

ECOLOGICAL AND BIOLOGICAL ASPECTS OF ENCLOSED BIOSPHERIC ECOSYSTEMS ON EARTH AND IN SPACE

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Biotechnological Restoration of Deserts as Method to Prevent Food and Energy Crises

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Today, the rates of land degradation increase due to various natural and anthropogenic factors. The expansion of sandy deserts leads to the loss of fertile land that could otherwise be used for cultivating energy, fruit and technical crops as well as for livestock farming and urban development.

The restoration of soil fertility is a cornerstone of the global EcoSpace program, conceptualized by engineer A. Unitsky. This visionary initiative presents a comprehensive framework for a sustainable and prosperous human civilization, ensuring the health of our planet for future generations.

The biotechnologies of soil fertility restoration, proposed in this study, can be used to improve the economic and environmental situation in regions with challenging agricultural conditions, as well as to enhance the quality of land that will be used in the construction of the General Planetary Vehicle overpass, Equatorial Linear City, string rail transport routes and ecohouses on Earth and, eventually, in the utilization of EcoCosmoHouses in near space.

Keywords:
biotechnologies, EcoSpace, energy crops, green manure, humus, restoration of deserts, uTerra biohumus.

Introduction

About 4.5–4.6 bln years ago [1], our entire planet was an uninhabited solid hot desert, which was later transformed by primitive organisms into a place comfortable for billions of species of living beings, including humans, – they created the biosphere. In the course of evolution, the key component of the biosphere was living fertile soil, the area of which is shrinking dramatically in modern conditions everywhere.

Land desertification (degradation) is a process that leads to a loss of soil fertility. The emergence of deserts accelerates soil degradation in local ecosystems, making it a self-catalyzing process. In general, population reductions of certain species of organisms initiate changes in trophic chains, eventually resulting in the development of desert flora, fauna and microbial communities. At the same time, many desert species of living organisms are unique and should be preserved.

In tropical and subtropical climates, agricultural activities, food production and energy generation are more feasible, provided there is access to water sources, essential macro- and microorganisms for fertility, sufficient organic matter and mineral compounds in the soil.

In the context of the development of modern technologies, many countries face food and water shortages and environmental pollution [2]. Some of these problems are caused by increasing desertification due to water and wind erosion, soil salinization, human activity, excessive and/or improper use of agrochemicals. Despite the fact that the impact of erosion is not an anthropogenic factor, it can be reduced by special reclamation techniques.

It is possible to turn sandy soils into fertile soils and to cover the needs of civilization in electricity and heat at the expense of light energy received by the Earth surface (after conversion – about 1 $kW \cdot h/m^2$ per day [3]). This can be done with the help of green manure (organic fertilizer) and fast-growing energy crops, as well as after soil restoration by applying biofertilizers based on modern organics, brown coal and oil shale [4], having mineral composition of relict plants, and products of their combustion (flue gases, ash and slag wastes). At complex processing of brown coal and other fossil fuels (coal, oil shale, peat) and the use of their combustion waste with the resulting organic fertilizers, a positive economic effect can be achieved.

Energy crops grown on soil that has been successively regenerated with organic fertilizers and green manure are then processed into raw materials for combustion – pellets, ethyl alcohol or biodiesel. The by-products can be used in agriculture as well as for desert conversion, thus forming a waste-free and inexhaustible cycle of solar energy utilization.

In the article the authors review the factors causing land degradation, consider the characteristic of deserts, substantiate the necessity of their restoration for the subsequent cultivation of energy crops. The paper presents the results of the laboratory experiment on creation of fertile soil from sandy soil, supplied to Unitsky String Technologies Inc. (Minsk, Belarus), shows the efficiency of the developed technique, estimates the amount of electricity that can be obtained with the help of this technology.

Role of Deserts in the Earth's Biosphere

Globally, degraded soils cover over 2 bln ha. Of these, 55.6 % are attributed to water erosion, 27.9 % to wind erosion, 12.2 % to chemical and biological degradation and 4.3 % to physical compaction and waterlogging. According to FAO and UNESCO criteria, arid areas are categorized into four groups:

- hyper-arid (less than 100 mm of precipitation);
- arid (100–200 mm);
- semi-arid (200–400 mm);
- dry sub-humid (400–800 mm).

A summary of the largest deserts [5] is given in Table 1.

Although the Antarctic and Arctic polar deserts meet the definition of a desert as areas with annual precipitation less than 250 mm, they are excluded from consideration in this article.

Every year, between 8 and 20 mln ha of land are lost globally due to degradation – a figure comparable to the entire area of Belarus (20.8 mln ha). However, deserts' impact on the planet's biosphere extends beyond purely negative aspects.

Negative aspects of deserts:

- unsuitability for agriculture due to inadequate agroclimatic conditions;
- inhabitability: significant expenses are required to ensure comfortable living conditions for humans;
- sand and dust storms in arid regions cause severe damage to infrastructure and pose risks to populations;
- desertification progression: presence of deserts in a region and improper land resource management exacerbate soil degradation.

Table 1 – Characteristics of major deserts

Name	Area, km²	Type	Region
Antarctic Desert	14,200,000	Polar	Antarctica
Arctic Desert	13,900,000	Polar	Arctic territories of Alaska, Canada, Greenland, Russia, Iceland
Sahara	9,200,000	Tropical	Algeria, Chad, Egypt, Libya, Mali, Mauritania, Morocco, Niger, Sudan, Tunisia, Western Sahara
Arabian Desert	2,330,000	Tropical	Saudi Arabia, Jordan, Iraq, Kuwait, Qatar, UAE, Oman, Yemen
Gobi	1,300,000	Subtropical	Mongolia, China
Kalahari	900,000	Subtropical	Angola, Botswana, Namibia, South Africa
Patagonian Desert	673,000	Subtropical	Argentina, Chile
Great Victoria Desert	647,000	Subtropical	Australia
Syrian Desert	520,000	Subtropical	Syria, Jordan, Iraq
Western U.S. Desert	492,000	Subtropical	USA

Positive aspects of deserts:

- habitat for unique, endemic plant and animal species;
- source of minerals for marine organisms: transportation of minerals from deserts to seas and oceans provides essential nutrients for marine ecosystems [6];
- special environmental conditions: absence of light pollution makes deserts ideal locations for astronomical research.

Causes of Desertification

Desertification arises from the complex interplay between natural (drought, water and wind erosion, soil salinization, vegetation degradation, etc.) and anthropogenic factors (pollution of soil and water with agricultural and industrial chemicals, mechanical field treatment, etc.). According to some estimates, 87 % of the causes of desertification are anthropogenic, while only 13 % are natural [7].

Land degradation is categorized based on the nature of impact into physical, chemical and biological degradation [8, 9]. Most often, multiple factors – or even all three types – are present simultaneously (Table 2).

Factors contributing to the decline in soil fertility exert a mutual compounding effect, significantly harming the planet's biosphere and destabilizing economies in affected regions. This leads to hunger, poverty and diseases. Between 1968 and 1973, desertification became a severe issue in Africa's Sahel region due to prolonged drought.

Table 2 – Factors of desertification

Physical	Chemical	Biological
Removal of the topsoil (poorly planned irrigation, lack of runoff management, excessive drainage).	Accumulation of industrial waste (by-products from chemical, oil, cement, steel and other factories).	Reduction in population and species diversity, disruption of the optimal balance of macro- and microorganisms due to changing agroclimatic conditions, use of mineral fertilizers and agrochemicals, noise pollution of soil [10].
Local waterlogging (rise in groundwater levels, improper irrigation, flooding from reservoirs).	Waste from coal-fired power plants (ash and slag wastes, fly ash, etc.).	Soil contamination with pathogenic microorganisms, worsening sanitary-epidemiological indicators (use of untreated organic waste, landfill of SHW).
Deflation (wind-driven soil particle removal).	Solid household waste (SHW, urban wastewater).	Decrease in humus content.
Compaction and formation of artificial clods in arable horizons (mechanical treatment of physically mature).	Soil pollution with agrochemicals (pesticides, insecticides, acaricides, fungicides, etc.).	Reduction in nutrients (loss through agricultural production, low buffer capacity, etc.)
Plowing / replacing calcium with sodium, low humus content.	Emissions related to vehicles and infrastructure (exhaust gases, wear particles of road surfaces and tires, de-icing salts, etc.)	
Loss of land due to construction, roads and mining		

It devastated the economies and social structures of many countries, including Mauritania, Senegal, Mali, Niger and Chad. Agriculture suffered greatly, particularly livestock farming and rainfed cultivation. The lack of forage and water led to the death of large herds of livestock, while crop failures resulted in catastrophic consequences. Over 250,000 inhabitants of the Sahel region died from famine. This desertification crisis highlighted the destructive impact of drought and other soil degradation factors on vulnerable ecosystems and the human communities dependent on them.

Goals of Biotechnological Restoration of Desert Soils

Restoring desert soils to form a stable biogeocenosis in previously barren areas can lead to increased population density and support for productive and hunting activities. The prioritization of land use directions for transformed areas should be determined on a case-by-case basis. To achieve maximum efficiency, crop rotation should be tailored to soil composition, climatic conditions and demand for plant products. The main goals of restoring the fertility of desert soils using biotechnology include:

- implementation of energy farming: reclaimed soils can be utilized for cultivating energy crops (Table 3) that are resilient to high temperatures, drought and pests, and can be used for producing wood, alcohol and biodiesel;
- food provision: restored desert soils expand the area of arable land available for growing agricultural crops;
- creation of comfortable human habitats: developing stable biogeocenoses in formerly desert territories allows for increased population density through residential and industrial construction, as well as the establishment of new logistic routes.

The crops listed in Table 3 can serve as energy resources, including for electricity generation. Combustion by-products such as ash-slag waste and carbon dioxide are beneficial for plant cultivation: ash can be used as a component of fertilizers, while carbon dioxide enhances photosynthesis processes. By-products from ethanol and biodiesel production (distillery stillage, rapeseed and sugarcane meal, etc.) can be utilized as feed additives, organic fertilizers, or incorporated into the soil as green manure.

Using data on the yield of target products per 1 ha and the efficiency factor of electricity generation and consumption in the region, an approximate calculation can be made to determine the average area of degraded soils required for energy crop cultivation to supply electricity to Belarus.

In 2023, Belarus' electricity consumption was approximately 41 bln kW·h. Assuming that the yield of degraded land is 50 % of fertile land, the required restored desert soil area for various crops can be calculated.

Calorific value of ethanol from 1 ha of sweet sorghum:

$$50\ \% \times 153\ \text{GJ} = 76.5\ \text{GJ}.$$

Since 1 GJ = 278 kW·h, it is possible to produce at 100 % efficiency factor from 1 ha/year:

$$278\ \text{kW}\cdot\text{h} \times 76.5 = 21{,}300\ \text{kW}\cdot\text{h}.$$

When obtaining electricity from ethyl alcohol, the efficiency factor of the generator will be about 40 %. Then the amount of electric energy from 1 ha/year will be equal to:

$$21{,}300\ \text{kW}\cdot\text{h} \times 40\ \% = 8{,}520\ \text{kW}\cdot\text{h}.$$

To obtain 41×10^9 kW·h would require:

$$41 \times 10^9\ \text{kW}\cdot\text{h} / 8{,}520\ \text{kW}\cdot\text{h} = 4.8\ \text{mln ha}.$$

Table 3 – Characteristics of energy crops

Crop	Type of raw material	Yield of raw material, tons/ha per year	Calorific value, MJ/kg	Calorific value per 1 ha per year, GJ
Paulownia	Wood	Up to 30	20	Up to 600
Sugarcane	Ethanol	Up to 7.5	30.6	Up to 230
Sweet sorghum	Ethanol	Up to 5	30.6	Up to 153
Rapeseed	Biodiesel	Up to 1	37.6	Up to 37.6
Sugar beet	Ethanol	Up to 10	30.6	Up to 306

In a similar application of paulownia in the form of pellets for CHP with an electrical efficiency factor equal to 26 % [11], the required crop area would reach 1.9 mln ha.

In the case of sugarcane cultivation with subsequent production of alcohol as fuel for a generator with an efficiency factor of 40 %, 3.2 mln ha would need to be reclaimed.

If biodiesel from rapeseed is used to generate electricity with an efficiency factor of 30 %, the required cultivated area would be 31.4 mln ha.

Cultivating sugar beet for ethanol production as generator fuel with 40 % efficiency factor would require 2.4 mln ha of restored soil.

The average area needed for the five promising energy crops totals 8.7 mln ha, equivalent to approximately 40 % of Belarus' territory. By reclaiming soils annually excluded from agricultural use, the country can be supplied with energy resources while also gaining valuable materials (wood from paulownia cultivation and fodder for agricultural animals from other crops).

The positive outcome of energy crop production on restored lands is also reducing reliance on fossil fuels and ensuring renewable energy sources. Additionally, by-products from processing these plants are fully utilized, enabling efficient conversion of solar energy into other forms (thermal, mechanical or electrical). This process simultaneously improves the planet's biophysical and climatic conditions, increases agricultural land (food and fodder crops can be used in crop rotation) and creates a comfortable habitat not only for humans but also for millions of other living organisms of flora and fauna, comprising microflora and microfauna.

Integrating energy crop cultivation with desert soil restoration addresses a common drawback of energy farming – the rising cost of food products in the region due to competition for land with food crops. This calculation can be expanded with additional factors, in particular the agroclimatic conditions of specific territories, existing technical and energy infrastructure, complexity of processing energy raw materials and demand for by-products.

The technology does have drawbacks, such as the need to increase the efficiency factor of systems utilizing energy crops, conducting research for optimization and the relatively more complex supply chain for energy raw materials compared to fossil fuels.

Pathways for Preserving Soil Fertility and Restoring Deserts

Upon analyzing the extent of desert soils and the resources (water, organic and mineral) required for their rehabilitation, it becomes evident that the economic feasibility of such measures necessitates the use of living organisms and the creation of suitable conditions for them. To prevent ecological issues, it is essential to address ways to reduce the environmental burden from transportation, energy, industrial and residential infrastructure – areas that have been theoretically studied in depth and are already being practically implemented by Unitsky String Technologies Inc.

The UST Inc.'s solutions, in their wide variety, are inherently ecological and geared toward environmental preservation. They are natural (biospheric) rather than nature-imitating. For instance, within the framework of Unitsky's Farm Enterprise (Maryina Gorka, Belarus), medicinal herbs are cultivated directly beneath the string rail transport structures. The experts have developed efficient organic farming technologies, many of which are applicable to restoring the fertility of desert soils [12–14].

Research has specifically focused on isolating unique, beneficial soil microorganisms (nitrogen-fixing and phosphate-solubilizing bacteria, bacteria capable of biodestructing brown coal, etc.) from various sources, which can be used to rehabilitate impoverished and infertile lands [15]. Additionally, optimal microclimates have been identified for greenhouses, along with parameters for lighting and irrigation regimes tailored to specific crops [16]. Studies have also examined mechanisms of biogenic element interactions in enclosed ecosystems under the EcoCosmoHouse project. The results offer solutions to overcome the challenges of seasonality in traditional plant cultivation, reduce water consumption and minimize emissions and costs by transforming biomass and secondary water resources into efficient organic fertilizers. Moreover, small enclosed ecosystems were created and analyzed during the research process.

UST Inc. produces uTerra fertility elixir and biohumus – biofertilizers derived from organic raw materials. These products contain agronomically valuable associations of microorganisms sourced from a unique world Bank of soils, as well as an organomineral complex of macro-, micro- and ultramicroelements for plant nutrition. These biofertilizers are effective across all soil types and can be applied to desert lands through comprehensive treatment and restoration efforts.

The implementation of these biotechnologies can prevent desertification and enable the development of agriculture in regions where it is challenging due to unfavorable agroclimatic conditions.

Biotechnological Stepwise Restoration Example: UAE Sand Soils

The methodology for rehabilitating desert sandy soils using biotechnologies is described below. The first stage involves applying the necessary quantity of uTerra biohumus. The second stage includes cultivating green manure with their subsequent incorporation into the soil alongside smaller doses of fertilizer.

By combining the technologies of using green manure and uTerra biohumus, it is expected to increase the humus content and plant nutrients in the soil, as well as improve its granulometric composition, aeration and water retention capacity.

Initial Data

The UAE's total area is 83,600 km^2. A significant part of it is occupied by sandy deserts (Figure 1), in particular the Rub' al Khali, and salt marshes.

Figure 1 – UAE soil (degraded site)

Let us consider physical and chemical properties of the most common sandy soil of UAE (sample from SWIG site, Ras Al Khaimah) (Table 4) and compare them with Russian chernozem (Table 5).

As shown in Table 4, UAE sand contains a high proportion of carbonates and exhibits an alkaline reaction. The total nitrogen content is very low at 0.03 %, while the content of mobile phosphorus is critically low (0.003 %). Although the total potassium is relatively high (0.6 %), it is bound within aluminosilicates, rendering it unavailable for plant uptake. The sand is rich in certain microelements such as magnesium and calcium, and salinity is minimal (halides less than 0.001 %). Evidently, such sandy soils are unsuitable for agriculture in their natural state.

Table 4 – Physical and chemical properties of UAE sand soil

Indicator	Actual Value
Primary	
Humus (organic matter), % by weight	0.01
Total nitrogen, % by weight	0.03
Total phosphorus, % by weight	0.02
Total potassium, % by weight	0.6
pH	8.8
Additional	
Amorphous silicon dioxide, mmol/kg	10
Sulfur, sulfides and sulfates in terms of sulfur (VI) oxide, % by weight	0.11
Halides in terms of chloride ion, % by weight	0.001
Mica, % by weight	0.05
Total silicon dioxide, % by weight	34.85
Aluminum oxide, % by weight	3.61
Iron (III) oxide, % by weight	1.26
Titanium (IV) oxide, % by weight	0.24
Water-soluble phosphorus (V) oxide, % by weight	0.003
Sodium oxide, % by weight	0.95
Calcium carbonate, % by weight	45.1
Magnesium carbonate, % by weight	12.1
Coal, % by weight	Not detected
Organic impurities	Not detected
Other impurities	Not detected

However, by enriching the soil with organic matter and essential mineral components, as well as correcting the pH, they can potentially be transformed for the production of organic agricultural crops.

Table 5 outlines the characteristics of various soil types, comparing UAE sand soil before and after reclamation with typical sod-podzolic soils and chernozem. The projected agrochemical indicators for restored UAE sand soils align with those of sod-podzolic soils, with adjusted acidity levels.

Table 5 – Characteristics of UAE sand soil before and after restoration, as well as of sod-podzolic soil and chernozem

Indicator	UAE sand soil before restoration	UAE sand soil after restoration	Sod-podzolic soil	Chernozem
Humus, %	0.01	2–4	2–4	8–12
Total nitrogen, %	0.03	0.1–0.2	0.1–0.2	0.5–0.75
Total phosphorus, %	0.02	0.05–0.16	0.05–0.16	0.1–0.3
Total potassium, %	0.6	1–2.5	1–2.5	2.5–3
pH	8.89	6–8	4–5.5	6.5–7

Scheme for Reclamation (Restoration) of Sandy Soils

The reclamation of desert soils is planned to be conducted cyclically using uTerra biohumus (organic matter – 50 %, total nitrogen – 0.9 %, total phosphorus – 0.9 %, total potassium – 0.9 %, pH – 7) and green manure.

uTerra biohumus is produced with the help of a specially bred earthworm, *Lumbricus* uTerris, which decomposes brown coal. It also incorporates agronomically valuable soil microorganisms from the world Bank of soils through the bioconversion of organic residues, brown coal, compost, peat, ash and by-products from the production of uTerra fertility elixir [12].

Types of Green Manure for Sandy Soil Reclamation

Green manure should be selected based on the region's climatic conditions and crop rotation, alternating cruciferous, cereal and leguminous crops. The general reclamation procedure remains unchanged.

Sudan grass (*Sorghum* × *drummondii*) (Figure 2) is a promising green manure. Its vegetation period is 90–120 days, while 25–65 tons of biomass per hectare are provided. The optimal growth temperature is 32–35 °C. This crop is undemanding to soil types and can thrive on light sandy, heavy clay and even saline soils, though it does not tolerate acidic soils. It withstands salt concentrations of up to 0.6–0.8 %. Sudan grass is also moisture-efficient, relying on its robust root system to extract water from deep soil layers during droughts.

Sudan grass demonstrates exceptional drought resistance, not only due to its robust root system but also its ability to halt growth during periods of severe moisture deficiency. This crop effectively loosens, drains and structures the soil, enhancing its aeration and water retention capacity.

Figure 2 – Sudan grass

White mustard (*Sinapis alba*) (Figure 3) is characterized by a vegetation period of 60–90 days, producing 30–40 tons of biomass per hectare. The optimal growth temperature is 25–28 °C.

White mustard enriches the soil with organic matter, nitrogen, phosphorus, potassium, sulfur and other elements in easily accessible forms. It simultaneously retains these nutrients in the soil, preventing leaching and accelerated mineralization of organic matter, which often occurs during tillage and crop cultivation.

Figure 3 – White mustard

Common buckwheat (*Fagopyrum esculentum*) (Figure 4) has a vegetation period of 60–80 days, yielding 30–40 tons of biomass per hectare. The optimal growth temperature is 25–30 °C. Its powerful root system loosens and structures the soil. In addition to its taproot, buckwheat has fine branched roots that penetrate up to 35 cm deep. As these roots decay, they leave channels in the soil that facilitate air and water movement. The roots play a crucial role in green manuring, releasing acids such as citric, oxalic and formic, which make poorly soluble phosphorus compounds more accessible to most plants.

Buckwheat should be plowed under 7–10 days after the start of flowering. It acts as a phytosanitary agent, cleansing the soil of pathogenic microorganisms that cause diseases in cereal crops, including root rot.

Figure 4 – Common buckwheat

Biotechnology for Restoring Sandy Soils

The first stage of the proposed reclamation scheme is the introduction of uTerra biohumus into the sandy soil and sowing of green manure.

At this stage, a calculated amount of uTerra biohumus (from 1 %) is applied to the top soil layer (20 cm), thoroughly mixed and selected green manure plants are sown. After 90–105 days (depending on weather conditions), green manure is incorporated into the topsoil. Irrigation is planned at a rate of 12 waterings of 150 m^3/ha per reclamation cycle, with each cycle lasting up to three months.

Then, depending on the growth rate, obtained plant biomass and other factors, the next cycle of growing green manure crops is carried out. Calculations show that it is possible to achieve the necessary effect in approximately six cycles.

Planned agrochemical characteristics of land reclamation are given in Table 6.

The calculation is performed as follows (using humus as an example):

$$m_h = 0.01 + 1 + 0.5 \times 5 + 0.2 \times 6 = 4.71\ \%,$$

where m_h – humus content, mass percentage after six cycles;

0.01 – initial percentage of humus in sandy soil;

1 – percentage of growth at initial addition of 2 % biohumus;

0.5 × 5 – growth over five cycles of addition of 1 % uTerra biohumus;

0.2 × 6 – humus growth due to biomass over six cycles.

Materials for reclamation are summarized in Table 7. It is evident that the materials required for soil restoration are relatively modest. During the first reclamation cycle, 2 % uTerra biohumus is applied to a depth of 20 cm, while subsequent cycles use 1 %. The sand density is assumed to be 1.5 g/cm^3. Later testing revealed that due to the robust growth of crops, the amount of biohumus applied was reduced.

Table 6 – Planned agrochemical characteristics of soil remediation

Indicator	UAE sandy soil before reclamation	uTerra biohumus	Increase per cycle (three months) from biomass of 6 t/ha of dry matter	Increase per cycle (three months) from 1 % humus in 20 cm layer (30 t/ha)	Increase per cycle (three months) from 2 % humus in 20 cm layer (60 t/ha)	Result after six cycles (18 months)
Humus, %	0.01	50	0.2	0.5	1	4.71
Total nitrogen, %	0.03	0.9	0.01	0.009	0.018	0.153
Total phosphorus, %	0.02	0.9	0.04	0.009	0.018	0.323
Total potassium, %	0.6	0.9	0.06	0.009	0.018	1.023
pH	8.89	7	–	–	–	7–8.8

Table 7 – Materials for reclamation per 1 ha

Materials	Quantity, tons	
	One cycle (three months)	Six cycles (18 months)
uTerra biohumus	30	210
Green manure seeds	0.02	0.14
Water	1,800	10,800

This theoretical analysis confirms that using a stepwise biotechnology approach with uTerra biohumus can restore soil fertility in approximately 18 months. The resulting soil will have agrochemical characteristics intermediate between chernozem and sod-podzolic soil, making it suitable for agriculture.

Testing Biotechnology for Restoring Sandy Soils

To determine the reclamation mechanism and refine the optimal percentage of uTerra biohumus application, an experiment on stepwise soil restoration was conducted by the Unitsky String Technologies Inc. from 2022 to 2024. The experiment utilized unwashed construction sand with a particle size of 0–3 mm, which is nutritionally similar to desert sands. Loose uTerra biohumus, derived partly from the production waste of uTerra fertility elixir, served as the source of plant nutrients and soil structuring. Green manure was irrigated with running water without the addition of organic or mineral fertilizers. Plastic containers measuring 50 × 40 cm with a surface area of 0.2 m^2 were used.

The list of plants and the timeline of activities were adapted to laboratory conditions. The following green manure crops were planted: rapeseed, oilseed radish, mustard, peas, oats, phacelia and beans.

Experimental parameters (subtropical desert conditions):

- temperature – 20 °C during the day, 16 °C at night;
- humidity – 60 %;
- illumination – 8,000 lx for 12 h.

The experiment is set up in three variants:

- control: no organic additives;
- variant 1: 1 % uTerra biohumus + two additional applications of 0.5 %;
- variant 2: 2 % uTerra biohumus + two additional applications of 1 %.

After 12 months of testing (five reclamation cycles), cultivated plants such as lettuce and tomatoes were grown on the treated sandy soil.

Cycle 1: on August 18, 2022, the experiment was initiated with the application of uTerra biohumus (Figure 5) and the sowing of a cruciferous plant mix (Figure 6). The green manure crops were incorporated into the soil on October 3, 2022.

Figure 5 – Containers with applied uTerra biohumus

Figure 6 – Mixture of green manure crops (rapeseed, oilseed radish, mustard)

Cycle 2: peas and oats were sown on October 3, 2022 (Figure 7) and incorporated on January 10, 2023.

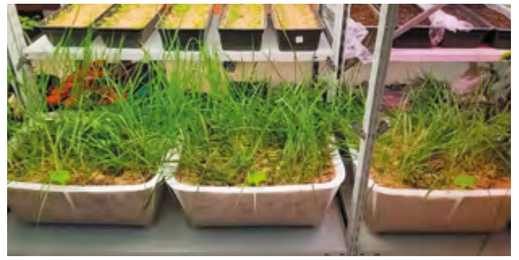

Figure 7 – Mixture of green manure crops (peas, oats)

Cycle 3: mustard was sown on January 10, 2023 (Figure 8) and incorporated on May 13, 2023.

Figure 8 – Mustard plants

Cycle 4: oat sowing was performed on May 13, 2023 (Figure 9) and incorporated on July 10, 2023.

Figure 9 – Oat plants

Cycle 5: phacelia and beans were sown on July 10, 2023 (Figure 10) and incorporated on August 15, 2023.

Figure 10 – Mixture of green manure crops (phacelia, beans)

Sowing of lettuce (Figure 11) was carried out on August 15, 2023 and harvesting was on October 25, 2023.

Lettuce yields were:

- control: 363 g (1,815 g/m^2, or 18.2 t/ha);
- variant 1: 725 g (3,625 g/m^2, or 36.3 t/ha);
- variant 2: 781 g (3,905 g/m^2, or 39.1 t/ha).

Figure 11 – Lettuce plants

Tomato planting (Figure 12) was carried out on October 25, 2023, harvesting on January 30, 2024.

Figure 12 – Tomato plants

Tomato fruit results (Figure 13):

- control: 117 g (585 g/m^2, or 5.85 t/ha);
- variant 1: 251 g (1,255 g/m^2, or 12.55 t/ha);
- variant 2: 368 g (1,840 g/m^2, or 18.4 t/ha).

Thus, from different variants of the experiment obtained from 5.85 to 18.4 tons of tomatoes per 1 ha.

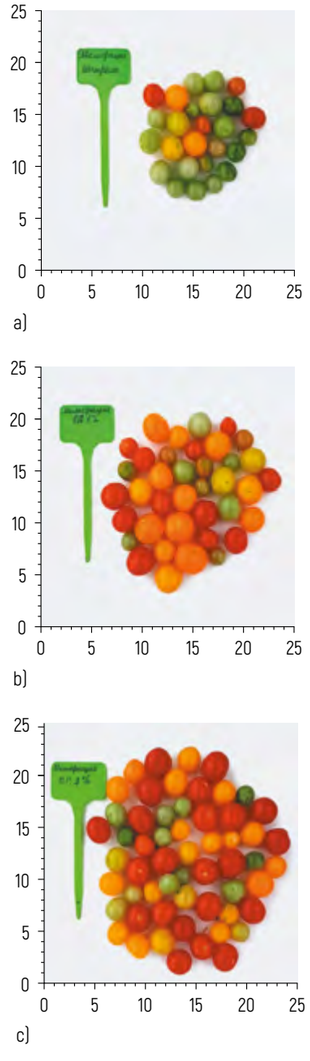

Figure 13 – Results of the experiment on tomato cultivation: a – control; b – variant 1; c – variant 2

Table 8 presents agrochemical results of soil remediation process in laboratory conditions.

Table 8 – Results of the soil remediation experiment

Indicator	Before restoration	Control	Variant 1	Variant 2
Humus, %	0.01	1.5	3	4.3
Nitrogen, mg/100 g	10	86	127	51
Phosphorus, mg/100 g	11	34	65	70
Potassium, mg/100 g	8	22	33	45
pH	8.89	8.6	8	6.3
Lettuce yield, t/ha	–	18.2	36.3	39.1
Tomato yield, t/ha	–	5.85	12.55	18.4

Based on the above results, we can conclude that the restoration of infertile soil by applying 2–4 % of uTerra biohumus and the use of green manure takes 12 months – during this time, fertile soil suitable for growing agricultural products has been obtained. A total application of 2 % of uTerra biohumus is sufficient, but the concentration can be increased to speed up the process if economically justified.

Conclusion

The authors propose a comprehensive approach to restoring desert sandy soils and utilizing reclaimed territories for environmentally sustainable energy crop production. Annually, up to 20 mln ha of agricultural land are lost, yet employing just 8.7 mln ha for energy farming could suffice to supply electricity to a country like Belarus.

The advantages of Unitsky String Technologies Inc. solutions, applied within the framework of the EcoSpace program, are highlighted as capable of reducing anthropogenic pressure on the environment and preventing land degradation.

The stepwise restoration of desert soils described in the article, using biotechnologies, enables the creation of fertile layers, improves water retention and aeration in the soil and enhances drought resistance at relatively low costs. Broad implementation of this approach could lead to the establishment of productive and sustainable ecosystems in arid regions. The biotechnological restoration of deserts requires fossil materials (brown coal, peat, etc.) only in the initial stage, while subsequently producing plant-based energy raw materials, the by-products generated through their application and processing – such as meal, distillery residues, plant remains and ash – hold value for both livestock farming and agriculture.

Using the example of desert soils in the UAE, the biotechnology of gradual fertility restoration in about 18 months is theoretically substantiated. The method involves six cycles of green manure cultivation and incorporation, along with the application of the required amount of uTerra biohumus at each stage, forming fertile soil through humus accumulation. This soil is suitable for most types of fruit and ornamental plants as well as technical crops.

In laboratory conditions, five reclamation cycles were conducted over 12 months (in a subtropical climate), followed by test cultivation of lettuce and tomatoes on the resulting fertile soil, with agrochemical analysis performed. Experimental data indicate that fertile soil can be created from sandy soil within 12 months using 2–4 % uTerra biohumus and five cycles of green manure cultivation and incorporation. The nutrient content in the soil created by this method allows for the cultivation of vegetable and green crops (tomatoes, lettuce) and is theoretically suitable for a wide range of energy crops such as paulownia, sorghum, rapeseed and sugarcane.

To assess the resilience of energy crops to climatic factors and determine cultivation specifics, an experimental paulownia plot was established at Unitsky's Farm Enterprise. Based on the experiment results, calculations of wood yield per hectare and refinement of cultivation parameters are planned.

Further experiments on desert soil restoration in tropical conditions, detailed analysis of obtained data, measurements of paulownia growth parameters at Unitsky's Farm Enterprise and in-depth studies of optimal energy production methods from plant raw materials are necessary.

Thus, the development of desert restoration biotechnologies represents a promising direction for creating a comfortable living environment, ensuring energy and food security in arid regions. This approach could prevent the global issue of soil degradation and positively impact the restoration of Earth's biosphere and biodiversity.

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Study of Soil Microbiota Activity at High Salt Content

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The research is focused on studying the impact of soil salinity on microbiological activity. The purpose of the work is to identify microorganism species immune to salinization, capable of maintaining their activity even at elevated salt content, as well as ensuring effective disposal of organic residues and soil fertility for a long time.

In the process of research, the influence of different concentrations of NaCl in the range from 0.05 to 1 % was analyzed. The results of experiments allowed to determine salt-resistant microorganisms and describe the conditions required to maintain their activity in saline soils. The data obtained can be used to optimize soil associations resistant to high salt content, as well as applied to plant cultivation in the EcoCosmoHouse (ECH) in orbit and in the ECH-Earth on the planet.

Keywords:
actinomycetes, EcoCosmoHouse (ECH), nitrogen-fixing bacteria, soil microorganisms, soil salinization.

Introduction

According to the Food and Agriculture Organization of the United Nations, currently, saline soils occupy vast areas – approximately 25 % of the entire land surface [1]. Soil salinization refers to the excessive accumulation of electrolytic (dissolved or absorbed) salts in the root zone, which suppresses or kills plants, reducing the quality and quantity of crops. Soils in deserts and semideserts have a high degree of salinity. In Russia, the total area of saline lands exceeds 40 mln ha. In Belarus, agricultural lands amount to 8.28 mln ha (39.9 % of the country's total area of 20.76 mln ha), and over the past seven years, the size of such lands has decreased by 1.5 % (0.35 mln ha) [2].

Excess salts are harmful to microorganisms and plants. The negative impact of soil salinization on biological objects leads to an alkaline reaction of the environment, high osmotic pressure, toxic effects of easily soluble salts (chlorides, nitrates, sulfates, carbonates, sodium and magnesium) as well as unfavorable water-physical properties of soils (reduced water permeability due to increased physical clay content, increased mineralization of organic matter), which causes a decrease in fertility levels and reduces the availability of macro-, micro- and ultramicroelements for plants [3].

In the case of salinization, there is a decrease in the degree of soil saturation with calcium due to its replacement by sodium and magnesium. It leads to the suppression of exchangeable calcium availability, the lack of which weakens the protective function of plants due to the membrane destabilization. The toxic effect of sodium is enhanced in the presence of chlorides, sharply worsening the absorption of nutrients from saline soil, especially NPK (nitrogen (N), phosphorus (P) and potassium (K)). Unbalanced mineral nutrition results in plant starvation, high susceptibility to pathogens and pests as well as reduced survival against extreme natural and anthropogenic factors [4].

Priority tasks include identifying and preventing factors causing soil salinization; preserving, reproducing fertility and rationally using saline soils in agriculture [5].

The microbial communities of the soil perform a fundamental role in cycling nutrients, in the volume of organic matter in the soil and in maintaining plant productivity. Thus, it is important to understand the microbial response to environmental stress, such as high concentrations of salts, which can be detrimental for sensitive microorganisms and decrease the activity of surviving cells [6].

Consequently, the aim of the study is to identify salt-tolerant microorganisms capable of maintaining their activity even under high salinity conditions and ensuring effective utilization of organic residues and soil fertility over a long period; to use them in obtaining substrates for plant cultivation in the EcoCosmoHouse (ECH) and ECH-Earth, where they will become a key element ensuring the stability and autonomy of these systems.

Objects and Methods of Research

Agronomically valuable microorganisms obtained from the world Bank of soils (created at Unitsky's Farm Enterprise, Maryina Gorka, Belarus), as well as actinomycetes, cellulolytic and nitrogen-fixing microorganisms with a complex of beneficial properties, isolated by the Biotechnologies Department of Unitsky String Technologies Inc. (Minsk, Belarus) were used for the preparation of the cultural liquid (hereinafter referred to as inoculum) [7, 8]: *Pseudomonas jessenii*, *Enterobacter cloacae*, *Pseudomonas umsongensis*, *Brevundimonas albigilva*, *Lelliottia* spp., *Citrobacter* spp., *Aeromonas* spp., *Bacillus* spp., *Paeniclostridium* spp., *Rhodococcus rhodochrous*, *Azotobacter vinelandii* BIM B-75. A series of experiments were conducted to study the effect of various salt concentrations on the number of microorganisms.

Among the widely distributed salts, sodium carbonate and chlorides are the most toxic, while sodium and magnesium sulfates are less so. Based on this, NaCl was added to the soil in different concentrations (from 0.05 to 1 %) and the inoculum of microorganisms (from 10 to 75 %). The control was the number of soil microorganisms without the addition of salt and inoculum as well as with the addition of NaCl in all the concentrations studied (from 0.05 to 1 %) but without the addition of inoculum (Table 1).

Table 1 – Symbols of experimental samples

Designation	Clarification
1	2
Inoculum 100 % (initial)	Pure inoculum
Control	Soil
Control + NaCl 1 %	Soil with NaCl 1 %
Control + NaCl 0.5 %	Soil with NaCl 0.5 %
Control + NaCl 0.05 %	Soil with NaCl 0.05 %
Inoculum 75 % + NaCl 1 %	Soil with inoculum 75 % and NaCl 1 %
Inoculum 75 % + NaCl 0.5 %	Soil with inoculum 75 % and NaCl 0.5 %
Inoculum 75 % + NaCl 0.05 %	Soil with inoculum 75 % and NaCl 0.05 %

End of Table 1

1	2
Inoculum 50 % + NaCl 1 %	Soil with inoculum 50 % and NaCl 1 %
Inoculum 50 % + NaCl 0.5 %	Soil with inoculum 50 % and NaCl 0.5 %
Inoculum 50 % + NaCl 0.05 %	Soil with inoculum 50 % and NaCl 0.05 %
Inoculum 20 % + NaCl 1 %	Soil with inoculum 20 % and NaCl 1 %
Inoculum 20 % + NaCl 0.5 %	Soil with inoculum 20 % and NaCl 0.5 %
Inoculum 20 % + NaCl 0.05 %	Soil with inoculum 20 % and NaCl 0.05 %
Inoculum 10 % + NaCl 1 %	Soil with inoculum 10 % and NaCl 1 %
Inoculum 10 % + NaCl 0.5 %	Soil with inoculum 10 % and NaCl 0.5 %
Inoculum 10 % + NaCl 0.05 %	Soil with inoculum 10 % and NaCl 0.05 %

During the study, microbiological and chemical analyses of the samples were performed on the 1st, 5th, 10th and 15th days. The microbiological analysis included the identification of the species and genus of microorganisms as well as the calculation of the total microbial count (TMC). The chemical analysis involved determining the content of NPK and other substances in the soil samples.

Research Results

Soil salinization creates unfavorable conditions for soil microorganisms. Increased salt concentrations lead to a high concentration gradient between the outer membrane of microbial cells and their surrounding environment. This hinders the normal transport of nutrients and ions through the cell membrane. Additionally, excess salts cause changes in the physicochemical properties of the substrate, making it less suitable for the life activities of microorganisms.

All these factors negatively affect the growth and activity of microorganisms, which in turn adversely impacts important biogenic processes in the soil, such as the mineralization of organic residues, nitrogen fixation and other biotransformations.

Salinity (especially the presence of table salt) has a strong inhibitory effect on soil microflora. Elevated concentrations of sodium and chloride ions hinder the normal metabolism and reproduction of microorganisms. This further exacerbates the negative consequences of salinization for biogenic processes in the soil.

The results of the experiments (Table 2) show that the groups of microorganisms in use are insensitive to the action of salts. However, at higher concentrations, the growth of the analyzed microorganisms is not observed.

Nitrogen-fixing bacteria were found to be the least resistant to salt. At concentrations above 0.05 %, they cease to develop, are sharply suppressed at a salt concentration of 1 %, and at more than 0.5 %, their life activities are completely inhibited.

A NaCl concentration of 0.05 % still allows cellulolytic bacteria to multiply; they can also withstand 0.5 % salt, but their numbers are halved. The number of actinomycetes decreases with increasing NaCl content, so that at 1 % salt, they are in an inactive state.

Analyzing the obtained data, it can be concluded that the selected microflora for the study is capable of tolerating higher concentrations of NaCl – up to 0.5 % – and remains active, participating in the processing of organic and mineral substances.

To fully understand the impact of salt on the microbial community, it is necessary to know not only the number of individual groups of microorganisms but also their total count.

From Table 3, it is evident that with an increase in the concentration of inoculum, there is generally an increase in the number of microorganisms in all samples. This indicates that the more microorganisms introduced, the higher their final count.

Additionally, it can be observed that with the same volume of inoculum, samples with lower NaCl concentrations usually have a higher TMC. This means that salt has an inhibitory effect on the growth and reproduction of microorganisms: the higher the concentration, the stronger this effect.

The experiment results demonstrate that to achieve the maximum level of total microorganisms, it is necessary to introduce a sufficient amount of inoculum and not to exceed the permissible salt concentration in the environment.

Together with recording the overall microbial contamination, the identification of the species and genus of microorganisms was carried out. This process was conducted to compare the microorganisms present in the initial inoculum and the obtained soil samples, and to identify new bacteria that were present in the soil before the addition of cultures.

Smear microscopy and Gram staining were performed to study the morphological characteristics of the microorganisms. Cultural properties were determined by inoculating on solid agar media. The shape, edge contour, size, diameter, color of colonies, their structure and consistency were taken into account. Herewith, differential diagnostic media were used to study the biochemical activity of cultures, including oxidase and catalase activity.

Table 2 – Microbiological indicators of saline soils

Sample composition	Number of microorganisms, CFU/g		
	Nitrogen-fixing bacteria	Cellulolytic bacteria	Actinomycetes
Inoculum 100 % (initial)	3×10^8	2×10^8	6×10^8
Inoculum 75 % + NaCl 1 %	–	–	–
Inoculum 75 % + NaCl 0.5 %	–	5×10^4	1×10^4
Inoculum 75 % + NaCl 0.05 %	1×10^5	3×10^6	1×10^6
Inoculum 50 % + NaCl 1 %	–	–	–
Inoculum 50 % + NaCl 0.5 %	–	2×10^4	2×10^4
Inoculum 50 % + NaCl 0.05 %	6×10^4	1×10^6	6×10^5
Inoculum 20 % + NaCl 1 %	–	–	–
Inoculum 20 % + NaCl 0.5 %	–	4×10^3	7×10^3
Inoculum 20 % + NaCl 0.05 %	8×10^4	5×10^5	2×10^5
Inoculum 10 % + NaCl 1 %	–	–	–
Inoculum 10 % + NaCl 0.5 %	–	8×10^3	5×10^4
Inoculum 10 % + NaCl 0.05 %	5×10^4	1×10^5	3×10^6

Table 3 – Microbiological results of soil salinization (general)

Sample composition	TMC, CFU/g			
	1st day	5th day	10th day	15th day
Inoculum 100 % (initial)	1×10^9	–	–	–
Control	6×10^8	–	–	–
Control + NaCl 1 %	–	5×10^7	1×10^7	5×10^3
Control + NaCl 0.5 %	–	2×10^8	5×10^7	1×10^5
Control + NaCl 0.05 %	–	2×10^8	3×10^7	9×10^5
Inoculum 75 % + NaCl 1 %	–	6×10^7	9×10^5	2×10^3
Inoculum 75 % + NaCl 0.5 %	–	7×10^7	4×10^6	1×10^5
Inoculum 75 % + NaCl 0.05 %	–	9×10^8	6×10^7	8×10^6
Inoculum 50 % + NaCl 1 %	–	1×10^8	9×10^6	2×10^2
Inoculum 50 % + NaCl 0.5 %	–	8×10^8	7×10^6	2×10^5
Inoculum 50 % + NaCl 0.05 %	–	1×10^8	8×10^7	2×10^6
Inoculum 20 % + NaCl 1 %	–	5×10^6	5×10^5	2×10^2
Inoculum 20 % + NaCl 0.5 %	–	9×10^7	3×10^5	9×10^3
Inoculum 20 % + NaCl 0.05 %	–	1×10^8	8×10^7	1×10^5
Inoculum 10 % + NaCl 1 %	–	6×10^6	3×10^4	8×10
Inoculum 10 % + NaCl 0.5 %	–	1×10^7	7×10^6	3×10^2
Inoculum 10 % + NaCl 0.05 %	–	2×10^8	7×10^7	2×10^4

Before conducting the experiment, Gram staining was performed to identify the microorganisms planned for use in the inoculum (Figure 1). The stained microorganisms included: *Pseudomonas jessenii*, *Enterobacter cloacae*, *Pseudomonas umsongensis*, *Brevundimonas albigilva*, *Lelliottia* spp., *Citrobacter* spp., *Aeromonas* spp., *Bacillus* spp., *Paeniclostridium* spp., *Rhodococcus rhodochrous*, *Azotobacter vinelandii* BIM B-75.

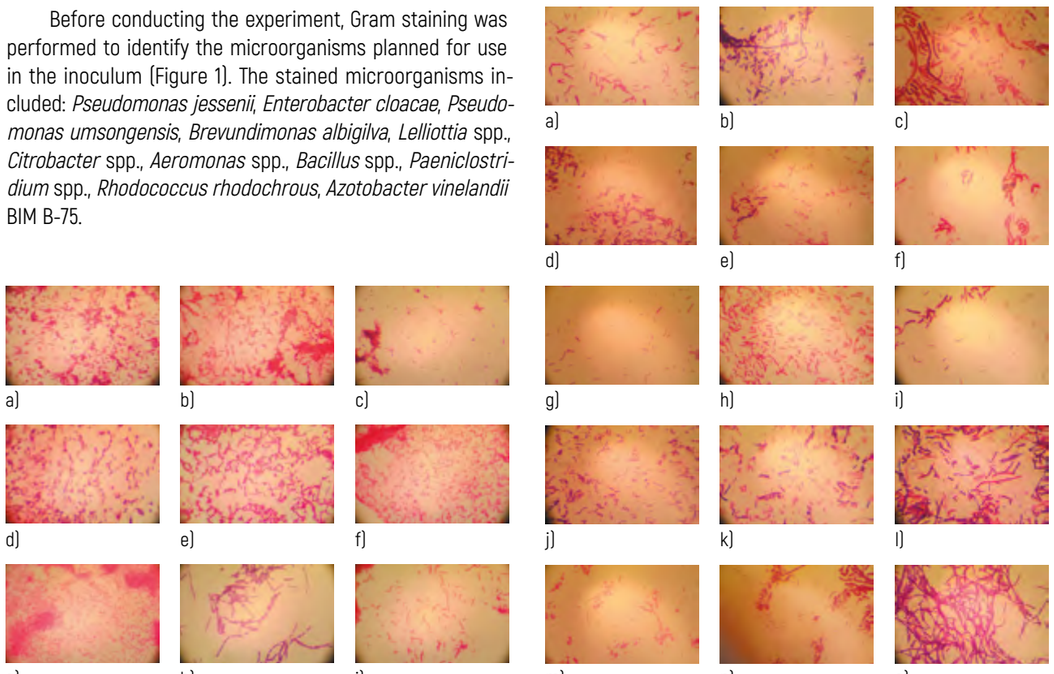

Figure 1 – Stained microbial cultures of under the microscope:
a – *Pseudomonas jessenii*; b – *Enterobacter cloacae*;
c – *Pseudomonas umsongensis*; d – *Brevundimonas albigilva*;
e – *Lelliottia* spp.; f – *Citrobacter* spp.; g – *Aeromonas* spp.;
h – *Bacillus* spp.; i – *Paeniclostridium* spp.;
j – *Rhodococcus rhodochrous*;
k – *Azotobacter vinelandii* BIM B-75

Figure 2 – Stained microbial cultures under the microscope:
a – control + NaCl 1 %; b – control + NaCl 0.5 %;
c – control + NaCl 0.05 %; d – inoculum 75 % + NaCl 1 %;
e – inoculum 75 % + NaCl 0.5 %; f – inoculum 75 % + NaCl 0.05 %;
g – inoculum 50 % + NaCl 1 %; h – inoculum 50 % + NaCl 0.5 %;
i – inoculum 50 % + NaCl 0.05 %; j – inoculum 20 % + NaCl 1 %;
k – inoculum 20 % + NaCl 0.5 %; l – inoculum 20 % + NaCl 0.05 %;
m – inoculum 10 % + NaCl 1 %; n – inoculum 10 % + NaCl 0.5 %;
o – inoculum 10 % + NaCl 0.05 %; p – control

On 15th day after the addition of NaCl to the soil, identification was carried out, revealing not only the microorganisms present in the initial inoculum but also microorganisms originally present in the soil, predominantly gram-negative rods (Figure 2).

The presence of microorganisms after 15 days indicates their resistance to soil salinization conditions. It can be assumed that these microorganisms possess mechanisms for adapting to high salt concentrations, allowing them to survive and maintain their activity in such an environment.

Influence of NaCl on Soil Elements Content

Table 4 presents the results of the quantitative analysis of the content of elements in the soil after the addition of NaCl. Herewith, it is evident that the added NaCl had almost no effect on the soluble salts of lithium, potassium and phosphorus. However, the concentration of nitrogen significantly decreased, while the concentration of sodium, as expected, noticeably increased. The calcium content initially increased but then returned to its original level.

Table 4 – Quantitative analysis of soil salinity, mg/100 g

Sample composition	Nitrogen	Phosphorus	Potassium	Sodium	Lithium	Calcium
Control	4,347.83	139.9	185.79	36.9	8.9	1,296.5
Control + NaCl 1 %	1,593.72	137.23	298.03	2,043.08	9.25	3,322.33
Control + NaCl 0.5 %	2,025.23	165.88	224.88	1,306.13	8.95	2,767.75
Control + NaCl 0.05 %	1,509.86	161.08	194.65	203.9	6.44	2,726.98
Inoculum 75 % + NaCl 1 %	1,053.99	176.33	178.33	765.1	8.03	1,647.47
Inoculum 75 % + NaCl 0.5 %	1,314.37	183.13	222.37	461.13	8.37	1,627.53
Inoculum 75 % + NaCl 0.05 %	1,708.37	174.43	218.77	135.57	7.27	1,351.87
Inoculum 50 % + NaCl 1 %	1,307.46	248.07	237.57	795.27	9.13	1,855.87
Inoculum 50 % + NaCl 0.5 %	1,449.76	190.3	251.27	510.9	7.53	1,626.63
Inoculum 50 % + NaCl 0.05 %	1,672.91	189.37	241.37	206.37	7.77	1,493.67
Inoculum 20 % + NaCl 1 %	1,550.09	183.53	237.97	662.53	9.23	1,711.9
Inoculum 20 % + NaCl 0.5 %	2,107.36	177.2	231.83	277.8	8.13	1,480.2
Inoculum 20 % + NaCl 0.05 %	1,882.31	189	223.03	127.3	7.4	1,310
Inoculum 10 % + NaCl 1 %	1,315.83	183.27	236.3	722.87	9.13	1,820.8
Inoculum 10 % + NaCl 0.5 %	1,414.68	143.1	242.03	400.47	8.7	1,593.3
Inoculum 10 % + NaCl 0.05 %	1,717.75	146.9	230.7	120.17	7.37	1,277.07

Nitrogen. Figure 3 shows the dynamics of the nitrogen content after the addition of NaCl.

A decrease in the concentration of the element is observed in all samples immediately after the addition of salt. High NaCl content could inhibit the activity of nitrogen-fixing bacteria and alter the osmotic conditions in the soil, making water and nutrients less accessible to microorganisms. This, in turn, could lead to a decrease in their activity and, consequently, a reduction in atmospheric nitrogen fixation.

In the control samples with NaCl 0.5 and 1 %, an increase in nitrogen concentration is noted on the 5th and 15th days, respectively. This is caused by the temporary release of the element from organic compounds in the soil under the influence of salt in the absence of competition from microorganisms.

In the samples with the addition of inoculum 20 % and NaCl 0.05 %, the nitrogen concentration increased on the 5th day, and in the samples with inoculum 20 % and NaCl 0.5 %, it increased on the 10th day. This fact may indicate the gradual adaptation of nitrogen-fixing microorganisms to salinization conditions and the restoration of their activity, which is also confirmed by the previously obtained results.

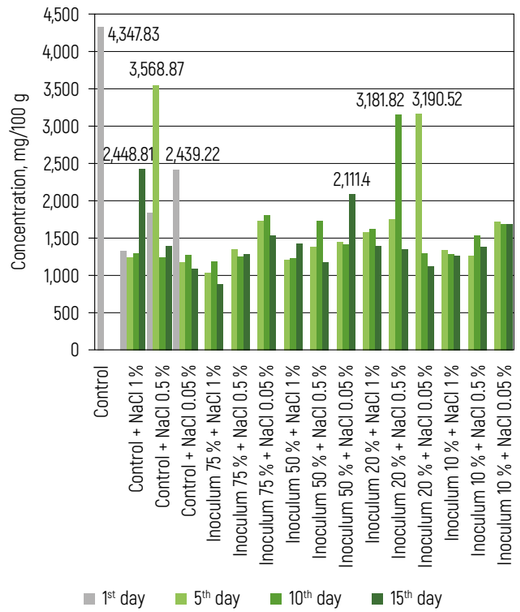

Figure 3 – Nitrogen content in soil

Phosphorus. Based on the presented data (Figure 4), it can be concluded that after the addition of NaCl, the phosphorus concentration practically did not change, with only a slight increase noted. This means that the presence of salt did not have a significant impact on the processes of mineralizing organic residues and releasing the element throughout the experiment.

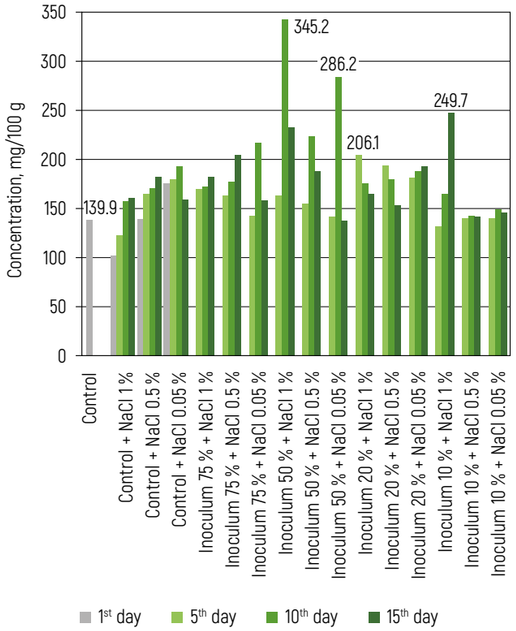

Figure 4 – Phosphorus content in soil

Calcium. The calcium concentration remains almost at the same level after the addition of NaCl, except for a sharp spike in the control samples with NaCl 1, 0.5 and 0.05 % on the 1st day (Figure 5). The presence of salt could have contributed to the temporary release of the element from organic and mineral compounds in the soil, leading to a sharp increase in its concentration.

Potassium. On the 5th day, an increase in potassium concentration is observed in the control sample with NaCl 1 % (Figure 6). However, in the samples with the addition of inoculum, a decrease in the element content is noted, probably due to its consumption by microorganisms for their metabolism.

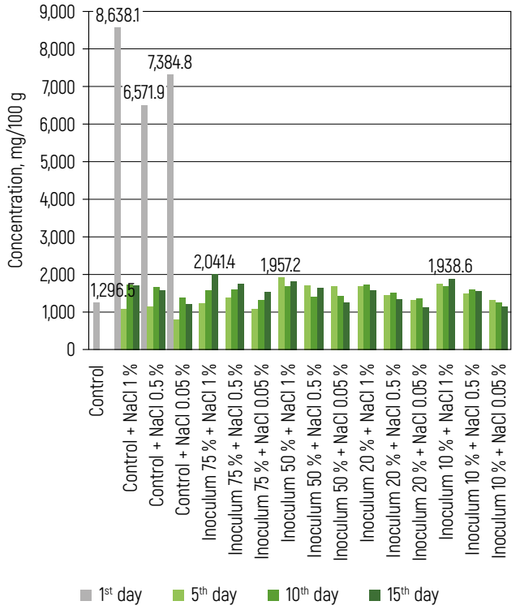

Figure 5 – Calcium content in soil

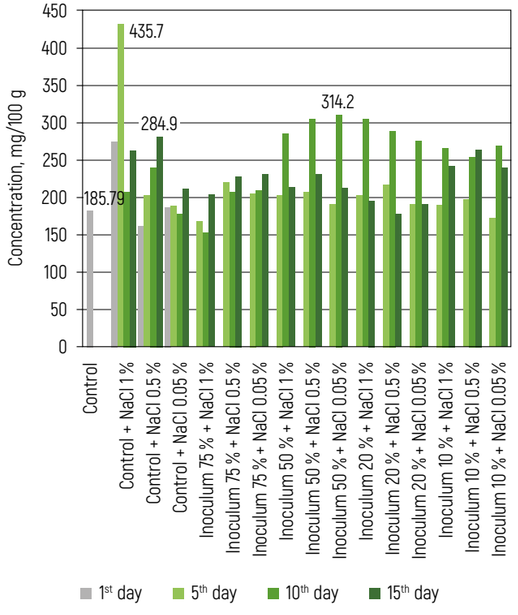

Figure 6 – Potassium content in soil

On the 10th day, the potassium concentration increased in most samples and remained relatively stable. This may be caused by the release of the element from soil minerals and organic compounds under the influence of NaCl as well as the adaptation of microorganisms to salinization conditions.

Therefore, the dynamics of potassium concentration in the soil are determined by the interaction between the microbial communities added to the inoculum and the processes of release and absorption of the element in the presence of salt. The stabilization of potassium levels on the 10th day indicates the establishment of a new equilibrium in the soil system after the addition of NaCl.

Sodium. A significant increase in sodium concentration is observed after the addition of NaCl (Figure 7), which is an expected result.

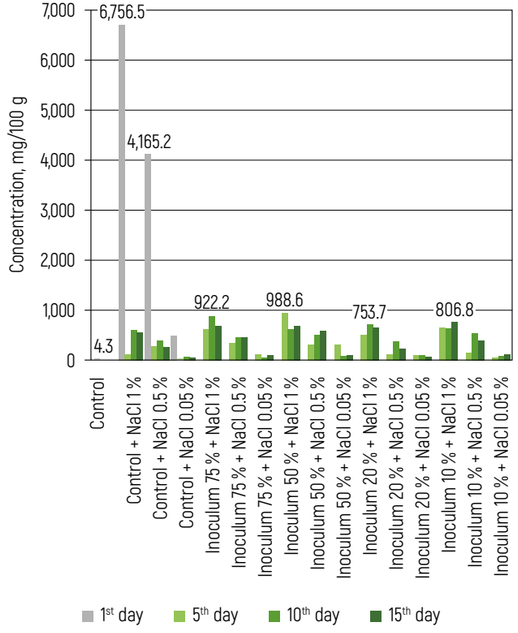

Figure 7 – Sodium content in soil

Lithium. The lithium concentration remains almost at the same level in all samples after the addition of NaCl. However, an increase is observed on the 1st day in two control samples with NaCl 1 and 0.5 % (Figure 8).

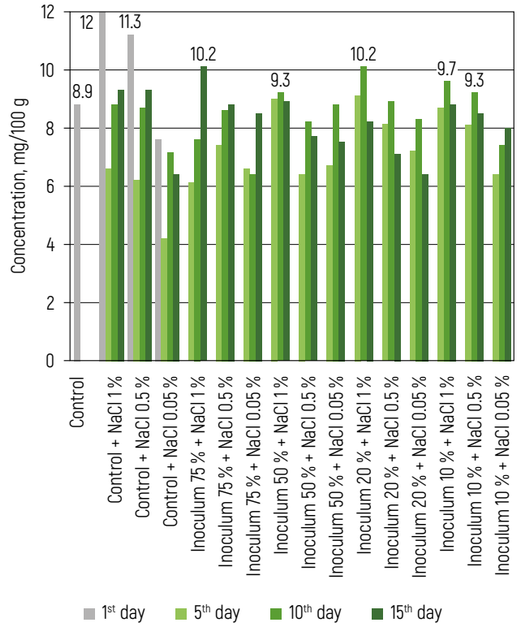

Figure 8 – Lithium content in soil

This may be due to the temporary release of lithium from soil compounds under the influence of salt. Nevertheless, in the following days, this effect was likely compensated by other processes, leading to the stabilization of the element concentration.

Conclusion

In the course of the study, a number of microorganisms were selected that are resistant to soil salinization conditions and possess mechanisms for adapting to high salt concentrations, allowing them to maintain their activity in such an environment. Accordingly, their application, along with the addition of organic fertilizers, can be beneficial for the reclamation of salt-affected soils. Bacteria capable of processing organic matter in the presence of significant salt content will contribute to improving soil structure and fertility.

The most resistant to salinization were cellulolytic microorganisms and actinomycetes. At the same time, nitrogen-fixing bacteria do not withstand salt concentrations above 0.05 %, which negatively affects the nitrogen regime of the soil.

To ensure a high total number of microorganisms in the soil, it is necessary to introduce a sufficient amount of inoculum with salt-resistant microorganisms and maintain a low salt concentration in the environment. This will create optimal conditions for bacterial development and the preservation of their activity.

This study has identified microorganisms with mechanisms for adapting to salinization and determined the factors necessary for their activity.

Such bacteria can be useful for creating and maintaining enclosed ecosystems, including in orbit in the ECH and on the planet in the ECH-Earth. In particular, they can be used in the design of artificial substrates for growing agricultural crops. Due to their resistance to salinization, these microorganisms will ensure the effective processing of organic residues and soil fertility over a long period. Additionally, they can be applied for biological wastewater treatment and waste disposal. This will help to maintain the autonomy of the ecosystem and an enclosed cycle of substances.

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Application of *Chlorella vulgaris* to Improve Efficiency of Quail Breeding in EcoCosmoHouse

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The possibility of using suspension of unicellular alga *Chlorella vulgaris* in the EcoCosmoHouse (ECH) as supplementary feeding for quails is considered. The method of chlorella cultivation is shown: the cultivation unit, nutrient medium and microclimate parameters for suspension preparation are described.

The method of keeping quails in the ECH is proposed, nutritional properties of the products obtained from them are reviewed. The studies on feeding chlorella suspension into poultry diet are presented. Qualitative (amount of protein from the egg white and yolk, number of deformed eggs) and quantitative (egg-laying capacity, live weight increase) productivity indicators regarding quails that received the suspension as a supplementary feeding were determined. Its influence on the general vital activity of poultry, condition of limbs and feather cover as well as on feed intake by quails was established.

Keywords:
chlorella, chlorella cultivation unit, EcoCosmoHouse (ECH), quail breeding, quail productivity.

Introduction

Microalgae occupy a special place among plant organisms, as they perform the unique process of storing solar energy in photosynthesis products with high efficiency and are the first trophic level organisms synthesizing organic matter in the World Ocean. The productivity of marine and freshwater microalgae is comparable to the productivity of all terrestrial plants, including agricultural lands [1].

With the large-scale space exploration such algae, especially chlorella, are considered a crucial component in enclosed ecological systems, ensuring biological air regeneration and food reproduction. This idea was first proposed by K. Tsiolkovsky, who suggested that these plant organisms could utilize human metabolic products during long-term space flights and extraterrestrial habitation.

The advantages of microalgae include the absence of noticeable changes in their physiological and population state and side effects when coexisting with humans in enclosed systems, high oxygen productivity (for chlorella – 25–30 l per day from 1 l of suspension) and the possibility of replenishing food supplies during extended space missions [2, 3].

According to the uSpace program developed by engineer A. Unitsky, chlorella is planned to be used in the EcoCosmoHouse (ECH) for oxygen production, wastewater treatment and as a food supplement for humans [4, 5]. Additionally, the possibility of using *Chlorella vulgaris* in the diet of farm animals should be considered. Therefore, this study aims to investigate the use of chlorella suspension as a feed additive to improve the productive performance of quails kept under the ECH conditions.

Chlorella as an Element of Enclosed Ecosystem

Chlorella (Figure 1) is an important subject of study in space biology as a producer of oxygen, nutrients and as an organism capable of purifying the atmosphere from harmful impurities. It was used for oxygen production in the enclosed ecosystems of the BIOS-1 and BIOS-2 projects. According to experiments, about 10 l of water with this microalga are sufficient to meet the carbon-oxygen balance needs of one person [2, 6].

Chlorella is a source of proteins, carbohydrates, lipids and vitamins. Its dry biomass contains 42–58 % protein, 12–55 % carbohydrates, 5–40 % lipids and up to 10 % minerals, depending on cultivation conditions. The protein of this microalga includes more than 40 amino acids, in particular all the essential ones.

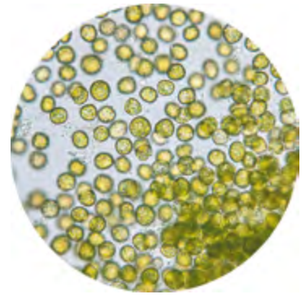

Figure 1 – *Chlorella vulgaris*

It contains aspartic, gamma-aminobutyric and glutamic acids, glycine, serine, alanine, cystine, tyrosine, proline and β-alanine. The nucleic acid content in chlorella varies from 4 to 7 % [6, 7].

Due to its high content of vitamins and other micronutrients, chlorella is a highly effective supplement to plant feeds and agricultural crops. In 1 g of its dry matter, it contains (in μg): carotene (provitamin A) – 1,000–1,600, vitamins B_1 – 2–18, B_2 – 21–28, B_6 – 9, C – 1,300–5,000, K – 6, PP – 110–180, E – 10–350, pantothenic acid – 12–17, folic acid – 485, biotin – 0.1, leucovorin – 22. Besides carotene, which is 7–10 times more abundant in chlorella than in, for example, rose hips or dried apricots, this alga, unlike higher plants, also includes pure vitamin A up to 1,000 μg per 1 g of dry matter as well as provitamin D – 1,000 μg and vitamin B_{12} – 0.0025–0.1 μg.

Chlorella contains a wide range of steroids, sterols, corticosteroids, sacogenins, steroid alkaloids, vitamin D group compounds and other substances that play a crucial role at every stage of development of any living organism. About 80 % of the fatty acids in this microalga are unsaturated, which are precursors of prostaglandins, possessing high biological activity and ensuring hormonal regulation of almost all physiological processes in animals as well as maintaining homeostasis.

The macro- and microelement composition of chlorella suspension includes calcium, phosphorus, magnesium, potassium, copper, iron, sulfur, zinc, cobalt, manganese, zirconium, rubidium, etc. The cells of this alga are rich in iodine [6–8].

In an enclosed gas and water ecosystem, chlorella can supply people with oxygen by absorbing carbon dioxide and utilizing their metabolic products almost indefinitely (experiments lasted up to a year), but humans cannot fully consume the synthesized biomass of chlorella [3]. Moreover, it is impossible to use only this microalga as food due

to the poor digestibility of its cell wall and a high protein content in its cells [9, 10]. However, chlorella biomass in the form of suspension, dry matter or paste is an excellent feed additive for farm animals, increasing resistance to infectious diseases, normalizing metabolism, improving digestive system function and removing toxins from the body [6, 11].

Cultivation of Chlorella in EcoCosmoHouse Conditions

The nutrient medium for cultivating chlorella must contain macro-, micro- and ultramicroelements that ensure the normal functioning of the cells. At the same time, during the preparation process, the suspension should not retain a large amount of unused nitrogen and nitrates, as this would make it unsuitable for animal consumption.

Optimizing the nutrient medium for growing chlorella is an effective method to enhance the biosynthetic activity of the alga for producing biologically active substances as well as to make such media more economical. The Biotechnology Department of Unitsky String Technologies Inc. (Minsk, Belarus) has experimentally developed its own nutrient medium formula for cultivating *Chlorella vulgaris*. For the first time, plant growth stimulants (IBA, NAA, 6-BAP, 2,4-D, 2,4-D + 6-BAP and NAA + kinetin) were introduced as additional components into the medium.

The cultivation period for each experiment was 14 days. During 10 of these days, measurements of the optical density of the chlorella suspension were taken in all containers (500 ml flasks) to monitor cell growth. For each stage, one flask of standard Tamiya medium (150 ml) was prepared, for which cell growth indicators were selected for optimization. Adjustments were made to the nitrogen (KNO_3), potassium and phosphorus (KH_2PO_4), magnesium ($MgSO_4$) content and plant growth stimulants. As a result, an optimal nutrient medium composition was formed (KNO_3; $MgSO_4 \cdot 7H_2O$; KH_2PO_4; $FeSO_4 \cdot 7H_2O$; EDTA; 6-BAP), containing the minimum amount of nitrates necessary only for the development and division of the cell structure itself.

This medium showed a better suitability for cultivating chlorella compared to the standard one and contributed to a constant increase in the concentration of the studied alga (Figure 2). The average cell growth value in the optimized nutrient medium was 3.4 mln/ml per day. For comparison: in Tamiya medium – 1.7 mln/ml; in unfiltered water – 0.7 mln/ml; no chlorella growth was observed in filtered water.

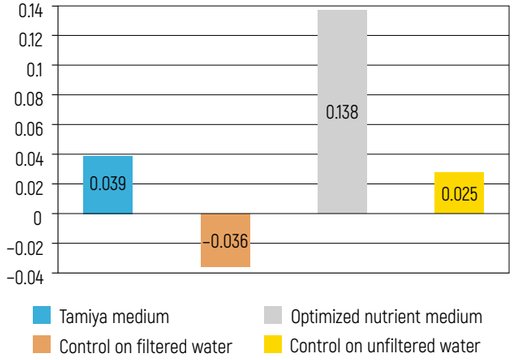

Figure 2 – Average daily growth of chlorella suspension (optical density)

The cultivation of chlorella was carried out in an experimental unit by Unitsky String Technologies Inc., designed for semiautomatic cultivation of unicellular algae (Figure 3). The device allows for the regulation of lighting periods. In our case, "day" (10 h) and "night" (14 h) cycles were used. The internal space of the unit contains four cultivation tanks (each with a nominal volume of 80 l), lighting system, mixing system, carbon dioxide supply and a system for draining the finished suspension.

Figure 3 – Experimental unit for chlorella cultivation:
1 – container with tanks; 2 – gas cylinder; 3 – control cabinet; 4, 5 – lids

Due to the fact that light is the main abiotic factor influencing the growth and development of chlorella, special attention was paid to lighting: LED lamps were arranged to cover the maximum surface area of each tank (Figure 4). The internal space of the unit was lined with aluminum foil which provided additional reflection of the light flow.

During the cultivation of chlorella under the created conditions (experimental unit, optimized nutrient medium, suitable microclimate parameters), a suspension with sufficient cell uniformity in all containers (Figure 5), a specially selected chemical composition and suitable for quail feeding was prepared. The obtained data can be applied in the organization of biospheric processes in the ECH.

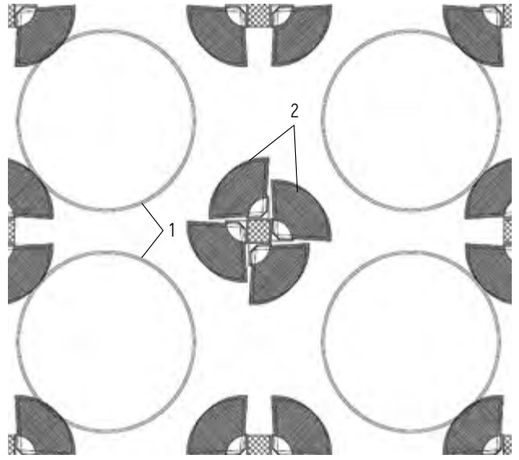

Figure 4 – Lighting arrangement inside the unit:
1 – tanks basin for chlorella growing; 2 – lamps

Figure 5 – Chlorella suspension under the microscope (40× magnification)

Keeping Quails in EcoCosmoHouse Conditions

During long-term experiments in the ground-based BIOS-3 complex with a crew and higher plants, it was found that in an artificial ecological system "human – higher plants," enclosed by gas at 100 %, water exchange at 80 % and food process at 55 %, a stable balanced cycle of substances is possible. However, animal products remained unavailable there [9].

In an isolated enclosed ecosystem, keeping small animals (rabbits, goats, sheep, alpacas, quails, chickens, small predators) [5] seems optimal, as they have high growth rates, short life cycles and high productivity. The corresponding technological equipment should have minimal volume and mass [12]. Smaller organisms have faster metabolism, which accelerates the processes of nutrition and element movement in an enclosed ecosystem [5].

Quails meet most of these requirements, as they do not need significant space, with the primary method of keeping them being in cages (Figure 6). These birds are characterized by small size, short incubation and sexual development periods, high productivity and metabolic rate [12]. They are unpretentious in terms of keeping conditions, have a gentle disposition, make pleasant sounds and lay eggs almost daily. The resistance of quails to infectious diseases allows them to be raised without vaccination, which eliminates the accumulation of medicinal substances in their bodies and eggs [13].

Figure 6 – Cage keeping of quails

Japanese quail chicks are capable of growing and developing under conditions of hypodynamia and prolonged artificial weightlessness [14]. Additionally, the embryogenesis of this bird can proceed in weightlessness without serious difficulties [15].

When using quails for egg and meat production in enclosed ecological systems, it is recommended to:

- place the birds in cells measuring 120 × 159 × 100 mm, restricting their movement;
- feed the quails with a moist compound feed (ratio with water 1 : 1), containing 1.14 MJ of metabolizable energy and 17 % crude protein per 100 g;
- maintain a light regime with a constant light day lasting 13 h and 30 min (illumination from 35 lx, but not more than 107 lx) [12].

One of the features of quail eggs is their ability to be stored for a long time. At room temperature, only some drying of their contents may be observed, but spoilage due to the development of microorganisms is excluded. Quail eggs and meat are considered dietary food products and are used in the treatment of many diseases [13, 16]. In terms of nutritional value, these eggs are not inferior to chicken eggs, and in terms of the amount of certain vitamins (A, B_1, B_2), microelements (magnesium, iron) and other nutrients, they even surpass them. For most brooding birds, the eggshell makes up more than 10 % of its mass, while for quails, it is 7.2 %. In five quail eggs, equal in weight to one chicken egg, there is five times more potassium, 4.5 times more iron and 2.5 times more vitamins B_1 and B_2. Additionally, this product contains a significant amount of vitamin A, nicotinic acid, phosphorus, copper, cobalt, limiting (threonine, valine, isoleucine, leucine, phenylalanine, histidine, lysine) and other (serine, glutamic acid, glycine, arginine) amino acids. Quail eggs are a concentrated biological set of essential substances for humans and can be consumed whole, including the shell [13].

Application of Chlorella Suspension as a Feed Additive for Quails

To enhance the efficiency of quail breeding, standard diets are often enriched. Among the live feed additives is chlorella which is also a natural probiotic and has antagonistic properties against pathogenic microorganisms [17, 18].

In this study, the strain of microalga *Chlorella vulgaris* IBCE C-19 was used, characterized by high productivity and meeting the requirements of industrial cultivation. It has pronounced planktonic properties, with cell sedimentation starting after 6–15 days in a resting state. Texas quails were chosen for the experiment due to their relatively large mass (live weight at 42 days is 27.6 and 22.4 % higher compared to the Omsk breed and Pharaoh, respectively), increased precocity and unpretentiousness in keeping.

Quails were raised from three weeks to 250 days of age for full control of the experiment. On the 48th day, it became possible to determine the sex of the chicks, and they were divided into two groups of 17 individuals: control (standard diet) and experimental (diet with chlorella feed additive). Each group consisted of 15 females and two males. The quails were kept in cage structures (Figure 7). The feeder was attached to the front wall of the cage, and the drinker to the side. Feeding was done manually, based on the norm of 25 g of compound feed before sexual maturity and 35 g after. Technological parameters (air humidity, temperature, illumination) met the requirements for poultry farming.

Figure 7 – Experimental groups of Texas quail breed

During the study, the chlorella suspension was added to the experimental group of quails through the drinking system every day: during the first week of keeping – at a rate of 5 ml/head, after three weeks – 15 ml/head and at 63 days of age – 25 ml/head. The control group received clean water without the suspension. The specified norms of compound feed and microalga were used in full and did not change during the experiment.

Quails that received chlorella as a feed additive to their standard diet did not produce any deformed eggs throughout the study. In the control group, 6 % of the eggs were rejected based on their appearance, particularly due to the condition of the shell (Figure 8). An approximately equal amount of substandard products was identified during periods of high egg-laying capacity and its decline, indicating that age was not a significant factor in egg deformation.

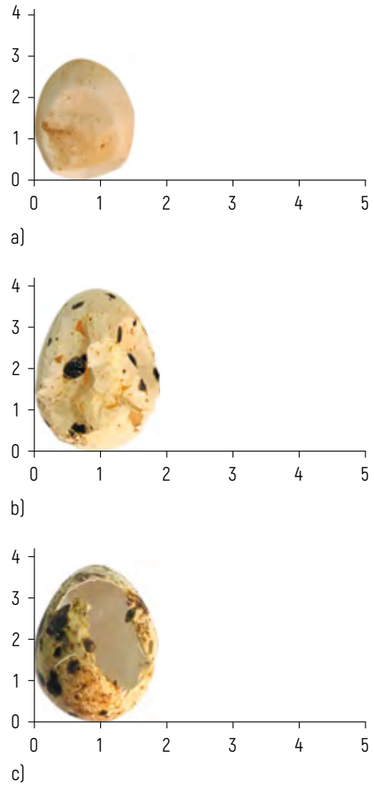

Figure 8 – Quail eggs from the control group:
a – absence of shell; b – thin shell; c – fragile shell

The lack of microelements in the control group quails was also observed in the form of joint deformities, which led to a reduced active life. Additionally, callous formations were noted. Similar states were found in quails receiving chlorella feed additive, but to a lesser extent: 6 % compared to 18 %. The third age group was most susceptible to such deformities.

The feed additive increased the egg productivity of the quails throughout the study (Figure 9), but it did not have a significant impact on egg-laying capacity related to the age of the birds.

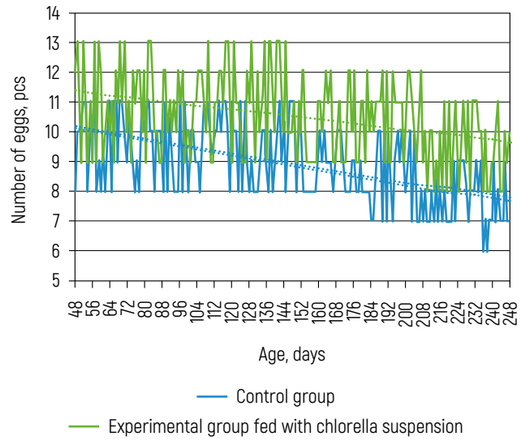

Figure 9 – Quail egg-laying capacity

Feather growth and development disorders were observed in both groups of birds throughout the experiment, with a ratio of nine individuals in the control group to three individuals in the group receiving the feed additive. The age factor did not affects this parameter.

The comprehensive vitamin deficiency in the control group quails was reflected in the reduction of size of compounds and structural components of the laid eggs (Table). Quantitative indicators (absolutely dry protein from egg white and absolutely dry protein from the yolk) were determined by the mass of denatured protein using hydrochloric acid: the average value of three eggs per group was considered.

Table – Quantitative indicators of the studied eggs

Indicator	Control group	Experimental group fed with chlorella suspension
Volume of raw egg white, ml	16	18
Mass of raw egg white, g	15.8	16.16
Volume of raw yolk, ml	11	12
Mass of raw yolk, g	15.4	14.97
Absolutely dry protein from egg white, g	2.16	2.38
Absolutely dry protein from yolk, g	0.61	0.89

Quails that received chlorella as a feed additive had increased protein content in their eggs, including four nonessential amino acids (serine, glutamic acid, glycine and arginine) and seven essential ones (threonine, valine, isoleucine, leucine, phenylalanine, histidine and lysine). Consequently, the content of these amino acids in the eggs was higher, indicating better organization of metabolic processes and transformation of nutrients into dietary products.

Additionally, it was found that quails receiving the feed additive consumed, on average, 23 % less compound feed despite the improvement in their overall condition.

Thus, adding *Chlorella vulgaris* suspension to the quails' diet improves their development, increases productivity and reduces feed consumption, which can be applied to optimize production processes in the ECH.

Conclusion

Animal products play a crucial role in providing humans with nutrients and biologically active substances, macro-, micro- and ultramicroelements. Therefore, for optimal human life in the ECH conditions, it is necessary to develop technology for keeping and feeding farm animals in an enclosed ecosystem. A suitable option, given the limited space, is the use of small animals that grow quickly, have a high feed conversion rate, significant productivity and are not too costly to maintain. Quails meet these requirements, providing products with dietary properties. Additionally, chlorella microalga can be used as a feed additive for these birds, playing an important role in the ECH: producing oxygen, absorbing carbon dioxide, purifying wastewater and serving as food. It contains over 650 substances, including essential amino acids, fats, vitamins, macro-, micro- and ultramicroelements in an easily digestible form, which significantly influence the growth, development, meat productivity and overall feed consumption of birds.

The optimized nutrient medium for cultivating chlorella, developed by the Biotechnology Department of Unitsky String Technologies Inc., has doubled the productivity of the alga compared to the standard nutrient medium and increased it by 4.8 times compared to water. During the research, conditions for growing microalga on the optimized nutrient medium in an experimental unit created by the Biotechnology Department were selected to obtain chlorella suspension for further use as a feed additive.

The main positive effects of using this suspension in the diet of quails:

- improved egg quality (the amount of protein from the yolk and egg white is 46 and 10 % higher compared to the control, respectively, and the number of deformed eggs is 6 % lower);
- increased egg-laying capacity by an average of 9 %;
- growth in live weight by 8 %;
- reduction in the number of pathologies (12 % fewer limb diseases, 35 % fewer feather growth disorders compared to the control);
- increased feed digestibility by 23 %.

The obtained data will be useful in establishing biospheric processes in the ECH. Chlorella, as a powerful producer of nutrients from solar energy, carbon dioxide, water and minerals, is an excellent feed additive for quails. In turn, quails are a source of nutrients for humans, and their waste products can be used to produce biohumus and further as fertilizer for plants. Thus, a constant cycle of substances will be maintained in the ECH.

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Study of Mycosymbiotrophy Process in Basidiomycete Fungi

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The mycorrhization of edible fungi from the genera *Boletus* and *Leccinum* with Scots pine (*Pinus sylvestris* L.), common barberry (*Berberis vulgaris* L.), common cranberry (*Vaccinium oxycoccos* L.) and silver birch (*Betula pendula* Roth) was analyzed in a laboratory unit. The experiment on the symbiosis between young seedlings and mycorrhizal fungi is described.

Microscopic photographs of the roots of seedlings that entered into symbiotic relationships with basidiomycete fungi are presented. A microbiological qualitative reaction was performed using *Bacillus amyloliquefaciens*, determining the presence of chitin-containing components in the root systems of the tested samples. The ability to form mycorrhiza with the selected plants was discovered, and an increased stable relationship between the cultures was observed. This can be applied in the biospheric-type enclosed ecosystem of the EcoCosmoHouse for incorporating fungi into the diet of people living in orbit.

Keywords:
basidiomycete fungi, chitin, chitosan, edible fungi, microbiological qualitative reaction, mycorrhiza, mycorrhizal formation, mycosymbiotrophy, microscopy, symbiosis.

Introduction

Mushrooms have a long history of being included in the human diet. Particular importance is given to those species that engage in symbiosis with plants [1], as these fungi are able to accumulate large amounts of protein and produce fruiting bodies more quickly.

Symbiotic fungi are biological organisms that establish long-term and mutually beneficial relationship with plant roots [2]. As a result, the mycelium gains access to nutrients, particularly organic ones such as carbohydrates, proteins, etc. Mushrooms, in turn, supply their "partners" with more nutrients and help them absorb water and mineral elements from the soil [3].

Each member of this union uses resources and energy efficiently, which leads to increased growth and development activity. Due to this process, symbiotic fungi accumulate useful substances more quickly and produce their fruit cells in the body, which makes them especially useful in terms of nutrition and economic benefits [4].

In European countries, mushrooms have long been a valued product, which has been salted, dried and pickled as well as used in the preparation of various dishes, such as soups, pies, etc. These culinary skills have been passed down from generation to generation, and many of them are still preserved.

Mushroom cultivation began more than 2,000 years ago. The ancient Greeks, the peoples of Italy, France, the USA, Japan, China and Southeast Asia were engaged in the cultivation of various types of mushrooms, such as champignons, oyster mushrooms, honey fungi, shiitake, etc. [5]. Edible mushrooms have been cultivated in Belarus since the 19th century, although there are references to this activity dating back even earlier. One method involves introducing finely dispersed mature mycelium of fungi into the soil beneath trees. However, results have not always been consistent [6]. In 1878, an article by N. Nikitin on the cultivation of edible mushrooms was published in Russia, which described positive experiments with birch boletes and saffron milk caps.

In the USSR, E. Klyushnikova, associate professor of Moscow State University, conducted the first serious scientific research on mushroom farming. In the late 1930s, she published her works whose ideas were widely shared. It was proved that the cultivated mushroom was a single-sex organism. E. Klyushnikova also created a training program at the Moscow State University's Department of Lower Plants to prepare specialists in edible mushrooms [7].

The cultivation of higher fungi is considered a challenging task due to the complex mechanisms of symbiotic interaction between fungi and plants. Not all species of plants are capable of serving as hosts for symbiotic fungi, and many fungi are also selective, making it difficult to obtain fruiting bodies under artificial conditions.

Mushroom cultivation in the enclosed ecosystem of the EcoCosmoHouse (ECH) will allow to establish a symbiosis between the mycorrhiza of the fungus and the root systems of plants. This will significantly improve the outflow of nutrients from the entire ECH area and distribute them among all plants [8].

The purpose of the article is to create a laboratory unit for mycorrhizal formation between basidial fungi of the genera *Boletus* and *Leccinum* and the following plants – Scots pine (*Pinus sylvestris* L.), common barberry (*Berberis vulgaris* L.), common cranberry (*Vaccinium oxycoccos* L.), silver birch (*Betula pendula* Roth). Thanks to this study, it is possible to comprehensively explore the effect of mycelium on root formation and the specifics of the interaction of higher fungi with plants. The results obtained will help to scale and implement the experiment in the field and develop a methodology for growing cap mushrooms.

Experimental Materials and Methods

To study the process of mycosymbiotrophy, a laboratory unit was created in the form of transparent narrow containers made of dense polycarbonate (Figure 1a).

One of four plants (Scots pine, common barberry, common cranberry and silver birch) was planted in each container, followed by mycelium of basidial fungi of the genera *Boletus* and *Leccinum* (Figure 1b).

a) b)

Figure 1 – Laboratory unit for symbiotic interaction of plants and basidial fungi:
a – appearance; b – application of fungi

The mycelium was cultivated in a liquid wort agar with sugar content of 7 vol. % with constant stirring on a PSU-10i orbital shaker (120 rpm at 20 °C) until complete overgrowth. The samples were planted on February 21, 2024, and the fungal mycelium was added the next day.

A birch bolete mycelium was added to the birch container, and a boletus mycelium was added to all other seedlings. Cultures of these fungi were obtained and isolated from natural habitats.

During the experiment, several variants of studies on the formation of mycosymbiotrophy of basidial fungi were carried out, namely:

- microscopy of the root section (10× magnification) after five months of cultivation – for visual inspection of the roots and root hairs surface;
- microbiological qualitative analysis for the presence of chitosan derived from chitin contained in the fungal cell wall. For the study, we took a strain of the *Bacillus amyloliquefaciens* bacterium that is capable of using chitin as the only carbon source. This bacterium uses several enzymes that form a chitinolytic enzyme complex: exochitinases, endochitinases and N-acetylglucosaminidase. As a result, the acetyl group cleaves from chitin (Figure 2).

To confirm the purity of the experiment, the use of various substrates is provided. As a first step, a pure culture of the *Bacillus amyloliquefaciens* bacterium strain was prepared. We also selected a special environment without a carbon source, so that the bacteria can use as a nutrient the substrates selected for the experiment: ammonium sulfate – 0.5 g/l, dipotassium phosphate trihydrate – 0.26 g/l, sodium chloride – 0.1 g/l, magnesium sulfate heptahydrate – 0.2 g/l, potassium sulfate – 0.1 g/l.

In this part of the experiment, we took the plant roots that had been cleaned of soil and were thought to contain mycorrhizal fungi, such as birch bolete and boletus. We also picked the fruiting body of oyster mushrooms and control substrate variants, namely powdered milk (a source of simple carbohydrates), flour from crab shells (a source of chitin), sand and earth (for negative control).

There was 1 g of all types of prepared substrates added to separate tubes containing 7 ml of sterile selective medium, and then 0.1 ml of an "overnight" bacterial culture was added aseptically. The cultivation of the samples took two days at a temperature of 33 °C. After the adaptation to the new substrate took place, we carried out the staining reaction with a drop of an alcoholic solution of potassium iodide.

Figure 2 – Reaction of chitin deacetylation and chitosan production

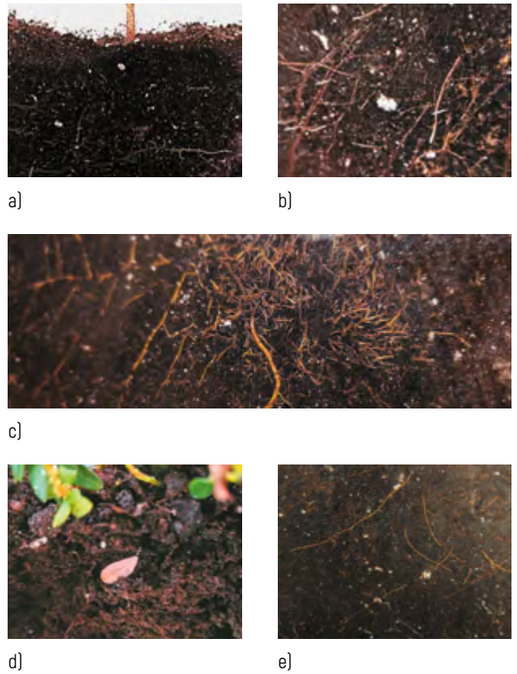
Chitin, which is contained in flour made from crab shells, along with chitosan and starch, were used in a selective medium for the cultivation of microorganisms as comparison solutions. A drop of an alcoholic solution of potassium iodide was added there.

Experimental Results

During the study, we monitored the growth of the plants (Figure 3, at the end of the experiment) and their root systems (Figure 4). In a container with a pine tree, the development of mycelium is visually noticeable (Figure 4b).

a) b) c) d)

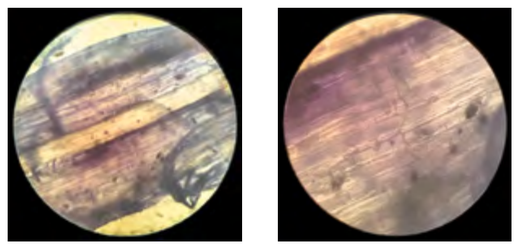
Figure 3 – Appearance of studied plants:
a – pine; b – barberry; c – cranberry; d – birch



a) b) c) d) e)

Figure 4 – Root systems of studied plants:
a – pine; b – basidial mycelium on pine roots;
c – barberry; d – cranberry; e – birch

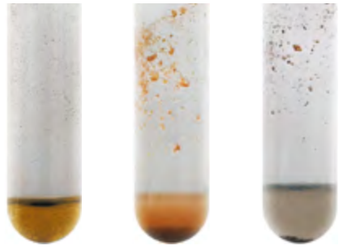
Fungal hyphae were found in the cellular structure of the samples that were microscopied before the microbiological method for detecting chitin (Figure 5), which indicates a symbiotic relationship between the plant and the basidiomycete.



a) b)

Figure 5 – Birch root with fungal hyphae under a microscope:
a – 100-fold lens magnification; b – 1,000-fold lens magnification

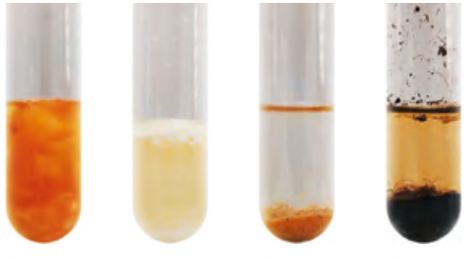
During the experiment using bacteria, the chitin test portion exhibited a strong turbidity in the medium, an orange-pink coloration and the formation of a thin film and bubbles (Figure 6b). When potassium iodide was added to test tubes with comparison solutions (without bacterial cultivation), one of which contained chitosan and the other contained chitin, one solution acquired an orange color that lasted for a long period of time, while the other solution changed color to a dark purple and gradually became discolored (Figures 6a, 6c). The precipitate in these two tubes had a dark color.



a) b) c)

Figure 6 – Solutions comparing qualitative reaction with potassium iodide:
a – chitosan; b – chitin exposed to bacterial enzymes; c – chitin

The fruiting body of the oyster mushroom, powdered milk, sand and earth after cultivation together with bacteria and after adding a drop of potassium iodide are shown in Figures 7, 8.



a) b) c) d)

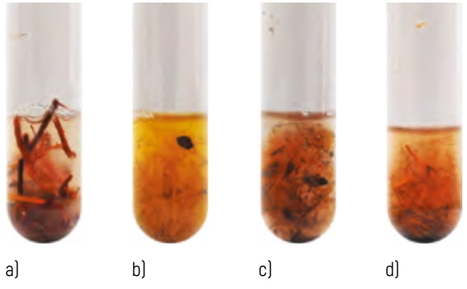
Figure 7 – Samples selected as a food source for bacteria before adding potassium iodide:
a – oyster mushroom fruiting body;
b – powdered milk; c – sand; d – earth

a) b) c) d)

Figure 8 – Samples selected as a food source for bacteria after adding potassium iodide:
a – oyster mushroom fruiting body;
b – powdered milk; c – sand; d – earth

Based on the data collected, it appears that the oyster mushroom fruiting bodies were exposed to enzymes, as the coloring became less intense but did not disappear completely. However, this may suggest a more complex process of cellular structure destruction, in contrast to the mycelial structure of basidial fungi. The powdered milk sample acquired a bright carrot color that did not change over time, indicating the absence of carbohydrates and a high protein content. The samples with sand and earth did not even show the development of microorganisms, which means that there were no carbon sources for bacteria.

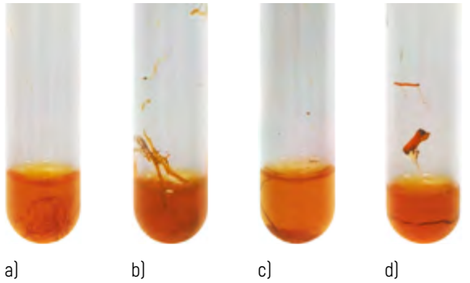
Figure 9 shows that in tubes with roots, there is turbidity in the medium and a thin film has formed, indicating an active increase in the number of microorganisms.



a) b) c) d)

Figure 9 – Plant roots after the effect of bacterial enzymes:
a – pine; b – barberry; c – cranberry; d – birch

After adding potassium iodide to these samples, the color of the solution changed to orange or orange-pink. The solution containing barberry roots had a more intense color, which gradually faded (Figure 10).



a) b) c) d)

Figure 10 – Plant roots after the effect of bacterial enzymes and after adding potassium iodide:
a – pine; b – barberry; c – cranberry; d – birch

In the cource of analysis of the samples, it was decided to perform their microscopic examination to study the root structure after treatment with potassium iodide. Figure 11 shows the darkening of the root edges.

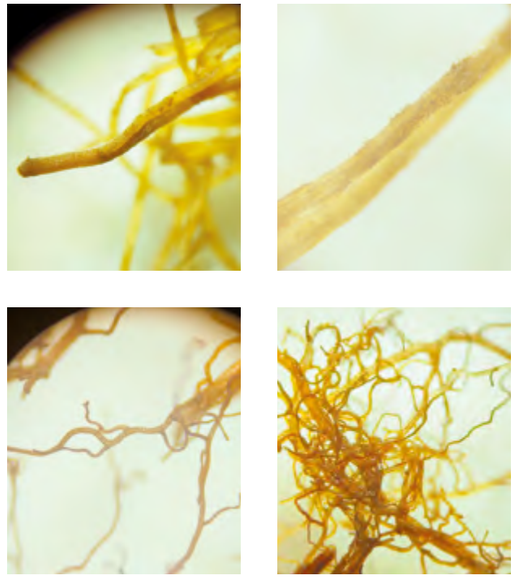


Figure 11 – Plant roots under a microscope after qualitative reaction

By visually evaluating the results of the microbiological qualitative reaction, we can conclude that both chitin and chitosan were present in the chitin sample that was exposed to the enzyme complex synthesized by the bacteria. This effect was observed in all samples with roots.

Conclusion

The article describes the author's approach to studying the interaction between basidial fungi and plants. This method allows us to determine the symbiosis between higher and lower fungi and different plant species, even in the absence of visible signs of connection. The results obtained can help us understand the mechanisms of mycorrhizal formation and resistance as well as identify crops that are capable of its formation.

The chitin complex analysis allowed us to conclude that the fungi mycelium was present on the roots of all the studied plants. The most stable symbiotic union was observed in the silver birch and the birch bolete, featuring many chitinous components integrated into the structure and evenly distributed throughout the young roots and stable orange coloring. Despite the fact that point-like growth of the mycelium was also observed in the Scots pine container, according to the qualitative reaction data, coexistence has proven to be less effective. Boletus had the most numerous symbiotic relationships with plants, so it took longer for them to adapt to each other, and birch bolete, as it turned out during the experiment, is a more selective type of basidial fungi.

Based on the results obtained, the selected bacterial strain (*Bacillus amyloliquefaciens*) can be used to protect plants from mold fungi, since the structure of lower fungi is much simpler, which means that bacteria can compete with them for nutrients. This strain of bacilli has already proven its effectiveness in agriculture as an antibiotic and fungicide for plants affected by pathogens. It also helps prevent negative reactions caused by changing soil conditions, which plants can perceive as a stressful factor. Additionally, it is effective in aquaculture farming.

The experiment confirms the formation of mycorrhiza during the introduction of mycelium using the presented method. Therefore, this technology can be applied in the enclosed ECH ecosystem. This approach will balance the diet of individuals living in orbit. A stable symbiotic interaction between fungi and plants will help improve the quality of the fertile soil and maintain its microbial diversity.

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Therapeutic Use of Essential Oils from Medicinal Herbs in EcoCosmoHouse Conditions

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The possibilities of waste-free production of essential oils from medicinal herbs cultivated in the EcoCosmoHouse (ECH), their compositions, properties and peculiarities of impact on human organism are investigated. The examples of using essential oils for therapeutic purposes for prevention and add-on treatment of certain diseases caused by the peculiarities of living in confined spaces are provided.

Aroma compounds with a complex healing effect have been created. Such blends can be used in confined ecosystems (ECH-Earth, ECH of Industrial Space Necklace "Orbit," space Ark for interstellar travels) as well as in terrestrial conditions as means of aromatherapy in case of manifestation of corresponding symptoms and as biologically active substances to replace synthetic fragrances in the natural cosmetic products.

Keywords:
aromatherapy, bioutilization, EcoCosmoHouse (ECH), enclosed ecosystem, essential oil, extraction, medicinal herb, natural fragrance.

Introduction

When considering therapeutic approaches and methods for producing pharmaceuticals for humans in near-Earth orbit, the principles of environmental sustainability, simplicity and waste-free processes are of utmost importance.

Currently, alongside traditional medicine, alternative treatment methods are gaining popularity. They have become particularly in demand due to the search for environmentally friendly ways of living on planet Earth. One such method is aromatherapy, where natural essential oils, extracted from the essential oil-bearing parts of plants, serve as active substances.

Although living conditions for humans in orbit will be as close as possible to those on Earth [1], it is important to consider the following: being isolated from natural UV radiation slows down processes that typically occur under the influence of sunlight on Earth. At the same time, such radiation stimulates the production of vitamin D, which regulates numerous vital processes [2]; it is also known to affect mental health. Based on previous research, it can be assumed that in the absence of natural sunlight, individuals are more susceptible to depression, loss of energy, mood deterioration and reduced productivity [3]. Additionally, heavy reliance on digital resources – an integral part of life in a technogenic society – negatively impacts psychological resilience, often leading to burnout, procrastination and chronic fatigue [4]. In an enclosed ecosystem, a lack of exposure to olfactory stimuli, which are typically provided by aromatic molecules from the surrounding plant world, may also adversely affect cognitive functions, immunity and neurogenesis [5]. To mitigate these symptoms, it is proposed to conduct aromatherapeutic procedures using compositions of essential oils derived from medicinal herbs.

The goal of the study is to develop essential oil compositions that can be used during prolonged stays in outer space for aromatherapy, as well as biologically active substances and alternatives to synthetic fragrances in the production of natural cosmetic products. The objectives are: to examine the therapeutic effects of essential oils; to propose methods for obtaining these oils in the EcoCosmoHouse (ECH) conditions; to select components and create compositions.

Aromatherapy

Aromatherapy is a form of traditional medicine that utilizes the volatility of components in essential oils derived from medicinal plants for therapeutic purposes.

One advantage of delivering essential oils into the body via the respiratory system is the rapid positive effect they exert on various systems, followed by their complete elimination without residual substances [6]. The mechanism of action involves psychoemotional and physiological responses to biologically active compounds within the oils, which stimulate olfactory nerve endings connected to the human limbic system [7].

Aromatherapy is particularly effective for preventing illnesses or addressing their initial symptoms. In cases of progressive diseases, it can serve as a supplementary treatment that accelerates recovery [8].

Given the complex, multicomponent composition of essential oils, it is necessary to consider the possibility of individual intolerance, which may lead to adverse reactions such as throat irritation, coughing, itching, skin irritation or changes in blood pressure. To prevent these side effects, preliminary olfactory or skin tests should be conducted [9].

Methods of Obtaining Essential Oils

To ensure comfortable living conditions in the ECH, a biosphere model of the planet will be created [1], enabling favorable conditions for growing plants widely used in cosmetology and medicine.

Previous studies addressed the cultivation of medicinal herbs in the ECH to produce extracts and tinctures for external and internal use [10]. This is possible due to the presence of flavonoids, saponins, carotenoids and other phytonutrients in these plants, which dissolve in water and alcohol, transferring into the final solution during infusion or boiling. Apart from these components, some plants also contain valuable lipophilic compounds – essential oils. These are highly volatile, multicomponent oily liquids composed of terpenes, terpenoids, ketones, amines, phenols, aldehydes and other aromatic compounds that determine the scent of the plants [11].

Various methods are used to extract essential oils from plant materials, such as pressing, extraction and maceration [12]. However, in the context of the ECH, the most promising method is steam distillation, an economical and technologically efficient process. This method allows for the complete extraction of essential oils while preserving their biological activity.

The plant material remaining after the extraction of essential oils is planned to be disposed by microorganisms and then incorporated into the biohumus produced in the ECH [13]. This method is one of the most efficient

and cost-effective biotechnological approaches for processing organic waste. Since only volatile components are extracted through steam distillation, the used raw material will still contain a significant amount of other biologically active substances. As a result, the humus obtained from bioutilization can be used as a nutrient for plant cultivation.

Formulating Essential Oil Compositions

As a rule, essential oils from a single plant contain several main active components of varying nature, which together exert a comprehensive healing effect on the body [14]. Considering the potential ailments associated with living in a confined space, the properties of essential oils listed in Table 1 are of particular interest when creating aromatherapeutic compositions for use in the ECH [15].

Table 1 – Properties of essential oils

Properties	Essential oils
Relaxing and calming	Geranium, marjoram, jasmine, melissa, chamomile, valerian, oregano, lavender, neroli, juniper, gardenia, sage, vanilla, tea tree, frankincense, bay, lemongrass, sandalwood, ylang-ylang, fennel, patchouli, mint
Antiseptic	Thyme, clove, oregano, anise, basil, bergamot, lemon, grapefruit, sage, cinnamon, juniper, lemongrass, tea tree, mint, eucalyptus, hyssop, calendula, bay, neroli, citronella
Immune-boosting	Basil, verbena, vetiver, eucalyptus, cedar, lemon, sage, lavender, mint, melissa, rosemary, frankincense, hyssop, tansy, citronella
Sleep-enhancing	Melissa, rose, mint, cypress, jasmine, chamomile, bergamot, sage, sandalwood, juniper, fennel, basil, ylang-ylang, neroli
Productivity-enhancing and stimulating	Immortelle, cinnamon, verbena, clove, magnolia, coriander, lemon, grapefruit, mandarin, sage, lavender, juniper, mint, rosemary, eucalyptus, tea tree

When preparing therapeutic compositions, the first step is to determine their intended purpose and select relevant components. Then, based on their chemical composition, ingredients are chosen to ensure that the predominant active substances complement one another, creating a synergistic effect. To avoid undesirable interactions between components, it is recommended to use no more than five essential oils in a blend. Additionally, to enhance the subjective appeal of the resulting aroma, the principle of complementary scents should be followed [16].

Research [17] indicates that pleasant fragrances improve cognitive functions, enhance quality of life and stabilize well-being. Therefore, the authors of this article selected essential oils that are widely recognized as pleasant – floral, citrus and woody aromas as well as their combinations.

Using data on the physiological effects of essential oils and principles of aroma compatibility, the authors developed variations of essential oil compositions based on medicinal herbs (Figure).

Figure – Developed compositions of essential oils

1. A calming blend of lavender, juniper and mint essential oils. A woody and spicy aromatic composition.

The predominant compound in lavender essential oil, linalool (20–30 %), reduces psychophysiological tension, stabilizes the nervous system and alleviates anxiety, depression and insomnia [18].

The α-pinene (30–60 %) and β-pinene (8–15 %) found in juniper essential oil help smooth impulsivity and irritability, balancing the emotional state [19].

Mint essential oil, containing nearly 90 % menthol, positively affects the psychoemotional state, relieves stress and reduces anxiety [20].

Composition proportions: 50 % lavender essential oil, 25 % juniper essential oil, 25 % mint essential oil.

2. An antiseptic blend of clove, bergamot, tea tree and bay essential oils. A spicy, tangy and herbal aromatic composition.

The main component of clove essential oil, eugenol (70–85 %), inhibits the activity of pathogenic microorganisms [21].

D-limonene (20–45 %) and linalyl acetate (up to 15 %) present in bergamot essential oil effectively disinfect and sanitize [22].

Terpinen-4-ol (30–45 %) in tea tree essential oil provides its bactericidal properties [23].

Cineole (25–70 %) in bay essential oil is considered an effective natural antioxidant [24].

Composition proportions: 20 % clove essential oil, 40 % bergamot essential oil, 20 % tea tree essential oil, 20 % bay essential oil.

3. An immune-boosting blend of verbena and cedar essential oils. A woody-citrus composition.

Verbena essential oil contains citral (30–45 %), which accelerates metabolic processes in the body and optimizes immune system function [25].

The main components of cedar essential oil, cedrol (15–40 %) and cedrene (10–30 %), have toning and stimulating effects, promoting rapid recovery of strength and energy during illness or excessive stress on the nervous system [26].

Composition proportions: 33.2 % verbena essential oil, 66.8 % cedar essential oil.

4. A sleep-enhancing blend of sage, sandalwood and neroli essential oils. A musky, woody-floral aromatic composition.

Sage essential oil helps relax, reduce tension and calm the nervous system due to its content of thujone (30–45 %) and camphor (up to 25 %) [27].

Sandalwood essential oil is used to alleviate insomnia and stress. Its primary components, α-santalol (41–55 %) and β-santalol (16–24 %), are responsible for the oil's biological activity [28].

Neroli essential oil contains linalool (23–54 %), which provides sedative effects on the nervous and cardiovascular systems [29].

Composition proportions: 33.3 % sage essential oil, 33.4 % sandalwood essential oil, 33.3 % neroli essential oil.

5. A productivity-enhancing blend of lemon, rosemary, magnolia and cinnamon essential oils. A floral-citrus, spicy aromatic composition.

Lemon essential oil, rich in D-limonene (up to 90 %), enhances focus, stimulates mental activity and promotes motivation [20].

The predominant components of rosemary essential oil, α- and β-pinene (about 30 %), reduce anxiety, improve focus and increase endurance [20].

Magnolia essential oil improves memory and mental concentration due to its sabinene content (10–20 %) [30].

Cinnamon essential oil combats chronic fatigue syndrome and inspires creative energy with its cinnamaldehyde content (65–80 %) [31].

Composition proportions: 25 % lemon essential oil, 25 % rosemary essential oil, 25 % magnolia essential oil, 25 % cinnamon essential oil.

The resulting essential oil blends are recommended for use in enclosed ecosystems, during extended stays in space, and in terrestrial conditions to address specific symptoms. Aromatherapy sessions should last 20–30 min with an essential oil concentration of 1–3 mg/m^3, allowing an individual in a calm and relaxed state to inhale approximately 0.1–0.6 mg of essential oil, sufficient to achieve a therapeutic effect [14].

Given that the microclimate in the ECH will facilitate year-round cultivation and harvesting of medicinal herbs, the developed blends are distinguished by their high biological activity, which is preserved due to the immediate use of aromatic compositions after production. The ability to maintain consistent growing conditions for essential oil plants will positively impact the composition of the oils, as their properties can vary with climate; in this case, they will remain constant. Moreover, it is assured that during the cultivation of raw materials and the extraction of essential oils, no chemical reagents are used, preserving the beneficial properties of the extracted substances. This fully aligns with the concept of product naturalness.

Applicating Essential Oil Compositions in Cosmetics

The properties of essential oils depend on their method of use, as they are multicomponent blends. In addition to their entry into the human body through the olfactory system, localized application of these substances is rational in an enclosed ecosystem with natural cosmetics [32]. This approach minimizes the number of ingredients in personal care products while enhancing their effectiveness due to the active components present in essential oils. The properties of the developed compositions when used in cosmetic products are shown in Table 2.

Thus, the use of the developed essential oil compositions in cosmetics enables the replacement of synthetic fragrances with natural ones, the creation of multi-care products with minimal raw components and fully aligns with the ideology of producing natural and effective cosmetics in the ECH. However, it is important to remember that achieving the desired results requires strict adherence to the regulated limits for incorporating these substances into cosmetic formulations. This restriction is necessary due to the high activity of essential oils, which is associated with their physicochemical and biological properties.

Table 2 – Properties of essential oil compositions in cosmetic products

Composition	Essential oil	Properties
Calming	Lavender	Accelerates the healing of skin wounds
	Juniper	Regenerates the skin, reduces swelling
	Mint	Effective for treating acne
Antiseptic	Clove	Increases skin permeability, enhancing the effectiveness of cosmetic products
	Bergamot	Tightens pores; masks specific raw component odors
	Tea tree	Provides anti-inflammatory effects
	Bay	Brightens pigmented spots, whitens the skin
Immune-boosting	Verbena	Smoothes and tones the skin, improves its elasticity
	Cedar	Rejuvenates the skin, enhances its turgor
Sleep-enhancing	Sage	Effective for reducing stretch marks; extends the shelf life of cosmetic products
	Sandalwood	Softens and soothes the skin
	Neroli	Helps skin regeneration, supports smoothing wrinkles
Productivity-enhancing	Limon	Stimulates blood circulation, regulates sebaceous gland functions
	Rosemary	Aids in preventing premature skin aging
	Magnolia	Effective against pigmentation
	Cinnamon	Eliminates dullness, improves complexion

Conclusion

Based on the theoretical analysis of long-term human habitation in Earth's orbit within the ECH (for many years) and in interstellar travel within space Arks (for many millennia), a conclusion has been drawn regarding the necessity of finding accessible and eco-friendly methods for maintaining human health.

To preserve and normalize psychological well-being, five essential oil compositions have been developed, intended for aromatherapy sessions as well as for use as ingredients in natural cosmetics. Their effectiveness has been substantiated, and samples have been produced. The technology for obtaining these blends is simplified and waste-free, fully aligning with the concept of eco-friendly and technologically simple production within the ECH.

Future plans include continuing research in this direction: expanding the range of essential oil compositions and observing their impact on human health.

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Development and Creation of Equipment for Growing Plants in Artificial Environment

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The purpose of this work is to investigate the methods for growing plants in closed artificial environments and to improve these methods for use in humusoponic systems. Natural humusoponic cultivation technologies are presented for growing plants in limited-volume artificial environment, utilizing uTerra fertility elixir. Based on the analysis of existing solutions and experimental data, technical requirements for the equipment have been formulated and prototypes have been developed to streamline the process of growing various crops.

The proposed concept is optimal for space exploration, as well as for the Arctic, Antarctica and the polar regions, and for the creation of underwater cities. Additionally, it is relevant in the context of modern technogenesis, particularly for the implementation of projects like "EcoCosmoHouse," "EcoCosmoHouse on planet Earth" and Equatorial Linear City for the needs of the Industrial Space Necklace "Orbit." Testing the proposed equipment will facilitate the development and refinement of new unique systems for humusoponic plant production in artificial environment.

Keywords:
artificial environment,
crop production,
humusoponic farm,
humusoponic stand,
humusoponics,
plant cultivation,
uTerra fertility elixir.

Introduction

Nutrition is a fundamental process that supplies humans with essential materials necessary for building and sustaining a healthy organism. Individuals must maintain and constantly replenish the need for macro-, micro- and ultramicroelements, vitamins and other substances found in food products as thousands of complex organic compounds. Most of the chemical elements from periodic table (over 80) are present in human tissues and fluids, participating in tens of thousands of biochemical processes within each living cell. Consequently, these elements are critical for the proper functioning of all systems within a multicellular organism. Food serves not only as a source of energy but also as a building material for the living body; the quality of food significantly influences health and longevity [1].

Providing healthy nutrition becomes especially crucial under challenging conditions such as space exploration, the Arctic, Antarctica, the polar regions and underwater city development. In these cases, traditional agriculture is either impossible or highly constrained. Therefore, innovative processes, technologies and equipment are required – such as the creation of artificial environment that enables plant cultivation under unfavorable external factors, limited spatial volume and reduced or absent daylight periods.

In modern times, an increasing number of people show interest in a healthy and eco-friendly lifestyle. The demand for individualized dietary plans that incorporate high-quality, fresh, natural and eco-friendly products is on the rise. Additionally, with over 50 % of the global population living in cities, urban farming technologies that enable convenient cultivation of vegetables and fruits nearby are gaining particular relevance [2].

Many researchers working in the field of protected cultivation believe that in the future, farmers will grow plants in underground greenhouses and urban farms. The quality of plant-based products can be significantly enhanced by utilizing natural technologies – such as humusoponics, wherein plants are nourished not from aqueous solutions of mineral chemical substances but from organic humate solutions transformed into a soluble form. Automated control systems will ensure optimal conditions for the cultivated plant species, thereby increasing the yield and quality of organic food products.

Consider existing technologies and systems for cultivating plants in artificial environments and/or confined spaces.

Hydroponic technology[1] offers several advantages for growing plants in artificial environment, including simplification of various cultivation stages, process automation and the ability to regulate environmental parameters [3]. Low-volume hydroponics is particularly suitable for producing crops in constrained spaces and under challenging external conditions.

Soilless methods represent the progression of modern agricultural trends. Interestingly, one of the Seven Wonders of the World – the Hanging Gardens of Semiramis – might have utilized primitive active-type hydroponic systems. Based on scarce evidence, it is believed that a mix of soil and stones served as a substrate for this remarkable greenery-covered structure. Unfortunately, descriptions of the nutrient solution have not survived.

It is important to note that nutrients essential for plant participation in complex elemental cycles do not materialize spontaneously; they must be incorporated into soil or the nutrient medium [4].

Humusoponic technology[2] involves an organomineral nutrient medium enriched with organic components derived from humic acid salts, a wide array of macro-, micro- and ultramicroelements, as well as associations of thousands of agriculturally valuable soil aerobic and anaerobic microorganisms present in the Earth's biosphere.

uTerra fertility elixir, recommended for use as a nutrient medium, comprises an extensive spectrum of organic components (humic substances, fulvic, organic and amino acids, fungal elicitors, soil aerobic and anaerobic microorganisms, etc.), macroelements (N, P, K, S, Ca, Mg), microelements (Si, Cu, I, Zn, Mn, B, Mo, Co, V, Na, Al) and ultramicroelements (Ba, Br, Ge, Li, Ni, Cr, F, Se, Ag) [4]. Its rich organomineral composition supports the cultivation of crops with exceptional flavor and beneficial properties, as this fertilizer can enrich plants with over 80 chemical elements in the form of an impressive variety of organic compounds [5].

The goal of this research is to develop technologies, processes and equipment for cultivating crops in artificial environments through the application of humusoponics. This approach necessitates precise management of various technological factors influencing plant growth. The automated control system must be sufficiently flexible to provide a wide range of adjustments tailored to the type of crop and its vegetative stage.

[1] A method of growing crops on artificial environment without soil. Plants get useful substances from the nutrient solution surrounding the roots.

[2] A method of plant cultivation that involves the use of a nutrient medium containing organic components based on humic acid salts and a wide range of macro-, micro- and ultramicroelements. Humusoponics is an integrated method of cultivation, which combines hydroponic and classical methods of crop production with the selection of soil compositions and nutrient solutions in such a way as to provide plants with the necessary complex of organomineral nutrients at all stages of development.

Requirements for Artificial Environments Designed for Plant Cultivation

Creating favorable conditions for plants within artificial environment systems is a critical task that requires a comprehensive approach to designing equipment capable of maintaining optimal technological regimes. Of particular importance is the composition of the nutrient medium used for plant development. To achieve ideal conditions, the following technological factors must be maintained within specific ranges depending on the plant species and its vegetative stage:

- lighting intensity and photoperiodism;
- light spectrum at different stages of plant development;
- plant feeding methods and regimes;
- temperature and humidity control;
- gas composition of the environment;
- nutrient medium composition and consistent maintenance.

Lighting

Plants rely on energy for growth, flowering, fruit maturation and reproduction. In natural conditions, sunlight serves as the primary energy source. To achieve the necessary level of artificial lighting, it is recommended to use phytolamps with wavelengths between 400–700 nm, providing a luminous flux of at least 120 μmol/(m²·s). The lamps should deliver uniform coverage across the cultivation area and be positioned at a height of up to 40 cm above the plant [6]. An optimal design allows for adjusting this distance as the crop grows.

The most effective parts of the light spectrum for photosynthesis are the blue (440–460 nm) and red (650–670 nm) bands (Figure 1). Therefore, phytolamps should integrate a combination of blue and red light-emitting elements for optimal results.

When using white light sources, attention should be paid to the color temperature (Figure 2).

Table 1 shows the reaction of plants to different ranges of color temperature and, accordingly, visible color [6].

There are three main types of artificial light sources for plants: fluorescent, high-intensity discharge (HID) and light-emitting diode (LED) lamps. Currently, LED lights are considered the most optimal choice due to their low energy consumption, high luminous efficiency, long lifespan and compact size. Additionally, LED systems are easily programmable, allowing specific lighting modes to be set for each stage of plant development.

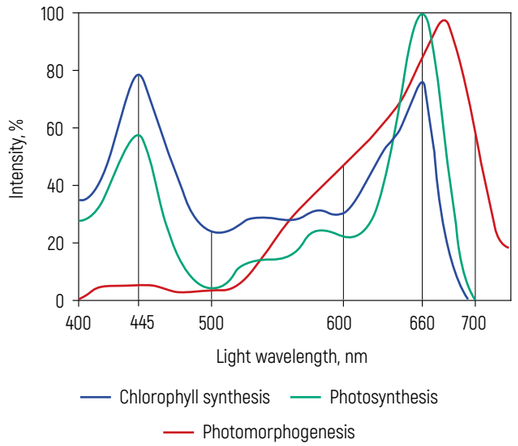

Figure 1 – Dependence of photosynthesis intensity and other processes on the light wavelength

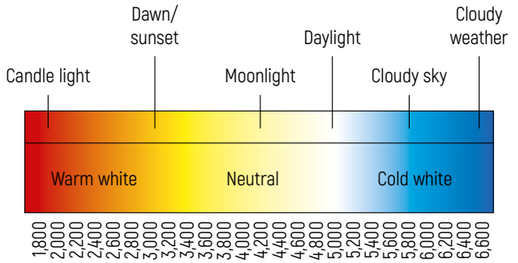

Figure 2 – Scale of measurement of conditional color temperature

Table 1 – Impact of white light sources on plants based on color temperature

Color temperature, K	Visible color	Impact on plants
1,500–3,000	Dark orange or dark red	Stimulates flowering
3,000–3,700	Yellow or neutral	Enhances photosynthesis throughout the growth phase
4,000	Neutral white	Ensures normal growth
4,000–5,000	Light blue	Accelerates leaf and stem growth
5,000–8,000	Dark blue	Improves leaf development

Photoperiodism[3] is a critical characteristic for the growth and development of crops. Plants naturally adapt to the alternation and variation of day and night lengths, reorganizing their developmental processes based on fluctuations in day duration. This adaptation allows plants to synchronize their growth stages with seasonal climatic features. Day length is perceived by plants as an environmental cue, signaling the start of flowering or preparation for adverse seasons. Photoperiodism is dependent on the developmental stage and may range from 12 h of lighting per day during the flowering phase to 18 h during the growth phase [7].

Nutritional System

Cultivating crops in artificial environments requires access to an adequate volume of nutrient solution at the right time. Below are potential methods for ensuring proper plant nutrition [8, 9].

Wick System (Figure 3). In this method, a wick is placed in a pot with a substrate, and its other end is submerged in the nutrient solution. The wick, made from synthetic or natural fibers, contains numerous capillary channels that transport the nutrient solution to the plant. Substrates such as perlite, vermiculite, coconut fiber or mineral wool are commonly used. However, this method is unsuitable for moisture-loving crops, as they cannot obtain sufficient nutrients via the wick and may perish as a result.

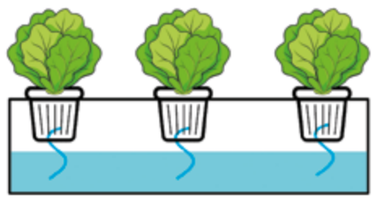

Figure 3 – Wick nutritional system

Periodic Flooding System (Figure 4). This method introduces nutrient solution to the plant root zone at specific intervals, promoting effective oxygen enrichment. As the water level rises, it displaces used air from the root zone. When the water level drops, fresh air penetrates the root zone. This system is easily automated and allows for optimal control of plant nutrition.

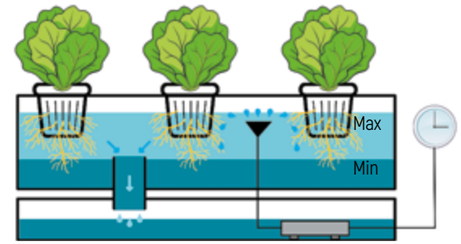

Figure 4 – Periodic flooding system

Water Culture System (Figure 5). The simplest hydroponic technology, this system uses a lightweight platform to support plants as they float on the nutrient solution. An air pump oxygenates the solution, which the plants absorb through their roots. Aeration of the root zone significantly improves water and nutrient uptake. Without this process, plants quickly perish.

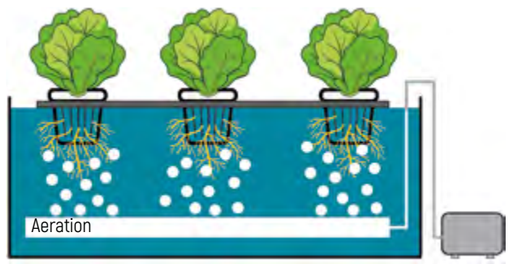

Figure 5 – Water culture system

Nutrient Film System (Figure 6). Nutrients are delivered via a pump and flow over the plant roots. The solution flow can be continuous or intermittent, depending on the type of crop. However, this process requires careful monitoring; extended system malfunctions can lead to crop failure. In this method, plants are generally placed in containers without a substrate, which can be a drawback in certain conditions. For example, plants with heavy top growth may require supportive structures like fine-mesh nets.

[3] Reaction of the organism to the diurnal rhythm of illumination: to the ratio of light (length of day) and dark (length of night) periods of the day; expressed in changes in the processes of growth and development.

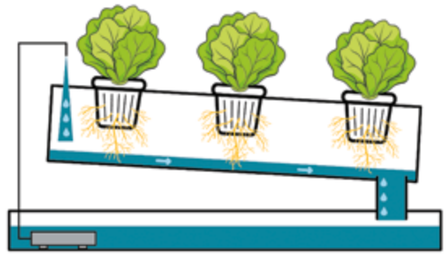

Figure 6 – Nutrient film system

Drip Irrigation System (Figure 7). This method involves watering each plant individually. Various substrates are used, but the system's sensitivity to nutrient solution delivery failures depends on the substrate type. An optimal irrigation cycle is essential; excess water can cause root rot due to oxygen deprivation, while insufficient water can lead to salt crystallization, hindering nutrient absorption.

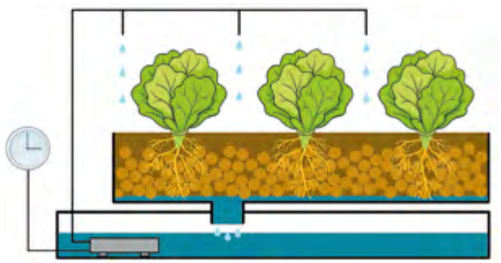

Figure 7 – Drip irrigation system

Aerohydroponic System (Figure 8). This system oxygenates water by passing it through air. Oxygenation can be achieved using air pumps, water pumps or vortexes.

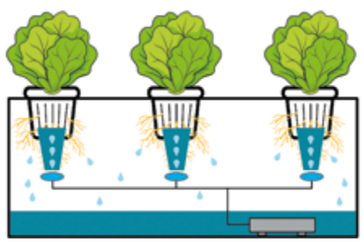

Figure 8 – Aerohydroponic system

Aeroponic System (Figure 9). In this technique, an ultrasonic membrane (vibrating at frequencies up to 2 MHz) converts the nutrient solution into a mist with particle sizes up to 5 µm. The plant roots are suspended in this mist, allowing them to absorb nutrients. Additionally, this technology helps increase humidity in greenhouses, reducing the risk of fungal or mold infections as water does not settle on the leaves.

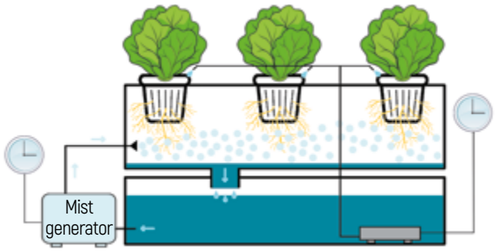

Figure 9 – Aeroponic system

Aquaponics System (Figure 10). The aquaponics system combines fish farming with plant cultivation. As part of their life cycle, fish release nitrogen, potassium, phosphorus, ammonia and carbon dioxide, which are processed by bacteria and then serve as nutrients for plants.

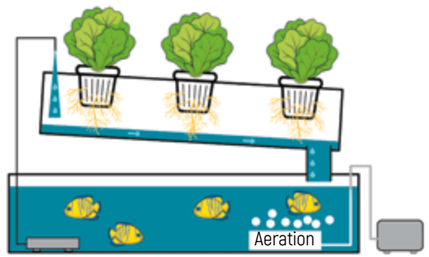

Figure 10 – Aquaponics system

Developing humusoponic systems involves the critical task of identifying technical and technological solutions that integrate the advantages of previously mentioned plant nutrition methods. Furthermore, it is essential to consider the requirements for cultivating different plant species, alongside the necessity for structural designs that ensure reliability and ease of maintenance for humusoponic systems.

Microclimate

Air humidity, along with temperature control, plays a vital role in plant development. By understanding these parameters, one can significantly improve the appearance of cultivated crops and create conditions conducive to harmonious flowering or fruiting.

Plants can generally be classified into the following groups: hygrophytes, which thrive in humidity levels of 70–90 %; xerophytes, which are drought-resistant; mesophytes, which prefer humidity levels of 50–60 %. Most indoor and greenhouse plants belong to the mesophyte category.

Air humidity affects cellular processes within plants. Dry, hot air hinders growth by disrupting respiration and photosynthesis functions. Insufficient humidity can lead to yellowing leaves, the appearance of spots and the dropping of buds and flowers. Young leaves are particularly vulnerable to low humidity. Conversely, high humidity can cause rot, mold, fungal diseases and the proliferation of harmful microorganisms and insects.

Methods for increasing humidity include:

- spraying water over the plants;
- placing open containers of water nearby;
- using porous materials like peat or moss that retain moisture;
- employing a humidifier [10].

A well-designed ventilation and air exchange system is regarded as a reliable method to maintain optimal humidity levels.

Nutrient Medium

A critical factor in cultivation is selecting the optimal nutrient medium that ensures plants receive all macro-, micro- and ultramicroelements essential for healthy growth and development. The primary components of nutrient media can include mineral salts (macro- and microelements), carbohydrate sources (sucrose, molasses and syrup), vitamins and more. In some cases, organic additives – like casein hydrolysate, coconut milk, yeast extract or corn endosperm – are incorporated into the nutrient mix.

In traditional agriculture, choosing the right soil composition is crucial. This often involves adding humus, sand and other components (depending on the plant type) to maintain the required levels of acidity, electrical conductivity and nutrient availability. However, common cultivation methods are either impractical or challenging in artificial environments. Therefore, humusoponics can be seen as a hybrid approach that combines hydroponic and traditional techniques.

Another key element of fertility is the activity of soil microorganisms. These microorganisms produce essential vitamins, enzymes, proteins and a range of organic compounds needed by plants at all developmental stages. In natural conditions, the presence of earthworms in the soil significantly boosts the activity of beneficial soil microorganisms. Introducing a specially bred earthworm species, *Lumbricus* uTerris, into the soil fosters the development of agriculturally valuable microorganism communities.

Moreover, earthworms aerate the soil, which effectively enriches the root system with oxygen. Plants extend their roots along the earthworm tunnels, gaining additional nutrients from the worms' excretions (coprolites). These excretions contain organic compounds, including humic substances, in forms that plants can easily absorb. This creates a symbiotic relationship between plants, earthworms and beneficial microorganisms.

Let us take a look at one of the products on the market, uTerra fertility elixir, which:

- boosting crop yield and quality while accelerating plant development through efficient nutrient supply and natural phytohormones;
- protecting plants from diseases and pests;
- reducing the concentration of heavy metals and radionuclides in plants by binding them in the soil;
- decreasing nitrate content in agricultural products;
- regulating and normalizing soil pH.

uTerra fertility elixir is produced in a specialized bioreactor using high-quality natural raw materials such as brown coal and uTerra granular humus which contains macro-, micro- and ultramicroelements. Additionally, the fertilizer includes carefully selected associations of agronomically valuable aerobic and anaerobic microorganisms (approximately 10 tln pcs/kg). Their growth is supported by balanced nutrients like molasses, honey, beekeeping products, humates derived from brown coal and specific organomineral additives enriched with macro-, micro- and ultramicroelements.

Technological Factors

For humusoponic systems to function efficiently, the following technological factors must be maintained within optimal ranges:

- oxygen levels in the root system. Adequate oxygen availability ensures plants can effectively absorb nutrients

from the substrate and nutrient solution, while preventing root decay and death;

• pH levels. Each plant species requires specific acidity parameters for comfortable growth. Incorrect pH levels can influence nutrient availability and uptake;

• electrical conductivity level. Its low value prevents plants from receiving adequate nutrients, leading to symptoms such as yellow or brown leaf discoloration, appearance of brown necrotic spots or holes on the leaves, growth delays and more. To support healthy development throughout all vegetative stages, electrical conductivity levels should be maintained within the range of 0.2–2.6 mS/cm.

Technical Solutions

To efficiently produce crops enriched with essential macro-, micro- and ultramicroelements and to achieve dietary diversity within closed artificial systems – including those located in outer space and under modern technogenic conditions – unique equipment must be designed. This equipment must account for all factors influencing plant development to the fullest extent. Focusing on a comprehensive approach and ensuring control and adjustability of these parameters will enable the production of natural, eco-friendly, nutritious and diverse yields in confined spaces within short timeframes, thereby enhancing human diets for healthy living.

When designing equipment, it is critical to understand its intended purpose within an artificial environment. Development objects should be categorized into several groups:

• city-farming facility designed for cultivating various crops using humusoponic systems; ideal for commercial applications;

• laboratory research facility that allows experimentation with various technological parameters. The data obtained can facilitate the implementation of rational solutions in the development of innovative equipment;

• individual use facility, enabling the creation of personal city farms at home where diverse crops can be grown for consumption without significant time or labor investments;

• decorative purpose facility aimed primarily at enhancing interior aesthetics.

Humusoponic Stand

The humusoponic stand is designed for conducting laboratory research, providing an extensive experimental framework to explore various classical agricultural practices and hybrid cultivation techniques based on humusoponics (Figure 11). This equipment enables the identification of optimal technical solutions and parameters necessary for large-scale industrial production of plant products.

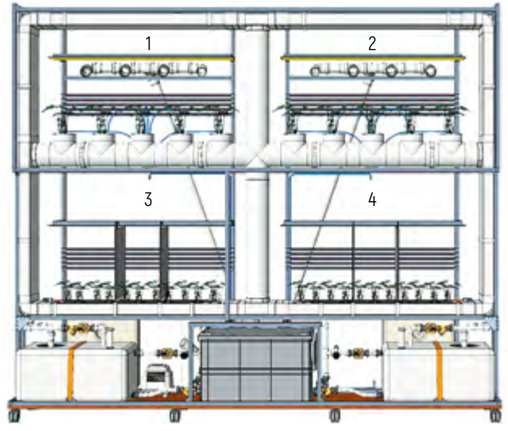

Figure 11 – 3D model of the humusoponic stand:
1, 2, 3, 4 – zones for investigating different cultivation methods;
upper and middle levels – dedicated to experiments,
lower level – for technological equipment placement

Based on the theoretical analysis of modern systems and cultivation methods, the stand has been structured into three levels and four zones (Figure 11), each facilitating independent research. The upper zones (1, 2) and the middle zones (3, 4) are functionally identical, enabling comparative experiments using various methodologies. The upper and middle levels are intended specifically for experiments, while the lower level accommodates technological equipment such as tanks, pumps, etc.

The stand is fully automated, allowing precise control of experiments. System data can be monitored and adjusted via a mobile application. The left (zones 1, 3) and right (zones 2, 4) circuits are identical, allowing parallel experiments under equivalent conditions. The lower level contains separate tanks for nutrient solutions and water for each circuit, which support drip irrigation for plants situated in zones 1 and 2 on the upper level. The middle reservoir houses water and an ultrasonic mist generator. The resulting mist is channeled upward and dispersed over zones 1 and 2 on the upper level. The mist irrigation system allows for the regulation of key parameters, including the frequency and duration of treatments as well as flow intensity. All tanks are equipped with level sensors for timely replenishment of nutrient solutions or water. Additionally, the lower level features a leak sensor to prevent potential system failures.

In zones 1 and 2, multiple methods can be employed, including drip irrigation and periodic flooding. The upper level is also equipped with overflow sensors for additional control over the nutrient solution levels within the system.

In zones 3 and 4, crops are cultivated using the nutrient film technique. A solution containing essential elements for plant development continuously circulates through the system and is aerated to enhance oxygenation of the root system. This improves the absorption of water and nutrients while also preventing root rot.

All four experimental zones are equipped with two lighting systems: overhead and lateral lighting. The overhead lighting comprises sets of LED strips emitting white light at different color temperatures, as well as red and blue phytolamps, with adjustable height options. The lateral lighting consists of horizontally arranged LED strips with adjustable light spectrum. The spacing between the LED strips and the spectral composition of the lateral lighting can be adjusted based on the growth stage and type of plant being cultivated.

For real-time monitoring and alarm notifications, a video camera is installed on the stand, with data transmitted directly to a mobile application.

Additionally, a reflective curtain is mounted on the back wall of the stand, while the front features a transparent panel coated with mirrored tint film. This design significantly enhances the light intensity in the experimental zones.

The humusoponic stand (Figure 12) allows for experiments to evaluate and compare the effects of various technological factors on plants, including:

• light intensity, spectral composition and photoperiodism;

• nutrient medium composition and substrate;

• nutrition systems;

• other factors (e.g., mist irrigation, carbon dioxide supply, nutrient medium aeration and more).

Figure 12 – Humusoponic stand

Humusoponic Mini-Farm

The humusoponic mini-farm (Figure 13) is designed for individual plant cultivation, providing an opportunity for anyone to enjoy a diverse range of fresh vegetables, leafy greens and medicinal plants rich in micro- and macroelements. These crops can be grown at home with minimal time and effort. Mini-farms are suitable for various environments, such as apartments, houses or offices.

Figure 13 – Humusoponic mini-farm

The mini-farm incorporates only overhead lighting, comprising sets of LED strips emitting white light at different color temperatures, as well as red and blue phytolamps. To enhance light intensity, a reflective curtain is mounted on the back wall of the farm, and the front is fitted with easily removable transparent panel coated with mirrored tint film. Experiments conducted using a Sekonic C-800 spectrometer showed that the presence of these panels increases light intensity by 53 %. They not only reduce light dispersion but also help maintain a specific air humidity level within the installation.

The mini-farm features a minimal level of automation. The nutrient solution is aerated to provide additional oxygen enrichment to the roots. Lighting and aeration modes are programmed and activated via a timer. The system is equipped with level sensors for the nutrient solution, which can be replenished through a filling port when necessary. Additionally, manual monitoring of nutrient medium pH levels, temperature, air humidity and electrical conductivity of nutrient solution is conducted to ensure optimal system performance.

The composition of the nutrient solution and substrate plays a crucial role in the effective functioning of these installations. Plants must be supplied with all essential nutrients. The use of uTerra fertility elixir promotes vigorous plant development and the accumulation of vegetative mass.

Humusoponic Planter

The humusoponic planter is designed for individual decorative use (Figure 14). It is an automated system consisting of an inner and outer pot. Plants are grown in the inner pot, while the outer pot contains the nutrient medium – a 1 % solution of uTerra fertility elixir. The outer pot has translucent walls and serves as an aquarium that can house guppy fish.

The planter includes a stand with a light fixture holder equipped with a phytolamp to provide supplemental illumination for the plant throughout all stages of its growth and development. The system integrates multiple nutrition methods, including drip irrigation, aquaponics, water culture and aerohydroponics. A drip irrigation tube connected to a bubble pump is submerged in the nutrient solution. As the nutrient solution, enriched with air bubbles, rises through the tube and irrigates the roots, the process also aerates the plant. Irrigation is managed automatically according to a programmable schedule. The plant absorbs the required amount of the nutrient solution, with excess passing through the substrate and returning to the outer pot.

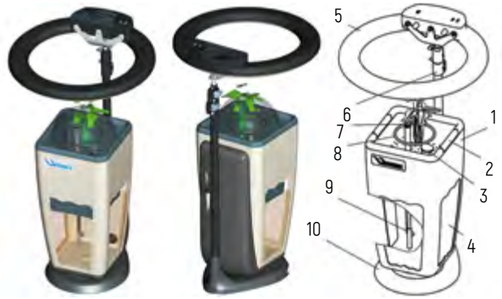

Figure 14 – Humusoponic planter:
1 – outer pot; 2 – inner pot; 3 – filling port;
4 – nutrient solution; 5 – light source; 6 – light stand;
7 – drip irrigation system; 8 – capillary tube;
9 – connection tube for drip irrigation linked to a compressor;
10 – stand with light fixture holder

Table 2 lists the automation and control requirements that, according to the developers, this system is expected to meet. Most key technological parameters are automatically controlled. They can be configured, regulated, adjusted and monitored through the dedicated mobile application, making plant care and growth control extremely simple and convenient for users.

The humusoponic planter includes a connection for an additional nutrient solution reservoir, which is useful during prolonged user absence. Furthermore, it is possible to install a reflective panel around the plant to enhance illumination. Preliminary experiments revealed that this solution can increase the light flux by 50 % or more.

The nutrient solution is one of the most critical factors affecting the efficiency of crop cultivation using humusoponic methods. For the humusoponic planter, it was decided to use an aqueous solution of uTerra soil elixir, as it serves as a source of humic and fulvic acids, macro-, micro- and ultramicroelements, as well as agriculturally valuable soil aerobic and anaerobic microorganisms needed at all stages of the plant life cycle. The compatibility of guppy fish with the aqueous solution of uTerra soil elixir was explored by the authors. The experimental results showed that the fish are comfortable in the uTerra solution at a concentration of 0.5–1 %. Additionally, an increase in electrical conductivity was observed. This change indicates a rise in overall salinity due to the presence of fish waste products in the solution, which also positively influences plant development within the humusoponic planter.

Table 2 – Functional requirements for humusoponic planter

Function		Description
Drip irrigation		Drip tube and bubble pump
Drip irrigation management		Automatic / programmable
Nutrient solution refilling		Manual (via filling port) / automatic
Nutrient solution level control		Automatic
Plant lighting management		Automatic / programmable
Aquarium lighting management		Automatic / programmable
Device for feeding light bulk products into a nutrient solution (fish food)		Automatic feeder
Automated control system cycle		Weekly
Recording of the automated control system operation history		Logging of operational data
Technological indicators controlled	pH of substrate	Manual
	Substrate humidity	Automatic
	Substrate temperature	Automatic
	pH of nutrient solution	Manual, periodic (in the external reservoir)
	Nutrient solution temperature	Automatic
	Nutrient solution electrical conductivity (salinity)	Automatic
Signal devices	Sound alarm	Buzzer
	Lighting indicator on stand	LED / LCD indicator
	Lighting indicator on planter	LED / LCD indicator
	Nutrient solution level alarm	LED / LCD indicator (intermittent buzzer during refilling)
	Technological indicators display	Visible via mobile application
Autonomous operation duration without human interaction		Up to 30 days

Humusoponic Bed

The humusoponic bed is designed for cultivating various crops (flowers, vegetables, microgreens, etc.) and their seedlings in domestic, field, greenhouse, garden and other settings. It lacks automation systems (Figure 15). This versatile device creates the most comfortable conditions for plants by optimizing cultivation parameters. The substrate consists of a specific ratio of soil, peat and crumbly vermicompost enriched with *Lumbricus* uTerris earthworms. The humusoponic bed employs either a nutrient film system or a wick system. The nutrient fluid is an aqueous solution of uTerra fertility elixir, with concentrations individually adjusted according to the type of plant and the pot / barrel volume. The combination of such favorable factors enables the cultivation of plants with a complete spectrum of essential macro-, micro- and ultramicroelements regardless of the surrounding environment, making it ideal for closed artificial systems and limited spaces.

Figure 15 – Humusoponic bed (option)

The primary areas of focus in the development and study of humusoponic beds is selecting eco-friendly materials for pot/barrel construction and identifying technological solutions to make this device a universal system, combining eco-friendliness, cost-effectiveness and cultivation efficiency for crops enriched with full spectrum of macro-, micro- and ultramicroelements.

Conclusion

Developing innovative cultivation systems for crops in confined artificial environments is a critical task, as it enables the provision of healthy nutrition under adverse external conditions, such as space exploration, Arctic and Antarctic regions, polar territories and underwater city construction. Another important challenge is ensuring dietary diversity amid modern technogenesis.

The unique range of humusoponic equipment proposed in the article allows the production of a wide variety of plant products for diverse consumer groups – from household users to large-scale industrial enterprises. Further testing of this technology will facilitate active adoption of humusoponic systems and their improvement. The foundational solutions, requirements and criteria outlined for these systems will achieve a high level of automation in the equipment, significantly reducing labor and time investment while enhancing crop yields and the quality of plant products.

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Biotechnological Recycling of Domestic Waste in EcoCosmoHouse

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In the design of the EcoCosmoHouse (ECH), which is a balanced and sustainable ecosystem, the necessity of addressing the complete recycling of domestic waste, including solid household waste (SHW), generated by its inhabitants, becomes inevitable. Biotechnological methods emerge as the most promising solution, enabling not only waste processing but also integrating SHW into the material cycle of the ECH during the manufacturing of plant products.

This discussion highlights the comprehensive utilization and disposal of SHW, defining key stages such as waste preparation (metal separation, shredding) and processing through the involvement of living organisms (earthworms, bacteria, fungi, algae).

Traditional waste disposal methods, such as landfill burial or incineration, contribute significantly to environmental pollution. Globally, a substantial volume of waste – approximately 2.1 bln tons – is generated annually, with 30 to 40 % of it not being disposed in an environmentally safe manner, causing immense harm to nature. Such practices must be avoided in the creation of enclosed ecosystems.

The proposed solutions, due to their simplicity and the characteristics of the resulting products, are applicable in enclosed ecosystems, in particular during the implementation of the terrestrial and cosmic components of the EcoSpace program (linear cities, ECH and other transport, infrastructure and industrial-residential components) and the processing production and consumer waste buried in landfills.

Keywords:
biodegradation,
cellulolytic microorganisms,
EcoCosmoHouse (ECH),
solid household waste (SHW),
waste recycling.

Introduction

The accumulation of waste is a global environmental issue. The volume of solid household waste (SHW) is constantly changing, reflecting the level of goods supply and largely depending on local infrastructure conditions. On average, a city with a population of about 1 mln generates approximately 3 mln m^3 (600,000 tons) of SHW. Around 30 % of this waste consists of paper, cardboard and food scraps; 1–5 % is made up of wood, plastics and ferrous metals; about 3 % includes textiles, leather, nonferrous metals, bones, rubber, stones and plaster. The remaining waste types are not classified due to their small quantities [1, 2].

One of the most serious challenges in waste management is the loss of valuable and high-quality food products (Figure 1). More than one-third of all food produced is never consumed, with annual food losses amounting to approximately 160 kg/person globally [3]. This volume would be enough to eliminate world hunger twice over.

The long-term functioning of the EcoCosmoHouse (ECH) as a balanced and sustainable ecosystem presents an engineering challenge, as no biosphere-scale environment of this kind has been successfully created before. During their life activities, people will generate a significant amount of waste within the complex, including various types of materials – from food scraps and packaging to spent resources and other residues. Therefore, it is essential to adhere to the most efficient waste disposal methods to maintain equilibrium and ensure long-term sustainability through full recycling. Moreover, the principles of ecological stability and the minimization of negative impact on the internal environment of the ECH must be taken into account.

On space stations, the exclusive use of modern waste disposal technologies is not feasible. Over time, significant volumes of both organic and inorganic waste will accumulate inside the ECH: plant residues, human and animal feces, dead organisms, leaves, peels, fruits, bones, feathers and more.

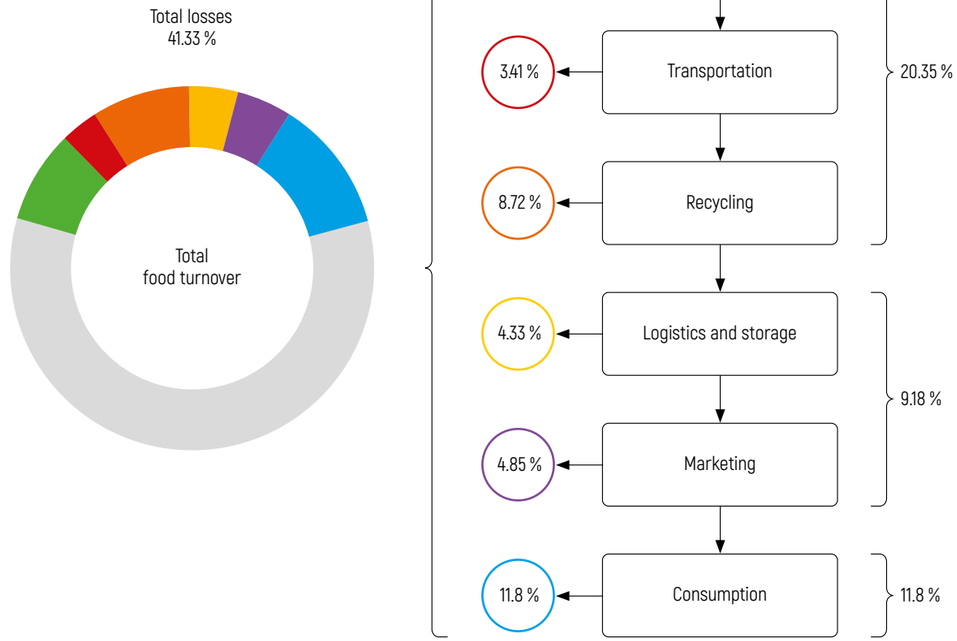

Figure 1 – Losses of valuable food products

This will lead to the formation of a layer of organic material that will undergo fermentation. During this process, organic substances will decompose under the influence of microorganisms and enzymes, resulting in the release of ammonia, methane and other chemical compounds.

Continuous accumulation of life-activity waste within the ECH will cause a buildup of such substances and increase the rate of fermentation and decomposition, which in turn will lead to the concentration of various elements in the soil: nitrogen, phosphorus, potassium, etc. Some areas may become more fertile, while others, from which elements migrate, may become less fertile, thereby disrupting the balance of the entire ecosystem. If the volume of waste exceeds the natural capacity of the environment to decompose and recycle it, other problems may arise: soil and water pollution, formation of harmful gases and unpleasant odors and the creation of favorable conditions for the spread of pathogens.

Therefore, measures must be taken to manage biowaste, including its disposal, recycling or repurposing as resources for other processes. This will help mitigate the negative impact of waste accumulation and maintain balance in the enclosed ecosystem. In the ECH, just like in Earth's live nature, there is no waste in the conventional sense – it is considered secondary raw material or a by-product.

In light of the above, the goal of this work is to develop a biotechnology for waste disposal in the ECH, which can also be applied to SHW generated by human life and economic activity and currently buried in vast quantities at landfills scattered across nearly the entire planet.

Specifics of Waste Management in ECH

The main source of waste generation in the ECH will be human activity. Every day, people will produce a significant amount of organic waste, such as food scraps and biological by-products. In addition, a substantial quantity of other organic and inorganic materials will inevitably be generated, including plastic, metal, glass and paper.

One solution to reduce contamination is to relocate production activities outside the residential modules. This approach would enhance the overall effectiveness of space stations developed by the logic of the EcoSpace program. Industrial waste and by-products generated in the Industrial Space Necklace "Orbit" (ISN "Orbit") should not pollute either the Earth or the residential sections of the ECH. Production costs can be significantly reduced by utilizing the unique technological conditions of space – such as weightlessness, vacuum and a high degree of cleanliness – and by eliminating the need for deep waste recycling, since the negative impact on Earth's biosphere is avoided.

The ECH is designed to eliminate nonrecyclable waste, as previously explored in studies related to the development of its biotechnological systems [4]. The waste generation coefficient is expected to be about 25 % of that on Earth. This reduction can be attributed to several factors:

- simplified logistics (shorter transportation routes and travel times) within the ECH and the ISN "Orbit" will proportionally reduce waste volumes;
- the use of eco-packaging and the ability to store products in vacuum conditions at cryogenic temperatures (e.g., outside the ECH, in its shadow) will help preserve food and raw materials longer without compromising quality or nutritional value;
- food production planning within an enclosed ecosystem will be significantly simpler compared to the unpredictable market conditions on Earth.

This approach can reduce waste generation by a factor of 3 to 5, considering that up to 40 % of food produced on Earth is lost before reaching the final consumer due to transportation losses, improper storage and overproduction. Furthermore, some types of pollution associated with plastics may also be excluded from the ECH.

To minimize the negative impact of waste on the surrounding environment, it is crucial to develop and implement effective waste management systems. These should cover the separation of non-compostable materials for recycling and the biotechnological disposal of organic waste through composting.

Industrial and production waste – including waste from the manufacturing, packaging and storage of food – must not contaminate the ECH ecosystem. The production process must be free from harmful and hazardous gases and liquids that could negatively affect the closed environment. Emissions containing toxic substances, heavy metals, hazardous chemicals and other pollutants must not be allowed to enter the atmosphere or water systems.

Substances such as hydrogen sulfide (H_2S), sulfur dioxide (SO_2), nitrogen oxides (NO_x) and similar compounds must not be released into the air. On Earth, these emissions contribute to climate change, smog formation and the degradation of air, water and soil quality, ultimately harming human health and the biosphere as a whole.

Typically, SHW at landfills forms a hazardous system composed of materials with diverse mass and density. Over time, this system undergoes intense biochemical decomposition, generating leachate and landfill biogas (mainly methane), which increases internal temperatures. This, in turn, accelerates chemical oxidation and can lead to further temperature rise and fires. Such combustion may occur both on the surface and deep within the waste layers (Figure 2).

In contrast to standard landfill storage practices, waste in the ECH should be integrated into natural energy transformation cycles through the biorecycling of SHW into a nutrient source for plants. This approach ensures maximum circularity of valuable micronutrients and significantly reduces methane emissions, making the technology suitable not only for space habitats but also for restoring Earth's natural biosphere.

Contamination of water by inorganic and organic substances also poses a danger to the closed environment. It mainly occurs due to sewage discharge and the runoff of fertile soil in coastal areas. A major concern in this context is the presence of hormones in wastewater. The concentrations of steroids and hormones in such water reach 0.1–196 ng/l of estrogens, 0.1–439 ng/l of progesterone, 0.06–(86 ± 2) ng/l of androgens, 0.1–433 ng/l of glucocorticoids and 26.6–100 ng/l of growth hormones [5]. Steroid hormones are microcontaminants found in water globally and pose a serious threat to both the environment and human health, even at low concentrations. While steroids (estrogens, progesterone and androgens) are essential for the development of the body and the maintenance of homeostasis, they are among the most widespread endocrine disruptors. The primary sources of steroid hormones in the environment are human and livestock excretions, agricultural runoff and veterinary and pharmaceutical drugs [6].

The volume of SHW generated is directly dependent on the standard of living and purchasing power in a given region, with environmental factors playing a key role. With rational resource use, the composition of waste can be forecast based on the potential for its recycling. For example, around 10 % of SHW consists of packaging plastic, which can be replaced with cellulose-based alternatives. This type of packaging is already being tested and does not present any negative characteristics in terms of consumer experience or environmental impact; its production is planned in the ECH using plant-based raw materials. Under the influence of microbial enzymes (*Cytophaga*, *Cellvibrio*, *Micromonospora*, *Streptomyces*, *Aspergillus* and others), cellulose undergoes hydrolysis, transforming first into the disaccharide cellobiose and then into glucose, which is oxidized into CO_2 and water. The simplified conversion chain is: cellulose – cellulase – cellobiose – cellobiase – glucose – $CO_2 + H_2O$.

Thanks to the optimally selected components of the ECH (production facilities, farms, systems, etc.), the volume of SHW can be reduced by 40 % or more. Using materials initially intended for recycling, including metals and glass, will cut emissions by an additional 20 % in line with their share in waste.

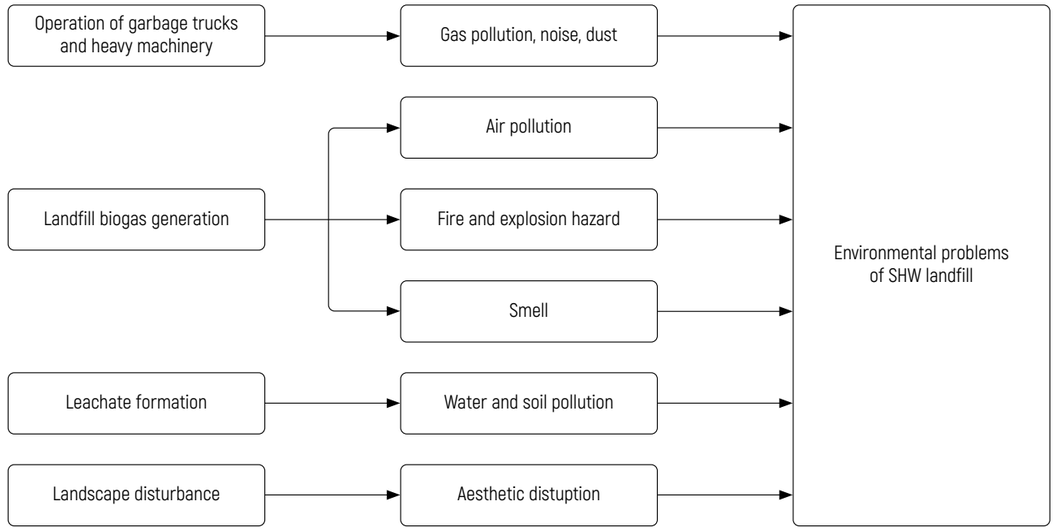

Figure 2 – Problems of SHW landfilling solved in ECH through the biological cycle

As a result, over 40 % of waste generated in the ECH will consist of cellulose, biopolymers (polymers), glass fragments, food waste, parts of household items and other shredded material, which will be separated into organic by-products and SHW.

Biotechnological Disposal of Organic By-Products in ECH

The disposal of organic waste generated through food consumption and the production of semifinished products is a key aspect of sustainable development and ecological balance in an enclosed ecosystem. This type of waste contains a significant amount of components that can serve as a nutritional base for various invertebrates.

Gastropods, such as giant African snails (*Lissachatina fulica*), Roman snails (*Helix pomatia*) and other mollusks suitable for human and animal consumption, are active consumers of plant-based organic waste. They serve as effective recyclers of inedible plant waste (leaves, stems, buds, remnants of inflorescences and fruits), which is fermented and broken down in their digestive systems, creating a valuable food source for soil bacteria.

Annelid worms, such as red Californian worms (*Eisenia fetida*), also play an important role as productive decomposers of organic waste. They feed on plant and food scraps, breaking them down into nutrient-rich compost with high organic content, which is a valuable fertilizer for agriculture and gardening within an enclosed ecosystem. At Unitsky String Technologies Inc. (Minsk, Belarus), a proprietary strain of earthworms – *Lumbricus* uTerris – has been developed for optimal vermicomposting. These worms not only serve as highly productive decomposers of organic matter but also provide a high-quality protein feed for farmed birds and fish, reducing the need for other types of feed and supporting increased weight gain. Under optimal conditions, one worm can produce up to 1,500 offspring per year and form up to 600 kg of biohumus per ton of compost. By combining snail and worm-based biotechnologies for organic waste disposal, the efficiency of the process is increased, with the resulting product being uTerra biohumus – a material with unique properties.

Nematodes, microscopic roundworms, are also important elements in organic waste recycling. Some species feed on microorganisms, including bacteria and fungi that break down organic material. By accumulating this valuable microbiome in their digestive systems, nematodes facilitate the decomposition of organic waste and accelerate the formation of nutrients. However, unlike annelid worms, nematodes also feed on the roots of living plants, which limits their application to natural background levels.

The use of invertebrates (gastropod mollusks, annelid worms and nematodes) for organic waste recycling offers several advantages. First, it reduces the volume of waste in the ECH, where space is limited. Second, it allows for the production of biohumus containing beneficial soil bacteria, as well as protein-rich meat in the form of gastropod mollusks.

Overall, breeding such animals contributes to the creation of a more sustainable and closed food chain, where the waste of one organism becomes a food source for another. For example, one *Lissachatina fulica* snail can process up to 200 g of plant material per day, while occupying an area of only 15 cm^2 (adult) or 5 cm^2 (juvenile), demonstrating its productivity and efficiency for the intended use in ECH conditions.

Waste Disposal of Wood and Cellulose-Containing Products in ECH

In an enclosed ecosystem where plants are present, wood formation processes for domestic needs occur continuously. Therefore, it is essential to organize the disposal of paper waste in advance.

Modern global technologies suggest using cellulolytic bacteria to convert cellulose. However, in most cases, these microorganisms are thermophilic and process the raw material with the formation of aldehydes and organic acids. This can negatively impact water resources and the overall biome of the enclosed ecosystem. Additionally, these bacteria emit an unpleasant odor due to the release of hydrogen sulfide and other gases during their life cycle.

Given this, the authors propose using basidiomycete fungi to recycle paper and other cellulose-containing materials. Basidiomycetes are effective decomposers of cellulose and are capable of breaking down paper waste. Moreover, they are a valuable food product.

In natural forest ecosystems, plant residues, including wood [7] and fallen leaves, are decomposed and mineralized by saprotrophs – organisms that use them as their main food source [8]. Among saprotrophs, fungi play a special role due to their diverse array of enzymes specialized in breaking down lignocellulosic compounds found in plants.

One such fungus is the reishi mushroom (*Ganoderma lucidum* (Curt.)). It grows on dead trees or fallen leaves. The mycelium of this saprotroph develops quickly and forms a dense crust over exposed areas, which helps retain moisture within its structure. In natural conditions, the fruiting bodies form in the fungus's second year. The sporangium, which contains spores, is located on a long stalk and can take various shapes depending on environmental conditions. When the mycelium develops on stumps or trees, the fruiting bodies of reishi mushroom form in a manner similar to other polypores. Numerous studies have identified anti-inflammatory, antiviral, antimicrobial, antiallergic and antitumor properties in this mushroom [9]. It is also low-maintenance, making it promising for the disposal of plant residues unsuitable for household use [10].

The growth and development of this polypore largely depend on the substrate used [11], and employing paper waste as such a substrate appears to be the most appropriate option. The authors of this article found that this allows fruiting bodies to form 20 % faster compared to using sawdust, twigs or leaf litter.

Biochemical tests show that the solid mycelium of the fungus, including reishi mushroom, contains a significant number of glycoproteins with lignin inclusions, giving the mycelium a dense structure with low moisture content. It quickly and thoroughly colonizes the paper substrate, and its hyphae penetrate through all layers (Figure 3).

Figure 3 – Mycelium of reishi mushroom on paper substrate

After a period of stable humidity, the substrate begins to dry out, and the formation of the fungus's first fruiting bodies starts after 70 days. The reishi mushroom is capable of almost completely absorbing the wood and cellulose from the growth substrate (Figure 4), meaning the entire wood structure is replaced by the fungus's hyphae.

a)

b)

Figure 4 – Cultivation of reishi mushroom on a birch log:
a – complete absorption of the wood by fungus;
b – mycelium without wood and cellulose

During the growth of the mycelium on paper, the development of cellulolytic bacteria was suppressed, resulting in the absence of any specific odor. Reishi mushroom, which has a pleasant mushroom aroma, is used in medicine and as a feed additive for farm animals. This property makes its application for the utilization of paper and leaf litter even more promising: after the paper is processed, the remaining dry mass consists mostly of the fungus's mycelium and becomes a valuable source of nutrition for animals in agriculture.

Not only medicinal mushrooms but also edible ones can be cultivated on wood and cellulose-based substrates: oyster mushroom (*Pleurotus ostreatus*), golden oyster (*Pleurotus citrinopileatus*), pink oyster (*Pleurotus djamor*), enoki / winter mushroom (*Flammulina velutipes*), summer mushroom (*Kuehneromyces mutabilis*), shiitake / edible lentinus (*Lentinula edodes*) and others.

Wheat straw, which will be regularly produced in the ECH as a result of cultivating this grain crop, is a suitable substrate for growing basidiomycetes, as it contains cellulose, hemicellulose and lignin that provide nutrients for these fungi.

An experiment conducted in the biological laboratory of Unitsky String Technologies Inc. revealed that any waste rich in lignocellulose can be used to cultivate basidiomycetes (Figure 5): cotton waste, straw, branches of fruit trees, sunflower seed husks and flax shives. It is possible to create mixtures of plant waste in specific proportions so that the total nitrogen content in the substrate is about 0.7 %.

a)

b)

Figure 5 – Cultivation of oyster mushroom
on various lignocellulosic substrates:
a – on straw; b – on straw with the addition of wood litter

The mushroom cultivation process consists of several stages. First, the substrate is soaked in hot water (92–95 °C) for 20 min to achieve maximum moisture saturation. It is then packed into special polypropylene bags with a filter. The next day, the cooled substrate is inoculated with pure mycelium of the basidiomycete in aseptic conditions. After that, the bag is hermetically sealed under sterile conditions and stored in a specially designated area with controlled climate parameters: relative humidity within 75–85 % and a temperature of around 20 °C. Oyster mushroom develops best on a substrates composed of fallen birch and oak leaves, flax shives and soft wheat straw (Figure 6).

Figure 6 – Substrate blocks for growing oyster mushrooms:
a, b – alder sawdust; c – flax shives; d – oak sawdust;
e, f – soft wheat straw

The proposed approaches offer an alternative to cellulolytic bacteria for cellulose and paper waste disposal. The use of basidiomycete fungi enables effective decomposition of paper and other cellulose-containing materials without polluting water or emitting specific odors, while the resulting substrate can be used to cultivate agronomically valuable soil microorganisms in the fertile soil layer. Moreover, this method can become part of the process for producing valuable food products.

Water Pollution Treatment in ECH

Engaging in agricultural activities, including running a farm or greenhouse in enclosed ecosystems, inevitably impacts the surrounding environment. These effects may manifest as water pollution caused by organic matter and soil runoff.

One potential source of water contamination is the increased concentration of organic substances in soil due to organic matter decomposition. While these substances benefit crop yields, their leaching into water sources, such as ponds or groundwater, can lead to water quality issues and negatively affect established ecosystems, including fish and other aquatic organisms.

Agricultural operations in the ECH must account for the likelihood of organic matter accumulating in water treatment systems. Activities like animal husbandry and crop production generate wastewater containing organic residues. To minimize their environmental impact, sustainable methods and water purification practices must be employed within enclosed ecosystems.

In the ECH, wastewater will be treated using sorbents, and the resulting sewage sludge will be processed by beneficial microorganisms and specific species of annelid worms. This will lead to the formation of fertile biohumus. The remaining contaminated water will be routed into designated containers equipped with biofilters composed of chlorella immobilized on mineral substrates (Figure 7) and other unicellular algae. The purification process will also involve the use of bivalve mollusks to regulate algae populations and provide a food source for fish and other animals [12, 13].

Figure 7 – *Chlorella vulgaris* on solid agar medium in a Petri dish

Disposal of Hard-to-Decompose SHW in ECH

In the ECH, shredded waste that cannot be directly converted into food or plant products is planned to be processed into highly fertile biohumus (even more fertile than rich chernozem) within the soil layer, using associations of agronomically valuable microorganisms, algae and fungi. This biohumus will, in turn, support the cultivation of any agricultural crops, as it serves as a universal nutrient medium for all terrestrial plants, being populated with beneficial microorganisms (around a trillion organisms per 1 kg). Thus, the matter cycle in the ECH is closed.

Materials such as rubber, glass, ceramics, paint, leather, textiles, rinse water, general sweepings and other types of waste are intended to be processed in several stages. All such materials will be shredded and put into the soil at a depth of 40–60 cm, where they will be further broken down by microorganisms living in the soil. The resulting biohumus can then also be used for plant cultivation (Figure 8).

Conclusion

This article outlines the challenges related to waste generation and disposal in enclosed ecosystems, such as the ECH, designed for the indefinite habitation of humans. The primary sources of waste are identified, and the distinction between industrial and domestic waste is substantiated. An analysis and classification of various types of SHW found in such systems is presented.

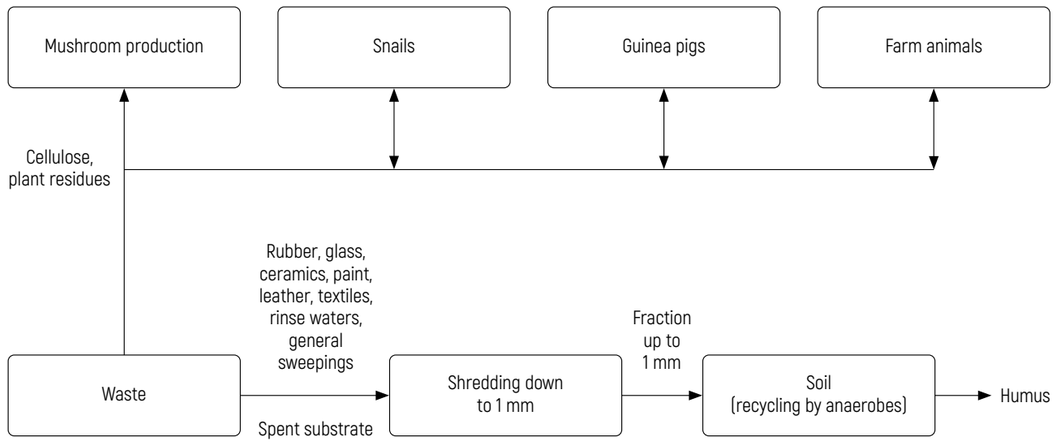

FIgure 8 – Scheme of waste disposal in ECH

The authors propose a biotechnological waste disposal method involving sequential separation of necessary components, shredding and deep integration into soil for further decomposition by agronomically valuable anaerobic soil microorganisms. The choice of anaerobes is based on their ability to function without oxygen while still recycling waste. Additionally, organic residues suitable for animal consumption are to be separated beforehand.

The study examines key species of biological organisms (worms, bacteria, microfungi, algae) involved in the decomposition process within the ECH and offers solutions for optimizing the use of secondary products. These measures aim to establish a closed-loop biosphere with continuous cycling of biogenic elements, without causing any damage to the internal environment and the well-being of the ECH inhabitants.

The data provided demonstrate that, through the use of selected technologies, it is possible to implement a self-sustaining ecosystem for human habitation, in which waste is completely recycled and reintegrated into the cycle via biological organisms and technical processing tools. The proposed concepts can be applied both in the ECH scenarios and in the development of ecohouses on Earth.

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Induction of Root Formation in *Amaranthus hypochondriacus* L. Under Influence of Elicitor from *Ganoderma lucidum* (Curt.)

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In the course of the research, the possibility of induction of root formation in *Amaranthus hypochondriacus* L. under the influence of a biogenic elicitor isolated from *Ganoderma lucidum* (Curt.) from the fungi collection of Unitsky String Technologies Inc. (Minsk, Belarus) was studied. The seeds were subjected to pre-sowing treatment in the form of soaking in elicitor solutions with concentrations of 5×10^{-2} and 1×10^{-3} ml/l.

To comprehensively evaluate the effect of the selected biologically active substance on *Amaranthus hypochondriacus* L. rhizogenesis, the following root system parameters were considered: branching frequency per 1 mm, total length, median diameter and area.

Biometric parameters were analyzed using ImageJ and RhizoVision software. The results of the study have revealed a positive effect of the obtained biostimulant on rhizogenesis.

Keywords:
Amaranthus hypochondriacus L., elicitors, Ganoderma lucidum (Curt.), growth stimulants, plant adaptation, rhizogenesis.

Introduction

Amaranthus hypochondriacus L. is one-year-old plant of the *Amaranthaceae* family. Due to its genetic potential, this crop is considered to be promising for agriculture [1], as it is capable of generating a large number of seeds (about 500,000 per plant), which are a valuable source of nutrients, vitamins, minerals and fiber. The protein content in amaranth can be as high as 18 % of the total seed biomass. Its grain is known for its balanced set of amino acids, including lysine and methionine, which in other cereals are usually available in insufficient amounts for humans. Rich in fiber, amaranth normalizes digestion and maintains healthy blood cholesterol levels. It is also a source of vitamins (in particular C and E), minerals (iron, calcium and magnesium) and antioxidants that help strengthen the immune system and protect the body from free radicals.

It is worth noting that amaranth flour is completely gluten-free, making it a valuable product for people with celiac disease – gluten intolerance. Moreover, amaranth starch has a higher proportion of easily digestible amylopectin compared to hard-to-digest amylose, which ensures faster amylolysis by enzymes and release of glucose. An additional factor contributing to the efficient digestion of amaranth starch is its highly dispersed structure. The size of starch granules ranges from 1.5 to 3 μm, which is much smaller than that of a cereal crop such as wheat (5–26 μm). This facilitates the access of digestive enzymes, such as amylase, to the starch polymers.

Amaranth is an unpretentious plant when cultivated in agriculture, well adapted to a wide range of environmental conditions; it grows successfully on different types of soils, comprising sandy, clay and dry-sandy soils, which allows it to be used in the EcoCosmoHouse (ECH) [2] as one of the main crops.

A valuable advantage of amaranth is its ability to tolerate saline and arid soils. Accordingly, it can survive and bear fruit even on soils with high salinity or with limited access to water, which is especially important in the ECH.

At extreme temperatures, lack of moisture or exposure to harmful substances and diseases, growth and development of amaranth can be slowed or disturbed, which negatively affects the yield. So, to cultivate this plant in the ECH, it is necessary to provide optimal conditions of cultivation and protection from stress factors.

Besides, amaranth is able to grow and develop actively in the juvenile stage: it quickly forms leaves and stems, accumulates biomass and, as a result, gives a high seed yield. This allows it to anticipate other plants in competition for resources, which is an advantage when cultivating the crop.

The development of roots is the main stage in the process of seed germination, and further growth of the aboveground part depends on the developed root system [3] which performs several important tasks: absorption of water and mineral substances, ensuring resistance in the soil, synthesis of certain hormones in the parenchyma and accumulation of nutrients. After seed germination, the root begins to synthesize cytokinins and gibberellins which are directed to the shoot and contribute to the development of stem apical meristems, functional activity of leaves. Stable development of the root system and the formation of shoots result in the accumulation of significant vegetative mass, which favorably affects the crop yield [3].

It should be noted that the process of root formation, or rhizogenesis, begins as early as the seed emergence stage. During this period, optimal conditions for root growth have to be provided, including sufficient moisture, nutrients and suitable soil. Changes in any parameters can be perceived as a stress factor and lead to slow growth and development of roots and even to the death of amaranth [3, 4].

In conventional agricultural systems, pesticides, herbicides and synthetic growth regulators are widely used to protect crops and stimulate their development. However, in controlled enclosed environments, such as the ECH, synthetic agrochemicals can have a negative impact on the microbiocenosis. Their use requires special precautions, which complicates the technological processes of plant cultivation. In addition, obtaining these substances in conditions of the limited ECH resources presents certain difficulties. Alternative, safer approaches are needed to protect and stimulate the growth of crops in controlled environments. In this regard, biogenic elicitors are most promising. They are environmentally harmless and can be produced directly in the ECH. The use of such biostimulants will make it possible to maintain optimal crop development while keeping the balance within the enclosed ecosystem.

Some elicitors are capable of activating plant protective responses, while others are capable of biochemical changes that can bring about an increase in biomass, stem diameter, root growth and stimulation of flowering [4, 5]. The use of these substances will increase survival and accelerate the process of plant adaptation through systemic stability, stimulation of protective functions and more efficient consumption of resources [6, 7].

The elicitors represent a variety of factors affecting plants and are divided into biotic and abiotic. Abiotic stressors can

include physical effects of wind on aboveground biomass, temperature fluctuations (comprising extreme temperature fluctuations), osmotic shock or the presence of heavy metals. Biotic elicitors may include exogenous proteins, plant cell wall materials, components of bacteria and fungi [8, 9]. For example, substances functionally required by fungi activate transmembrane pattern-recognition receptors (PRR) that have evolved during coevolution in plant cells, resulting in stimulation of secondary metabolite production [5, 8, 10, 11].

Thus, the use of elicitors increases plant survival and adaptability due to the activation of systemic protective mechanisms and optimization of resource consumption.

The aim of this research is to evaluate the effect of elicitors isolated from saprophytic fungi, *Ganoderma lucidum* (Curt.), on the process of root formation in *Amaranthus hypochondriacus* L. under aseptic conditions.

Materials and Methods of Research

Aseptic roots of *Amaranthus hypochondriacus* L. seedlings were used as the object of the study. Plant seeds were pre-stratified at 6 °C for 10 days.

For the experiment, biogenic elicitor was obtained from *Ganoderma lucidum* (Curt.) according to the method developed by the employees of Unitsky String Technologies Inc. (Minsk, Belarus). Before sowing, amaranth seeds were soaked for 5 h in aqueous solutions of this substance in two concentrations: 5×10^{-2} and 1×10^{-3} ml/l. Control seeds were soaked in distilled water.

After exposure in elicitor solutions, seeds were sown in Petri dishes seven pieces each in four samples. Murashige and Skoog medium containing a standardized list of vitamins, micro- and macronutrients was used as nutrient medium. Petri dishes were vertically placed in a specialized rack to minimize light exposure to the root system of the seedlings. Then they were transferred to a growing chamber with a 16-hour photoperiod and a temperature of 26 °C.

To evaluate the effect of fungal elicitor, the following parameters of root growth and development were recorded:

- branching frequency per 1 mm;
- total length;
- median diameter;
- area.

Measurements were made on the 4th, 6th, 11th and 14th days by photorecording and subsequent photo analysis using ImageJ and RhizoVision software [12].

Experimental Part

The parameter of seed germination was not analyzed under the conditions of this experiment, but it is worth noting the differences in their germination in the variations of the experiment. Thus, visually, in all samples of the experiment, the best germination was observed in seeds treated with elicitor, especially at a concentration of 5×10^{-2} ml/l (Figure 1).

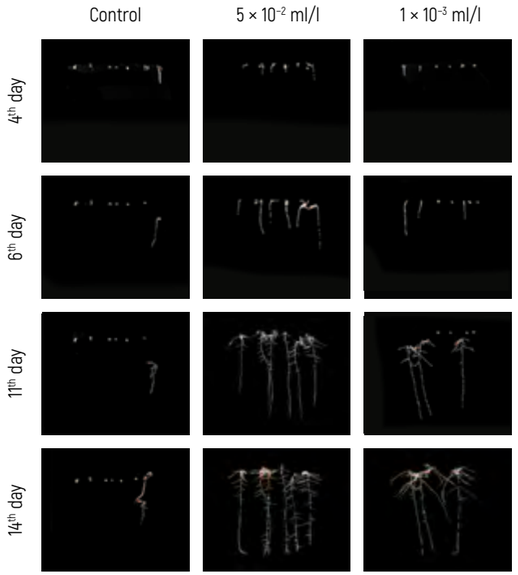

Figure 1 – Induction of root system development of *Amaranthus hypochondriacus* L. under the influence of fungal elicitor

The photorecording showed that on the 4th day at an elicitor concentration of 5×10^{-2} ml/l, the number of successfully germinated seeds was higher compared to the control group and the group with a lower dose of substance (1×10^{-3} ml/l). In addition, a more developed root system was observed in plants that received the high concentration of elicitor. The results of measurements are provided in Table.

The investigated parameters affect the ability of the root system to soil exploration. Thus, when the root length increases, the plant penetrates into deeper soil layers and, accordingly, is more adapted to changing environmental conditions, including drought.

Table – Biometric indices of the root system of *Amaranthus hypochondriacus* L. grown under the influence of fungal elicitor

Sample number	4th day of vegetation				6th day of vegetation				11th day of vegetation				14th day of vegetation			
	L, mm	*N*	*d*, mm	*S*, mm²	*L*, mm	*N*	*d*, mm	*S*, mm²	*L*, mm	*N*	*d*, mm	*S*, mm²	*L*, mm	*N*	*d*, mm	*S*, mm²
Control																
1	12.8	0.55	0.59	22.44	32.94	0.64	0.3	31.31	41.89	0.17	0.47	65.94	70.54	0.45	0.35	94.48
2	18.02	0.72	0.44	31.39	49.54	0.81	0.33	66.65	101.94	0.17	0.47	160.57	215.13	0.58	0.35	374.96
3	16.75	0.6	0.44	28.91	48.04	0.54	0.33	60.33	178.26	0.38	0.47	320.67	344.57	0.44	0.7	884.92
4	18.67	0.16	0.29	20.24	78.05	0.51	0.3	82.48	238.15	0.25	0.47	385.68	471.87	0.32	0.35	693.96
Average index	16.56	0.51	0.44	25.74	52.14	0.62	0.32	60.19	140.06	0.24	0.47	233.21	275.53	0.45	0.44	512.08
Elicitor concentration 5×10^{-2} ml/l																
1	107.86	0.73	0.33	165.29	235.61	0.67	0.3	364.57	863.25	0.33	0.49	1,612.47	1,215.71	0.35	0.35	1,891.84
2	87.03	0.89	0.3	92.32	137.02	0.56	0.3	154.79	460.16	0.18	0.49	766.91	987.72	0.3	0.35	1,632.94
3	31.56	0.67	0.3	37.27	77.33	0.91	0.3	102.92	342.9	0.35	0.49	585.88	705.78	0.45	0.35	1,375.96
4	88.5	0.51	0.3	103.25	189.96	0.87	0.3	205.81	327.64	0.22	0.49	552.83	662.62	0.38	0.35	1,040.8
Average index	78.74	0.7	0.3	99.53	159.98	0.75	0.3	207.02	498.49	0.27	0.49	879.52	892.96	0.37	0.35	1,485.38
Elicitor concentration 1×10^{-3} ml/l																
1	10.13	0.2	0.29	10.71	67.39	0.85	0.34	90.24	170.61	0.22	0.48	268.58	198.13	0.18	0.35	261.57
2	40.42	0.64	0.44	70.63	94.45	0.7	0.43	135.74	464.39	0.31	0.48	783.79	717.44	0.37	0.35	1,258
3	22.25	0.67	0.44	37.26	72.95	0.63	0.45	106.05	387.23	0.28	0.48	656.21	825.92	0.33	0.35	1,348.05
4	13.8	0.73	0.44	18.38	129.66	0.82	0.45	205.82	652.44	0.27	0.48	1,177.39	1,138.66	0.35	0.35	1,766.12
Average index	21.65	0.56	0.4	34.25	91.11	0.75	0.42	134.46	418.67	0.27	0.48	721.49	720.04	0.31	0.35	1,158.43

Note – *L* – total length; *N* – branching frequency per 1 mm; *d* – median diameter; *S* – area.

Throughout the experiment, the samples with an elicitor concentration of 5×10^{-2} ml/l showed the highest results in terms of total root system length (Figure 2). Thus, on the 4th day, this index at the elicitor concentration of 5×10^{-2} ml/l was 4.75 times greater than in the control group and 3.64 times greater than in the group with the elicitor concentration of 1×10^{-3} ml/l.

As the experiment continued, the difference between the studied variants slightly was smoothing out but still remained significant. On the 14th day, it amounted to 3.24 times in the control and 1.24 times at a lower concentration of the active ingredient.

The diameter of roots, their branching frequency and total length directly affect the root system area of the plant, which determines the total root surface available for absorption of water, micro- and macronutrients from the soil.

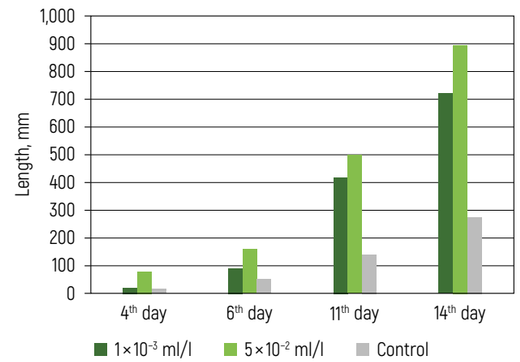

Figure 2 – Dynamics of changes in the total length of the root system of *Amaranthus hypochondriacus* L. under the influence of fungal elicitor

The branching frequency in the root system is a measure of the density of lateral branches per unit length of the main root (axial root). The greater the frequency, the denser the roots are distributed in the soil. Sometimes the frequency is high, but some plants, especially epiphytes (aquatic species), are exceptions.

The branching process usually involves the formation of root hairs, the number of which may depend on the root diameter and is induced by symbiotic interaction with fungi (mycorrhiza).

The monitoring of the obtained data confirms the advantage of soaking seeds in a solution with a high elicitor concentration for root branching. A significant difference between the variants was observed at the initial stage (Figure 3). On the 4th day of the experiment, the branching frequency index was 0.7 at an elicitor concentration of 5×10^{-2} ml/l, while it was 0.51 in the control group. At an elicitor concentration of 1×10^{-3} ml/l, a relatively similar result of 0.56 was recorded.

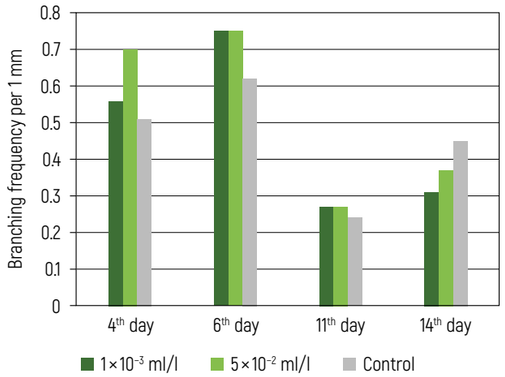

Figure 3 – Dynamics of changes
in the branching frequency per 1 mm
of the roots of *Amaranthus hypochondriacus* L.
under the influence of fungal elicitor

Thereafter, the difference between the variants was smoothing out. On the 6th day of the experiment, the branching frequency index was 0.75 for an elicitor concentration of 5×10^{-2} ml/l and for a concentration of 1×10^{-3} ml/l, while in the control group it was 0.62 (Figure 3). In the last day of the ongoing experiment, the index of the control group exceeded the others and reached 0.45, while it was 0.37 for a concentration of 5×10^{-2} ml/l and 0.31 for a concentration of 1×10^{-3} ml/l.

Low values are observed for the 5×10^{-2} ml/l variant in the median root diameter diagram (Figure 4). For example, on the 4th and 6th day, it was 0.3 mm compared to the control – 0.44 mm and 0.32 mm, respectively. The diameter for variants with an elicitor concentration of 1×10^{-3} ml/l ranged from 0.4 to 0.42 mm. On the 11th day, the median diameters for all variants were close and reached (0.48 ± 0.01) mm. On the 14th day, the highest value of 0.44 mm was in the control group.

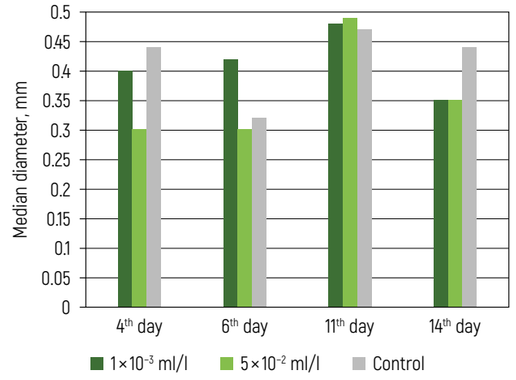

Figure 4 – Dynamics of changes
in the median diameter
of the roots of *Amaranthus hypochondriacus* L.
under the influence of fungal elicitor

These results can be explained as follows: the median diameter is the diameter value that divides the sample into two equal parts: 50 % of the diameters are smaller than the median value and the remaining diameters are larger. In the variant with high elicitor concentration, the values of the number of root branches prevail on the 4th, 6th and 11th day, which corresponds to an increased number of newly formed roots. Their diameter will be smaller than those already formed, which leads to lower values of median diameter.

When analyzing the root system area, it was found that at an elicitor concentration of 5×10^{-2} ml/l, high values prevailed for all measurements (Figure 5), which is consistent with expectations based on previous analysis of the parameters studied. For lower elicitor concentration, excess values over controls were also observed. For example, on the 14th day, the total root area of plants in the group with high elicitor concentration was 1,485.38 cm^2, which was 2.9 times higher than the control value and 1.28 times higher than when the elicitor concentration is low.

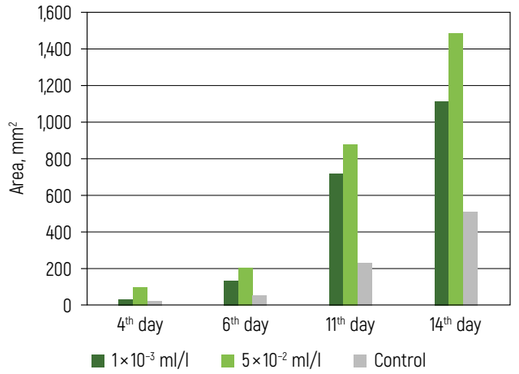

Figure 5 – Dynamics of changes
in the root system area of *Amaranthus hypochondriacus* L.
under the influence of fungal elicitor

Conclusion

The switch to the use of biogenic elicitors instead of synthetic agrochemicals is an important step in the creation of sustainable plant cultivation technologies in controlled enclosed environments.

Experimental data indicate better root system development in plants obtained from seeds pretreated with the elicitor from *Ganoderma lucidum* (Curt.) compared to the control group. The greatest stimulation of rhizogenesis was observed at the elicitor concentration of 5×10^{-2} ml/l and averaged about 50 %. Thus, the results of the study indicate that soaking seeds in a solution with high elicitor content facilitates an increase in the total length, area and branching frequency of the root system, especially in the early stages of plant development. At the same time, the difference between the variants decreases with time, which is explained by the earlier development of the root system under the influence of elicitor.

Upon extrapolation of the experimental data, one can expect a reduction in the plant fruiting periods as well as an increase in the accessibility of nutrient elements by the root system. The conducted work allowed us to obtain a number of important results confirming the potential of elicitor isolated from *Ganoderma lucidum* (Curt.) in the induction of root system development of *Amaranthus hypochondriacus* L. and emphasizing the role of this biostimulant in increasing the yield and stability of cultivated plants under the ECH conditions and in other enclosed ecosystems.

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Effect of Bacterial-Origin Elicitors on Growth and Development of Field Pea

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The effect of biologically active substances with elicitor action, derived from the bacterium *Pseudomonas aurantiaca*, on the stimulation of growth and development of annual herbaceous legumes was investigated using field pea (*Pisum arvense* L.) as the model plant. Alongside the *Pseudomonas aurantiaca* cell culture, pure amino acid tryptophan and metabolic products of these bacteria were utilized as elicitors. Plants were cultivated on Ellis liquid nutrient medium supplemented with various growth stimulants, applied every seven days throughout the vegetation period. During the experiment, parameters such as average daily growth, average pea fruit mass and the vegetative mass of plants (both dry and wet) were analyzed. The findings indicate the potential of the tested substances as biogenic fertilizers. These results could be particularly valuable in enclosed ecosystems, EcoCosmoHouses, to enhance plant growth and development.

Keywords:
elicitors,
field pea (Pisum arvense L.),
growth stimulants,
Pseudomonas aurantiaca,
rhizobacteria.

Introduction

The exogenous application of biological growth regulators to crops is a crucial element of modern agricultural production technology [1]. L-tryptophan serves as a physiological precursor to auxin biosynthesis in both microorganisms and higher plants, influencing the modulation of their growth and development [2]. Auxin is closely associated with the development of the root system under abiotic stress conditions, such as salinity, drought and heavy metal contamination. Changes in auxin metabolism play a regulatory role in stress-induced alterations in root morphology [3]. L-tryptophan may enhance plant stress resistance by positively affecting the levels of endogenous hormones and physiological processes.

Natural agricultural ecosystems are directly dependent on microorganisms present in the soil and root zone, which lead to increased crop yields [4, 5]. Beneficial rhizosphere microbes are key factors in determining plant health and soil fertility, as they participate in many critical ecosystem processes, such as biological control of plant pathogens, nutrient cycling and seed germination [6].

Most fluorescent pseudomonads isolated from the rhizosphere of plants promote their growth through direct and indirect mechanisms. For instance, *Pseudomonas aurantiaca*, a subspecies of *Pseudomonas chlororaphis* [7, 8], produces phytohormones such as indole-3-acetic acid – one of the most physiologically active auxins, a product of L-tryptophan metabolism, directly contributing to crop growth [9, 10]. Additionally, they produce secondary metabolites that suppress the development of pathogenic bacteria and fungi, thus indirectly affecting plants [11, 12].

In the experiment, field pea (*Pisum arvense* L.) was used as a model plant to analyze the effects of selected stimulants on legume crops. The plant is rich in protein, carbohydrates, dietary fiber, vitamins and minerals, and can be used as a partial substitute for animal protein. The proteins and starch of peas interact with carbohydrate, protein and oil fractions of various ingredients in food products. In agriculture, the crop is grown as a rotational one to break disease cycles, serve as an alternative to summer fallow and increase the yield of grain and oilseed crops.

In enclosed biosphere ecosystems (e.g., EcoCosmoHouses), plants are a key component for maintaining natural balance. They influence the gas composition, equilibrium in soil organism associations and the cycling of chemical elements and water balance. In classical agriculture, a large number of chemical fertilizers are used for stable crop development, which is unacceptable in a closed environment as it would disrupt the natural processes of all ecosystem components. Therefore, developing natural stimulants for plant growth and development is a relevant field in enclosed ecosystem research.

Based on the above, the aim of this study is to analyze the effectiveness of the following elicitor-type compounds: bacterial tryptophan extracted from *Pseudomonas aurantiaca*; pure bacterial culture; chemically synthesized tryptophan.

Materials and Methods of Research

The study object chosen is field pea of the shelling variety. Seeds were germinated in universal soil until the formation of three true leaves. Then, the seedlings were transferred to containers filled with Ellis nutrient medium with the addition of an elicitor. The control was pure Ellis medium.

The stimulants used were designated as follows:

1) Bacterial I – bacterial tryptophan obtained from *Pseudomonas aurantiaca*;

2) Bacterial II – pure culture of *Pseudomonas aurantiaca* bacteria;

3) Tryptophan – pure amino acid.

To determine the effect of elicitors, a concentration of 5×10^{-3} ml/l was chosen. Each experiment was conducted in triplicate.

Containers with plants were placed on light shelves at a temperature of 25 °C, light intensity of 6,000 lx and a 14-hour photoperiod. The nutrient medium was added as needed. The stimulants were applied twice – on the 14th and 25th days of vegetation. Under these conditions, the containers were maintained throughout the study. Seven days after the start of the experiment, the first changes were recorded. Plant height measurements were taken every 4–8 days. The total vegetation period was 36 days.

Study Results

All the studied elicitors had a positive impact on the growth and development of plants compared to the control. Table 1 presents the data of weekly measurements of field pea stem heights.

As a result of the effect of elicitors, an increase in the maximum plant size by 24.6 % was observed: from 44.7 cm in the control to 55.7 cm in the "Bacterial I" variant. The experiment with tryptophan also showed high values – 54 cm, which is 20.8 % higher compared to the control. The application of the "Bacterial II" stimulator also contributed to a significant acceleration in vegetative mass growth.

Table 1 – Effect of elicitors on field pea height, cm

Experimental option	Vegetation day					
	7th	14th	18th	25th	28th	36th
Control						
1	4	12.5	17	18.5	22	34
2	4.3	12.5	20	25	32	50
3	4	15.5	25.5	31	40	50
Average	4.1	13.5	20.8	24.8	31.3	44.7
Bacterial I						
1	4	13.5	23.5	28	36	60
2	1.5	9	15.5	18	23.5	40
3	3.1	15.5	29	34	44	67
Average	2.9	12.7	22.7	26.7	34.5	55.7
Bacterial II						
1	3	10	19.5	24	31	50
2	3.7	15	26.5	31	39	55
3	2	10.5	21	25	32	47
Average	2.9	11.8	22.3	26.7	34	50.7
Tryptophan						
1	3	11.5	21	26	32	53
2	4.3	16.5	28	34	42	55
3	3.5	14	24	30	37	54
Average	3.6	14	24.3	30	37	54

Figure 1 shows the impact of elicitors on the accumulation of wet and dry mass by the shoots of field peas. The highest values (35.16 and 10.9 g, respectively) were obtained with the addition of pure culture of *Pseudomonas aurantiaca* bacteria was added to the nutrient medium ("Bacterial II" variant).

When assessing the daily growth rate at the initial stages of the experiment, the highest induction was observed for the elicitor "Bacterial I" – 2.6 cm/day. The variability of the data is visualized in Figure 2. Based on the growth graph, it can be concluded that all variants of stimulants contributed to faster growth of the peas during the experiment.

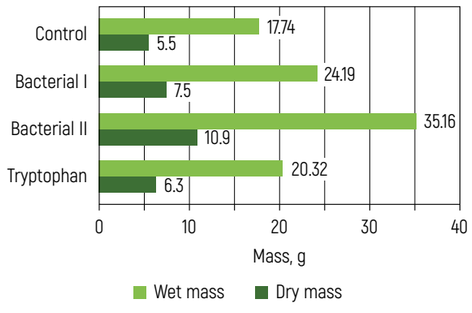

Figure 1 – Vegetative mass of field pea samples under study

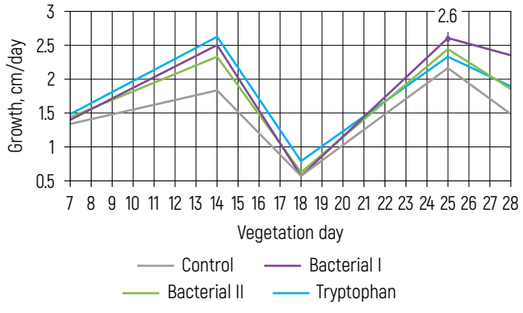

Figure 2 – Daily growth of field peas under the influence of elicitors

Table 2 presents the final data on crop yield.

The main characteristics of the peas and yield provide insight into the full potential productivity of the crop under the influence of the studied stimulants. Differences in the indicators may be related to the load caused by insect pests, leading to the exclusion of some plants at early stages and disrupting overall statistical significance.

The experiment with the "Bacterial I" elicitor resulted in a total pea mass of 3.432 g, while tryptophan yielded 1.556 g. All tested substances demonstrated results 1.1–4.9 times higher compared to the control variant.

There is a correlation between the values of pea mass (Table 2) and vegetative mass (Figure 1). Figure 3 shows the seed set (number of peas).

Table 2 – Effect of elicitors on field pea yield

Experimental option	Number of pea pods	Number of peas		Average pea diameter, mm	Total pea mass, g
		Normal	Underdeveloped		
Control					
1	1	2	1	6	0.581
2	1	4	2		
3	1	2	4		
Total	3	8	7		
Bacterial I					
1	4	–	23	8	3.432
2	3	6	4		
3	4	9	19		
Total	11	15	46		
Bacterial II					
1	2	5	3	7.3	1.215
2	2	5	3		
3	–	–	–		
Total	4	10	6		
Tryptophan					
1	2	5	–	7.4	1.556
2	2	5	2		
3	–	–	–		
Total	4	10	2		

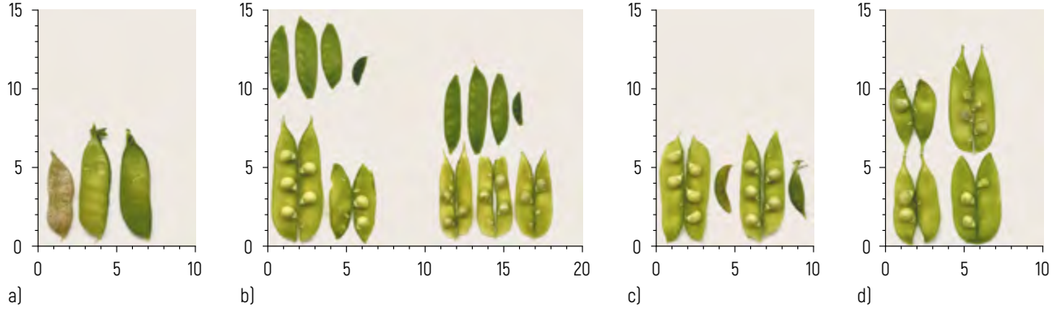

Figure 3 – Seed set of field pea pods: a – Control; b – Bacterial I; c – Bacterial II; d – Tryptophan

The best yield performance was observed for the "Bacterial I" and "Tryptophan" variants. In a laboratory experiment, it is difficult to achieve maximum productivity and seed set, but even visually, a significant difference is noticeable at the early stages of ripeness.

Conclusion

As a result of the conducted research, it was found that all tested elicitors possess growth-stimulating properties. The highest induction was observed with the "Bacterial I" and "Tryptophan" variants.

The effectiveness of these substances is explained not only by the interaction of their biogenic components with plant cell PRRs, activating the organism's immune potential, but also by the possible presence of secondary synthesis products of elicitors in the form of agrochemical compositions based on potassium lactate, which likely leads to the formation of biologically active or auxiliary organic substances, causing a positive response in plants through growth stimulation. Among other reasons for such a reaction in field peas is the production of indole-3-acetic acid by growth-stimulating rhizobacteria. Recent scientific publications [5–7] suggest that tryptophan can regulate the activity of auxin biosynthesis by both spontaneous soil microflora and induced rhizobacterial strains. One condition for the hormonal effect of rhizosphere microflora on plants is the presence of sufficient amounts of tryptophan in the rhizosphere. Additionally, the number and colonizing activity of rhizobacteria influence crop growth stimulation.

The study showed that the use of an elicitor obtained from bacterial tryptophan results in an increase in vegetative mass (by 36 % compared to the control), as well as in yield (4.9 times compared to the control) of field peas. Therefore, bacterial and chemically synthesized tryptophan compounds can be used in the enclosed ecosystem of EcoCosmoHouse [13] to stimulate plant growth and development. Further evaluations are planned to assess the impact of the most promising variant, "Bacterial I," on other agricultural crops, as well as to analyze the quality of the resulting products.

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Biochemical Composition of Apple Fruits when Using uTerra Fertility Elixir

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The effect of liquid organic complex fertilizer uTerra (fertility elixir) on the biochemical composition of plant products, in particular fruits of domestic apple tree (*Malus domestica*) which can be grown in the EcoCosmoHouse (ECH), was examined. Throughout the experiment, conducted in the orchard of Unitsky's Farm Enterprise (Maryina Gorka, Belarus), regular monitoring of the plants' physiological state was carried out. This article presents findings on vitamin C content, total sugars in apple fruits, etc. The data demonstrate a positive impact of uTerra fertility elixir. Similar beneficial effects were observed in other fruit, berry, vegetable and green crops, which highlights the fertilizer's broad applicability. The study also explores the potential of uTerra as a means to enhance plant productivity and, consequently, the organic nutrition available to flora, fauna and humans within an enclosed biosphere-type ecosystem like ECH.

Keywords:
biochemical composition, domestic apple tree (Malus domestica), EcoCosmoHouse (ECH), enclosed ecosystem, fertility elixir, liquid organic complex plant fertilizer uTerra.

Introduction

Modern agriculture faces significant challenges related to the need to improve the quality of cultivated vegetables, fruits, grains and other crops. The pursuit of increased production volumes and high yields often leads to a decline in nutritional value, taste and shelf life. Moreover, intensive technologies in the agro-industrial sector are frequently associated with environmental pollution and disruptions to ecological balance [1].

The use of pesticides, herbicides and other agrochemicals leaves harmful residues on crops, posing a health risk to the population. Additionally, such practices contribute to soil degradation, a decline in biodiversity and disturbances in natural ecosystem cycles. Due to soil depletion and early harvesting, fruits often contain lower levels of vitamins, minerals and other essential nutrients [2].

Under these conditions, there is a growing demand for the development and implementation of new methods that ensure high-quality agricultural products without harming the environment. A transition to more sustainable, eco-friendly and gentle cultivation techniques for fruits and vegetables is necessary.

This article focuses on an innovative technology aimed at enhancing the nutritional value of plant-based products. It presents the results of using liquid organic complex plant fertilizer uTerra in the orchard of Unitsky's Farm Enterprise (Maryina Gorka, Belarus) and explores the potential of this fertility elixir as an environmentally friendly fertilizer within the closed system of the EcoCosmoHouse (ECH) [3]. The study aims to assess the impact of uTerra on the biochemical composition of domestic apple tree (*Malus domestica*).

Materials and Methods of Research

The testing of uTerra fertility elixir was conducted at Unitsky's Farm Enterprise, where the total orchard area is 15 ha. The physiological condition of the trees was monitored monthly. During the vegetation period, four treatments of orchard crops with uTerra fertility elixir were carried out. Subsequently, a series of laboratory analyses was performed.

1. Chemical analyses. The following parameters were determined:

- moisture content – according to GOST 28268-89;
- ash content – according to STB 2042-2010;
- pH – according to STB 17.13.05-36-2015;
- nitrate content – according to STB 17.13.05-28-2014.

2. Microbiological analysis. Colony-forming units (CFU/g) were counted using Koch's method.

3. Biochemical analyses. The following parameters were determined:

- total sugar content – using a colorimetric method based on changes in the intensity of copper glycerate solution color when boiled with extracts;
- vitamin C content – using iodometric titration with starch as an indicator;
- chlorophyll (*a* and *b*) and total carotenoid content – using spectrophotometry from a single alcohol extract.

4. Physiological analyses. Phenological observations were carried out throughout the entire ontogenesis, identifying phenophases and stages of plant development.

5. Bud viability analysis. Microscopy was performed to assess bud viability. Observations were conducted using a binocular stereomicroscope MS-1 Led (TM "Micromed," Russia) with 4× magnification.

Experimental Part

Determining the biochemical composition of fruits is an important task for both agricultural producers and consumers. Vegetables and fruits are valuable sources of vitamins, minerals and other biologically active substances that play a key role in maintaining human health. However, nutrient content can vary significantly depending on various factors, such as variety, cultivation methods, storage conditions and transportation. Analyzing vitamin content allows producers to identify these factors and take timely measures to optimize cultivation technology [4].

The effectiveness of uTerra fertility elixir has been previously studied at the Belarusian State Agricultural Academy (BSAA, Gorki, Belarus). It was found that fertilization contributed to an increase in vitamin C content (compared to the control, i.e., without processing) by 23 % in lettuce leaves, 14 % in radish roots, 12 % in tomato fruits and 27 % in cucumbers. Additionally, an increase in sugar content was observed in tomatoes and cucumbers, directly influencing the taste quality of the products [5–10].

uTerra fertility elixir is obtained through bioprocessing of relict fossil raw materials (brown coal, oil shale, peat), uTerra crumbly biohumus (an inoculant formed from agronomically valuable microorganisms sourced from the world Bank of soils established at Unitsky's Farm Enterprise), molasses, honey, natural elicitors, sea salt, mineral and organic plant nutrients

and other complex organic and mineral components. The fertilizer has a balanced composition of macro-, micro- and ultramicroelements, organic compounds and thousands of agronomically valuable species of aerobic and anaerobic soil microorganisms [11].

Table 1 presents the results of visual monitoring of the fruit trees in the orchard of Unitsky's Farm Enterprise.

An analysis of the soil was conducted before applying uTerra fertility elixir (May 8, 2024) and after the fourth treatment of apple trees (June 20, 2024). The results are presented in Table 2.

The microbiological indicator reflects the number of agronomically valuable microorganisms present in 1 g of soil. This characteristic is crucial for assessing soil health, its ability to accumulate macro-, micro- and ultramicroelements and to convert them into plant-available forms through bacterial metabolic processes. The optimal pH range for orchards is between 6 and 7, which falls within the norm [12]. The nitrate content indicates the current availability of nitrogen in the soil for plants. A decrease in ash content percentage corresponds to an increase in organic matter (by 1.9 %).

Table 1 – Visual observations of the orchard of Unitsky's Farm Enterprise

Period	Completed work	Observations, notes
Phenophase II	Inspection of the physiological condition of fruit trees after the winter period	All trees survived the winter, indicating high frost resistance of the varieties. Bud formation and development are stable (Figure 1). Bud samples were collected for histological analysis to assess viability
Phenophase III	Inspection of the physiological condition of trees for mineral nutrient deficiency, inflorescence formation and flowering abundance	Trees are blooming profusely (Figure 2a). Flowers are undamaged. Blossom drop is minimal, and most flowers are pollinated
Phenophase IV	Inspection of the physiological condition of trees for mineral nutrient deficiency and pathogenic load assessment; evaluation of fruit set formation	Fruit formation is stable (Figure 2b). Leaf samples were collected for further analysis of chlorophyll content and histological examination
Phenophase V	Inspection of the physiological condition of trees for mineral nutrient deficiency and pathogenic load assessment; evaluation of fruit ripeness	Fruit formation remains stable, and the ripening stage has begun. Active growth processes, intensive formation of fruit-bearing wood and high photosynthetic productivity significantly influence fruit tree yield

Table 2 – Soil indicators

Date	Microbiological indicator, CFU/g	pH	Nitrate content, mg/100 g	Moisture content, %	Ash content, %
May 8, 2024	1×10^6	5.6	39.9	16.06	95.4
June 20, 2024	2×10^7	6	44.3	18.09	93.5

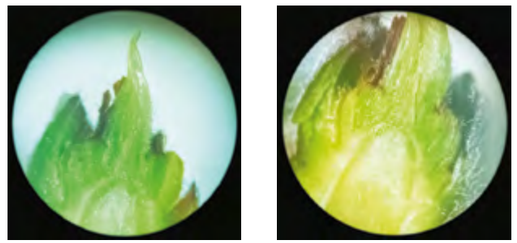

Figure 1 – Apple bud samples (section, 4× magnification)

a)

b)

Figure 2 – The orchard of Unitsky's Farm Enterprise: a – apple tree blossom stage; b – apple fruit set stage

To assess productivity and diagnose the physiological state of the trees, an analysis of plant pigment content was conducted. This allows for the evaluation of photosynthetic capacity, growth, development and the accumulation of reserve nutrients. Additionally, this study helps identify micronutrient deficiencies, in particular magnesium, iron, molybdenum and zinc.

Chlorophyll (*a* and *b*) is the primary pigment involved in photosynthesis. Its structure includes a magnesium ion, making chlorophyll content a key factor in the biosynthesis of this element. Iron, which plays a role in cellular respiration and nitrogen fixation, and zinc, which is part of enzyme compositions, are also involved in biochemical synthesis reactions. The ratio of chlorophyll *a* to *b* in plants varies depending on species, age, environmental conditions and other factors, typically ranging from 2.5 : 1 to 4.5 : 1 [13]. Figure 3 presents the results of chlorophyll *a* and *b* determination in apple tree leaves.

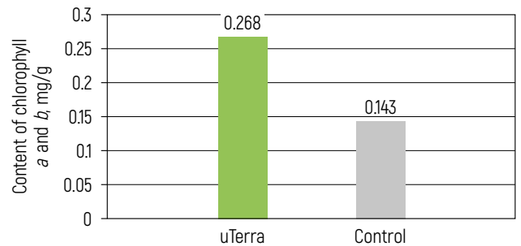

Figure 3 – Content of chlorophyll *a* and *b* in apple tree leaves

Carotenoids are a group of fat-soluble pigments that play an important role in photosynthesis and plant protection as well as giving color to many plant organs, including fruits, flowers and leaves. Like chlorophyll, carotenoids participate in capturing light waves during photosynthesis, especially under stress conditions (such as drought and temperature fluctuations). One of the main carotenoids found in plants is β-carotene. Measuring the content of these pigments, along with chlorophyll analysis, helps to comprehensively assess the photosynthetic activity and overall physiological condition of the crops [13]. Figure 4 shows the content of carotenoids in apple tree leaves.

During the study of chlorophyll and carotenoid content (Figures 3, 4), it was found that the pigment levels were higher in trees treated with uTerra fertility elixir. This indicates that the fertilizer promotes the stimulation of pigment accumulation due to the presence of necessary macro- and microelements.

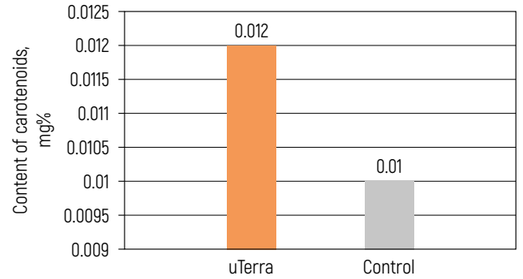

Figure 4 – Content of carotenoids (calculated as β-carotene) in apple tree leaves

Tree growth strength depends on environmental conditions and the physiological state of the plants. Rapidly growing trees increase in height by 50–100 cm/year. The assessment of apple tree growth strength in the orchard at Unitsky's Farm Enterprise is presented in Table 3.

Table 3 – Assessment of apple tree growth strength

Variant	Length of one-year-old shoots, cm*	Thickness of one-year-old shoots, mm*
uTerra	26 ± 2	6 ± 1
Control	26 ± 1	5 ± 1

* ± SD (standard deviation).

There was a stable growth of shoots, with the highest growth strength observed in the trees treated with uTerra fertility elixir.

The determination of vitamin C content in apple fruits holds significant scientific and practical value. This substance is not synthesized by the human body and must be obtained from food. It has high antioxidant activity, supports the immune system, improves iron absorption, plays a role in collagen formation and performs numerous other functions. The concentration of vitamin C serves as an indicator of the overall quality of apples, as it correlates with other indicators, such as freshness, ripeness and resistance to spoilage. Its content in fruits varies depending on the variety, maturity

stage, conditions of growing and storage. Thus, accurately determining the content of ascorbic acid is essential for assessing the nutritional value and quality of apples [14].

During the study, the biochemical indicators of the products were analyzed (Table 4).

Table 4 – Biochemical indicators of apple tree fruits

Variant	Vitamin C content, mg/100 g	Total sugar content, %
uTerra	15.18	6.9
Control	12.34	6.48

The content of vitamin C in the treatment group was 23 % higher compared to the control, which correlates with the increased ascorbic acid content observed in experiments by the BSAA. The synthesis of vitamin C is associated with active oxidation-reduction reactions in plant cells. Temperature fluctuations, as well as soil moisture, significantly affect its quantity. Therefore, uTerra fertility elixir helps enhance plant resistance to rapidly changing environmental factors.

Additionally, it is worth noting that apple yield was significantly higher in the year of fertilizer application according to usage norms, amounting to:

- 55,626 kg of apples in 2023;
- 61,500 kg of apples in 2024.

Conclusion

The experiment revealed that when apple trees were treated with uTerra fertility elixir, fruit set occurred (without any drop of the blossoms), and the fruit orchard actively developed, preparing for fruit-bearing (phenophase V). The physiological maturity of the fruits was reached. The treatment contributed to the rapid growth of shoots and their sufficient thickness, which, in turn, affects the delivery of macro-, micro- and ultramicroelements from the roots to the leaves.

During the research at Unitsky's Farm Enterprise, relatively dry weather was observed, and the formation of stronger young shoots due to uTerra fertility elixir treatment indicated an increase in their drought resistance. The leaf analysis (including histological and biochemical) showed no pathology in chlorophyll synthesis, which suggests an adequate supply of micronutrients (magnesium, manganese, zinc, iron). The chlorophyll content (*a* and *b*) increased by 87 %, and this pigment contributes to enhanced plant growth and development, their resistance to stress and positively influences the accumulation of necessary nutrients and biologically active substances (vitamins, antioxidants, proteins, etc.).

The application of uTerra fertility elixir improved the quality of the apple fruits (an increase of vitamin C by 23 %, total sugars by 6.5 %), which positively affects their nutritional value for humans. At the same time, the content of agronomically valuable microorganisms in the soil and organic matter increased, indicating active processing of the organic part of the substrate by cellulolytic microorganisms, thus improving its fertility.

An essential task for human technogenic civilization is to improve the quality of life and health for the world's population as well as to conserve the planet's resources. In an enclosed biosphere-type ecosystem, such as in the ECH, the search for means to maintain autonomy is required, which implies large-scale efforts from a wide range of specialists and the organization of relevant activities. One of the issues to be solved is provision of organic plant products, which cannot be produced without biofertilizers containing the full spectrum of agronomically valuable soil microorganisms.

The experimental data presented in the article highlight the necessity and effectiveness of using uTerra fertility elixir for growing agricultural products in a closed system. A comprehensive approach, combining technological, ecological and social aspects, is key to the successful implementation of the ECH concept, aimed at improving the quality of life and health for the population in the long term.

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Methodical Approach to Determining Nutritional Value of Food Products

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Recently, there has been a noticeable trend shifting from a protein-lipid dietary model to a carbohydrate-lipid one. This shift is characterized by a reduced intake of micronutrients which are essential for human health and serve as biologically active compounds. Additionally, to maximize profits, the food production utilizing intensive agricultural technologies has expanded. The situation leads to increased costs for cultivating eco-products, rising prices and, consequently, the emergence of inexpensive alternatives that have high energy values but low nutritional quality. This negatively impacts the physical and psychological health of individuals and their immune systems.

In the article, the authors examine a crucial factor for active human life – the nutritional value of modern products in terms of the presence of necessary biologically active compounds – and also study the relationship between macronutrients and the glycemic index that indicates the rate at which food is splitting and converting into glucose. The results obtained are essential for ensuring healthy, natural (biospheric) nutrition for individuals as part of the EcoSpace program and all its terrestrial and cosmic aspects: linear cities, specifically Equatorial Linear City; EcoCosmoHouses (ECH) and ECH-Earth; other transport, infrastructure and industrial-residential components of the program.

Keywords:
bioproduction, diet, EcoCosmoHouse (ECH), macronutrients, microelements, ultramicroelements, vitamins.

Introduction

The EcoCosmoHouse (ECH) is an integral part of the residential and industrial infrastructure of the orbital industrial complex – the space Industrial Space Necklace "Orbit" (ISN "Orbit"). At the same time, it is an enclosed ecosystem in which all residents must receive balanced and wholesome nutrition [1].

In modern conditions, the nutritional value of food decreases due to many factors in their industrial production. The use of pesticides, agrochemicals and antibiotics contributes to the efficiency of the agricultural sector but, in many cases, worsens the quality of the products. Additionally, there is a decrease in the concentration of micronutrients in food, and contamination by the chemicals used is observed. Improper storage of raw materials and deep processing of produce, which ensure satisfactory logistical parameters, also negatively affect the quality of the products. In the ECH, it is planned to establish a culture of plant production based on organic farming using biofertilizers, which will help avoid the aforementioned shortcomings and logistical costs.

Healthy nutrition is grounded on foods that meet the physiological needs of the body, support its optimal development and functioning and are aimed at preventing diseases [2, 3]. A variety of vegetables and fruits in the diet provides a wide range of nutrients necessary for human health. However, the nutritional value of foods can vary depending on their region of cultivation and preparation technology.

To inform consumers and support food producers and suppliers, a coefficient of nutritional value utility for vegetables and fruits has been developed. This coefficient allows people to analyze the nutritional significance of plant products and make more informed decisions when choosing their diet.

Nutritional value reflects the beneficial properties of products for the human body. The main components of nutritional value are macronutrients (proteins, fats, carbohydrates), vitamins, minerals, antioxidants and dietary fibers [4, 5]. Each of them plays a special role in maintaining the physiological functions of the body. In addition, it is necessary to consider the glycemic index (GI), which determines the rate at which glucose enters the bloodstream as a result of carbohydrate breakdown in the human body compared to pure glucose.

In the ECH, proper nutrition will be of paramount importance, as it determines the longevity and stable psychoemotional state of its residents [6]. Therefore, it is needed to analyze and outline the criteria for the value of food products for the healthiest and fullest life in the ECH, which is the goal of this work.

Nutrient Composition of Foods and Its Impact on Food Quality

Human health is an active process of maintaining and improving physical and mental well-being, optimal work capacity and social activity throughout life. The World Health Organization defines health not only as the absence of diseases or physical defects but also as complete well-being on physical, mental and social levels. In this sense, the concept is viewed as a dynamic state that allows an individual to perform their species-specific functions with minimal expenditure of biological resources. A person's adaptive potential is an indicator of their ability to maintain optimal functioning even in adverse environmental conditions [7]. Thus, when assessing health, it is more accurate to speak not about the ratio of pathology and normality, but about a person's ability to perform their biological and social functions.

Nutritionists use various scales of nutritional value to create individualized diet plans [8]. For example, persons with diabetes are advised to prefer foods with a low or medium GI (less than 55). Such a restriction helps them avoid sharp spikes in blood sugar levels, while including dishes with valuable vitamins and minerals in their daily diet contributes to overall health enhancement. At the same time, athletes are recommended to consume foods with a high GI (more than 70) for rapid energy recovery after intense workouts.

Detailed analysis of food products also allows for consideration of particular preferences and needs, ensuring an accurate and personalized approach to nutrition. Therefore, a well-informed choice of foods promotes a conscious understanding of their impact on health, leading to the proper formulation of a diet, which is important for achieving health, physical and mental well-being goals.

Food products contain numerous chemical substances that can be classified for ease of study based on their nutrient content and physiological and biochemical properties. One such classification [9] suggests two categories of food substances: nutrients and non-nutrient components. Nutrients are divided into macronutrients (proteins, fats, carbohydrates) and micronutrients (vitamins and vitamin-like substances, as well as mineral substances (macro-, micro- and ultramicroelements), etc.).

Macronutrients

Figure 1 shows the classification of macronutrients – the main food substances required by humans daily in relatively large amounts.

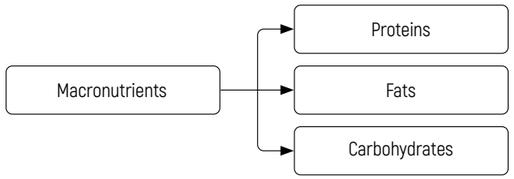

Figure 1 – Classification of macronutrients

Proteins are considered a component of food that receives particular attention when choosing a diet; they perform a number of functions (Figure 2). Proteins are chemical polymers made up of amino acids. The diversity of proteins is due to 20 amino acids, which are synthesized by the body (nonessential) or obtained from food (essential). The structure of proteins includes not only primary but also secondary, tertiary and quaternary sequences of amino acids, where the spatial arrangement of these elements is described.

The value of proteins for the body is determined by the presence of essential amino acids, their ratio with nonessential amino acids and the degree of digestibility. For example, animal proteins are absorbed by 60–90 %, while plant proteins are absorbed by 40–60 %.

There is a classification of proteins based on their biological value:

- complete proteins (biologically valuable) – contain all essential amino acids;
- incomplete proteins – lack at least one of the essential amino acids.

Table 1 presents the general characteristics of animal and plant proteins [10].

Table 1 – General characteristics of proteins

Characteristic	Complete proteins	Incomplete proteins
Chemical structure	Molecules consisting of 20 amino acids	Molecules consisting of fewer than 20 amino acids
Sources	Animal products: meat, fish, eggs, dairy products	Plant products: legumes, grains, nuts
Digestibility	High	Moderate
Main functions	Building material for tissues; act as hormones; function as enzymes	Energy source; perform some structural functions
Daily requirement for adults	0.8–1.5 g/kg of body weight	–

Proteins make up about 20 % of the dry cell mass and are the main building material for the body, performing a structural function. Additionally, proteins can serve as an energy source, providing up to 12 % of the body's daily energy needs. The average daily protein intake for an adult is 0.8–1.5 g/kg of body weight; during intense physical activity, it is 2–4 g/kg. The oxidation of 1 g of protein releases approximately 4 kcal of energy [11].

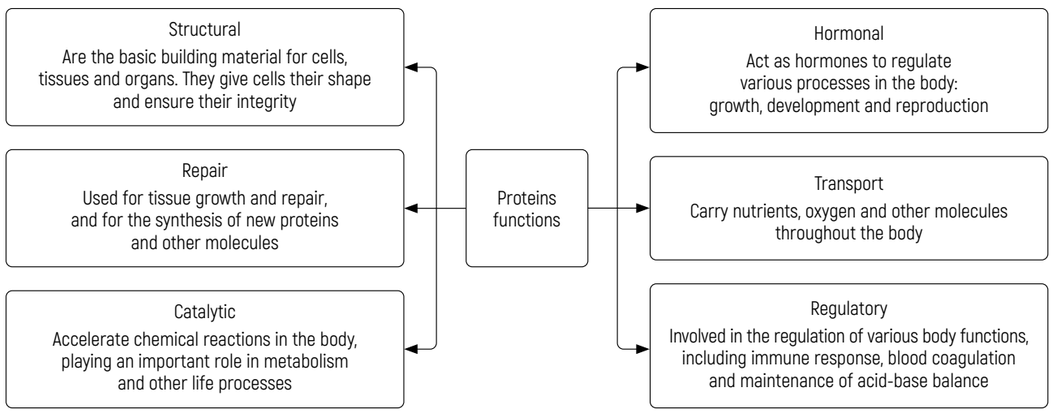

Figure 2 – Proteins functions

The digestibility of proteins depends on the method of food preparation. The optimal temperature for preserving their benefits is up to 76 °C (higher temperatures enhance protein denaturation, reducing its digestibility) [12, 13].

The body's need for proteins increases during intense physical and mental activities, pregnancy, infectious diseases and vitamin deficiencies.

Fats are a significant part of human nutrition because they perform a number of vital functions (Figure 3).

There are saturated and unsaturated fatty acids that make up fats. Saturated fatty acids can be partially synthesized in the body and are called nonessential. They are mainly found in animal products (meat, butter, etc.). Unsaturated fatty acids are not synthesized in the human body and are therefore essential. They are divided into monounsaturated and polyunsaturated. Monounsaturated fatty acids are found, for example, in olive oil and avocados, while polyunsaturated fatty acids are found in vegetable oils (sunflower, corn, flaxseed) and fatty fish.

The biological value of fats is determined by the content of essential fatty acids, as well as their digestibility and absorption in the gastrointestinal tract [14].

Table 2 presents the general characteristics of animal and plant fats [15].

Adults are recommended to consume 50–100 g of fats daily. This norm includes not only margarines and visible culinary fats but also hidden fats found in animal products (meat, fish, dairy products). Excessive restriction of fats can lead to immune problems, nervous system dysfunction and reduced lifespan. However, their excess is also harmful, as it causes atherosclerosis, obesity and metabolic disorders.

Table 2 – General characteristics of fats

Characteristic	Saturated fats	Unsaturated fats
Sources	Animal products (meat, lard, dairy products), coconut and palm oil	Vegetable oils (olive, sunflower, canola), nuts, avocados, fish
Health impact	Increase the risk of cardiovascular diseases with excessive consumption	Reduce the risk of cardiovascular diseases with moderate consumption
Main functions	Energy source, building material for cell membrane tissues, facilitate the absorption of fat-soluble vitamins	Energy source, have anti-inflammatory effects, regulate metabolism
Daily requirement for adults	No more than 20–25 g	50–100 g

There are three main types of fats: saturated, monounsaturated and polyunsaturated. Polyunsaturated fats, found in nuts, seeds and fish, are particularly important for health.

Fats can be of animal or plant origin. Their optimal level in the diet is 20–35 % of the total caloric intake.

It is essential to maintain a balance between different types of fats, as each of them performs specific functions. For example, omega-3 fatty acids have anti-inflammatory effects, while omega-6 fatty acids, found in sunflower oil, contribute to inflammatory processes in the body.

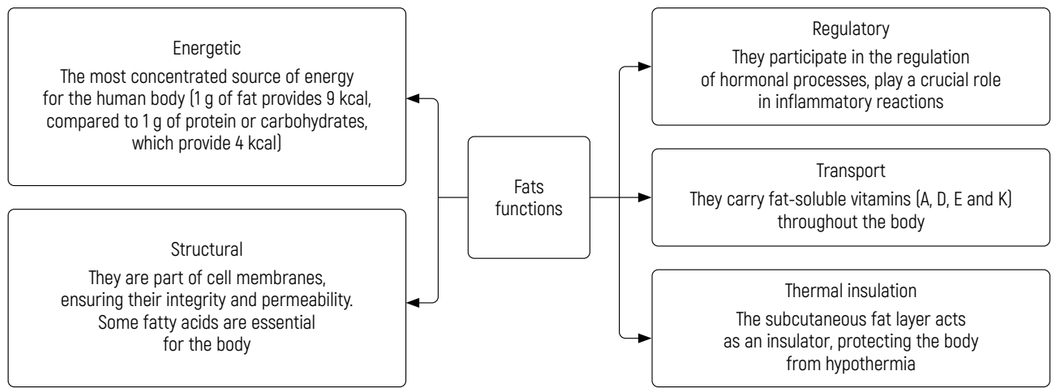

Figure 3 – Fats functions

Carbohydrates are important nutrients that perform many functions in the human body (Figure 4). These substances are indispensable for maintaining health, physical and mental well-being. They provide energy, influence growth and development and participate in the regulation of various body functions.

Table 3 presents the general characteristics of carbohydrates [10].

Among carbohydrates, glucose holds a special place due to its presence in a large number of polysaccharides. This monosaccharide is used by the brain for energy, with the only alternative being ketone bodies formed during a low-carbohydrate diet. For energy storage, the body produces a polymer of glucose – glycogen, the only carbohydrate of animal origin. It accumulates primarily in the liver of animals (including poultry), fish and also in muscles.

The digestion of carbohydrate-rich foods (oligosaccharides and starch) begins in the oral cavity under the action of salivary enzymes (α-amylase and α-glucosidase). The final breakdown of polysaccharides and the absorption of the resulting monomers occur in the intestine.

Monosaccharides are absorbed both in the oral cavity and in the lower sections of the gastrointestinal tract. This is why many dietary recommendations suggest including fruits, especially sweet ones, in separate meals, as well as separating starchy and protein foods to improve digestibility [16, 17].

Additionally, among carbohydrates it is necessary to note cow's milk oligosaccharide – lactose (content up to 5 %). In some people, as they age, the gastrointestinal tract stops producing lactase, the enzyme that breaks down milk sugar. These individuals cannot tolerate milk but can drink kefir, where this sugar is converted into lactic acid by kefir yeast.

Among digestible polysaccharides, starch holds a special place, accounting for up to 80 % of carbohydrate consumption worldwide.

There is a class of carbohydrates that are not digested by the body but perform important functions (e.g., cellulose, pectin substances, lignin, etc.). Although fiber is hardly absorbed in the small intestine, the normal digestion process is impossible without it.

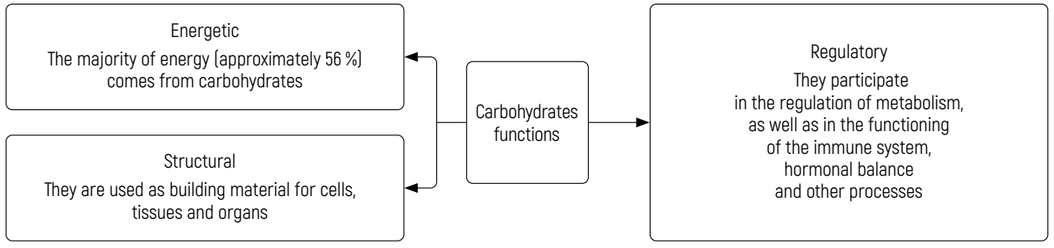

Figure 4 – Carbohydrates functions

Table 3 – General characteristics of carbohydrates

Characteristic	Monosaccharides (glucose, fructose)	Disaccharides (sucrose, lactose)	Polysaccharides (starch, glycogen)
Chemical structure	Simple sugars, include one molecule	Consist of two monosaccharide molecules	Polymer: long chains (linear or branched)
Sources	Sweet vegetables, fruits, honey, berries	Fruits, honey, sugar, dairy products	Cereals and pseudo-cereal products, pasta, bread, potatoes
Digestibility	Rapid	Moderate	Slow
Main functions	Rapid energy supply	Energy source, improves the taste of food	Long-term energy source, structural components of cells
Daily requirement for adults	50–100 g	20–50 g	200–400 g

Fiber and other ballast substances create favorable conditions for the movement of food through the gastrointestinal tract, promote the development of necessary microflora in the intestine and help remove cholesterol from the body. Polysaccharides (fiber, pectins) that swell in water increase in volume, thereby reducing appetite, as well as they can bind micro- and ultramicroelements (calcium, magnesium, phosphorus, iron, zinc, copper, etc.) in food and release them during digestion.

Optimal fiber content in the daily diet is about 1–2 % (25 g), with sources including fruits, vegetables, berries, leafy greens and whole grain bread.

A deficiency of carbohydrates in the daily menu causes serious physiological changes: functional disorders of the central nervous system, weakened mental activity and muscle atrophy.

An excess of carbohydrates, especially easily digestible ones, is one of the causes of metabolic disorders, leading to obesity, diabetes and other diseases.

Although fiber, as part of complex carbohydrates, is not digested and absorbed by the body, it plays an important role in maintaining the health of the digestive system by enhancing intestinal peristalsis and optimizing the digestive process. Additionally, fiber helps regulate blood sugar levels.

The only source of this complex carbohydrate is plant-based foods, such as vegetables and grains. In some seeds, for example, chia, there is water-insoluble fiber that has the ability to absorb moisture and increase in volume. Once in the stomach, this fiber transforms into prebiotics, which serve as food for beneficial bacteria that support the gut microflora.

Micronutrients

Micronutrients include vitamins, vitamin-like substances as well as minerals (macro-, micro- and ultramicroelements), among others. These compounds, like macronutrients, are essential for the body, as their deficiency negatively affects human health, a fact that has been discovered relatively recently. The daily intake ranges from tens of milligrams to micrograms.

Vitamins are indispensable organic compounds that play a vital role in the smooth functioning of the body. They act as cofactors for enzymes and hormones, optimizing metabolism, enhancing cognitive and physical abilities and increasing the body's endurance and resistance to diseases. Most vitamins are not produced in the human body, so they must be regularly obtained from food. Certain vitamins accumulate in tissues, creating a reserve that is used when necessary. Many of them are synthesized by gut microbiota, replenishing their supply even in the absence of dietary intake.

Chemically, vitamins are classified into water-soluble, fat-soluble and vitamin-like substances. Water-soluble vitamins include some B vitamins (B_1, B_2, B_6, B_9, B_{12}), PP vitamins (B_3) and C. Fat-soluble vitamins are A, D, E and K. Vitamin-like substances include vitamins B_{15}, B_4, B_8, P and others.

A deficiency of any of these vitamins causes a metabolic imbalance, which may not manifest externally in the early stages. Over time, developing hypovitaminosis (decreased levels of vitamins in the body) can lead to severe pathologies known as avitaminosis. Such changes result in the weakening of the body's defense mechanisms, making it more susceptible to adverse environmental factors [18].

Minerals constitute a minor portion of food products, typically 0.7–1.5 %. Unlike macronutrients, they do not have energy value but are essential for maintaining health and building the cells of the human body.

Minerals perform a wide range of functions: they support osmotic pressure necessary for the normal functioning of cells and tissues; are components of hemoglobin, hormones and enzymes; and serve as building materials for bones and teeth. In ion form, they participate in nerve signal transmission, blood clotting and other physiological processes.

Minerals are divided into two categories: macroelements and microelements. Macroelements (calcium (Ca), phosphorus (P), magnesium (Mg), sodium (Na), potassium (K), chlorine (Cl) and sulfur (S)) are present in relatively large quantities in food products. Microelements (iron (Fe), zinc (Zn), fluorine (F) and copper (Cu)) are found in smaller amounts [19]. Table 4 describes the main sources and functions of minerals [20].

Table 4 – Main sources and functions of minerals

Mineral	Main sources	Main functions
1	2	3
Ca	Dairy products, fish, grains, nuts, fruits	Forms the basis of bone tissue, affects the processes of the nervous and cardiovascular systems

End of Table 4

1	2	3
P	Milk, fish, bread	Part of proteins and bone tissue, involved in energy metabolism
Mg	Nuts, oats, barley, beans, vegetables, leafy greens	Participates in bone formation, regulation of nerve tissue and carbohydrate and energy metabolism
Na	Table salt, fresh vegetables	Regulates blood pressure, water balance, activates digestive enzymes
K	Dried fruits, peas, beans, grapes	Regulates the acid-base balance of the blood, participates in nerve impulse transmission, activates several enzymes
Cl	Table salt, bread	Involved in the formation of gastric juice, blood plasma, activates several enzymes
S	Protein-rich foods	Part of amino acids, hormones and vitamins
Fe	Meat, grains, legumes, cranberries, strawberries, apricots	Involved in the formation of hemoglobin and some enzymes
Zn	Legumes, grains, yeast, animal liver, including poultry	Part of the insulin hormone, involved in carbohydrate metabolism

Biogenic ultramicroelements are chemical compounds found in living organisms in extremely small quantities (from micrograms to nanograms).

Ultramicroelements (iodine (I), chromium (Cr), molybdenum (Mo), cobalt (Co), selenium (Se), germanium (Ge), gold (Au), etc.) perform vital functions in the human body: they participate in bone formation; regulate insulin secretion; affect brain function, hormones and neurotransmitters; and are components of proteins and enzymes. More than 80 elements from the periodic table are considered biogenic substances to varying degrees, and their functions require further study.

The amount of these elements needed to maintain health is extremely small, but their benefits are invaluable. Additionally, the presence of some ultramicroelements enhances the absorption of other compounds [21, 22].

Comprehensive Analysis of Nutritional Value of Food Products

Tables 5 and 6 present data on the content of major nutrients and the GI in vegetables and fruits typical for temperate and tropical climate zones, as these are the most suitable for agriculture. It should be noted that the values may fluctuate depending on the variety, ripeness and method of thermal processing of the fruits. The data in Tables 5 and 6 are provided as approximate values.

A comprehensive analysis of the nutritional value is important for understanding the extensive qualitative characteristics of food products, which are the building materials for the human body. The classification of nutrients should be expanded and refined for a more accurate determination of the impact of food products on health, with the goal of selecting an optimal diet and organizing the production of agricultural products using organic farming methods.

In 2023–2024, the Belarusian State Agricultural Academy, in collaboration with the Unitsky String Technologies Inc., carried out trials of uTerra fertility elixir on the following crops: radish, lettuce, tomato and cucumber [23–28].

The results of experiments conducted in protected soil showed that the use of this biofertilizer increased the vitamin C content in fruits by an average of 20 %, soluble carbohydrates by 22 % and essential biogenic macroelements by 12 %. Laboratory data also noted a positive effect of uTerra on the taste and aroma of vegetables. Further studies are planned to investigate the impact of biofertilizers on the amount of ultramicroelements in plant products.

Factors Negatively Affecting Food Products in Modern Conditions

Intensive Agricultural Methods

Excessive use of pesticides and herbicides leads to the contamination of food products with chemicals. Additionally, the application of synthetic fertilizers contributes to soil depletion and reduces the nutritional value of the harvest. Intensive livestock farming leads to the degradation of water and soil quality due to the presence of animal waste and antibiotics, which are extensively used in agriculture.

Industrial Processing

Many modern food products undergo extensive processing, which can lead to the loss of nutrients and excessive content of saturated fats, sugar and salt. Artificial additives (preservatives, colorants, flavorings) negatively affect health.

Table 5 – Content of major nutrients and GI value in fruits grown in temperate climate zone

Fruit	Fats, g/100 g	Proteins, g/100 g	Carbohydrates, g/100 g	Dietary fiber, g/100 g	Vitamins	Minerals	Antioxidants	GI
Apple	0.2	0.3	13.8	3	C, E, B_6	K, Mg, Fe	Flavonoids	40
Pear	0.1	0.4	15.5	3.1	A, C, E	K, Ca, Mg, Fe	Flavonoids	38
Cherry	0.2	1	12.8	2.1	A, C, B_6	K, Mg, Ca, Fe	Anthocyanins	22
Plum	0.3	0.7	11.4	1.4	C, K, A	K, Mg, Fe, Ca	Flavonoids	29
Strawberry	0.3	0.7	7.7	2	C, K, B_6	Mn, Mg, K, Ca	Anthocyanins	40
Potato	0.1	2	17	2.4	C, B_6	K, Mg, Fe, P	Carotenoids	80
Carrot	0.2	0.9	9.6	2.8	C, A, K, B_6	K, Ca, Mg, Fe	Carotenoids	47
Beet	0.1	1.6	9.6	2.8	C, B_9, B_6	K, Mn, Fe, Mg	Polyphenols, betalains	64
Cabbage (white)	0.1	1.1	5.8	2.5	B_9, C, B_6	K, Ca, Mg, Fe	Glucosinolates, carotenoids	45

Table 6 – Content of major nutrients and GI value in fruits grown in a tropical climate zone

Fruit	Fats, g/100 g	Proteins, g/100 g	Carbohydrates, g/100 g	Dietary fiber, g/100 g	Vitamins	Minerals	Antioxidants	GI
Mango	0.4	0.8	16.8	1.6	A, C, B_6	K, Mg, Ca, Fe	Carotenoids	51
Papaya	0.3	0.5	11.8	1.7	A, C, B_6	K, Mg, Ca, Fe	Carotenoids	60
Banana	0.3	1.1	22.8	2.6	C, B_6	K, Mg	Flavonoids	51
Pineapple	0.1	0.5	13.1	1.4	C, B_6	K, Mg, Ca	Flavonoids	59
Avocado	14.7	4.6	8.5	6.7	E, K, B_5, B_6, B_9, C	K, Mg, Ca, Fe	Carotenoids	15
Kiwi	0.5	1.1	14.7	3	C, E, K	K, Mg, Ca, Fe	Flavonoids	52
Pitahaya	0.4	3	11	3	C, B_1, B_2, B_3	K, Mg	Flavonoids	48
Guava	0.6	2.6	12.2	5.4	A, C, E, B_9	K, Mg, Ca, Fe	Carotenoids	78
Passion Fruit	0.7	2.2	12.1	10.4	A, C, B_6	K, Mg	Carotenoids	30

Environmental Pollution

Air, water and soil pollution provoke the accumulation of toxins in food products. Heavy metals (lead, mercury) can be found in fish and seafood. The widespread use of plastics also has negative consequences, as small pieces of this material enter the food chain.

Climate Change

Climate change affects crop yields as well as the nutritional value and safety of food products.

Extreme weather events (drought, flood, abnormal temperature, etc.) can damage crops and disrupt food supply chains.

Consumer Habits

Consumer habits (including the daily consumption of meals high in processed foods, sugar and unhealthy fats) can negatively impact overall health and increase the risk of chronic diseases. Failure to observe the rules of storage and improper food preparation can lead to the proliferation of pathogenic microorganisms and food spoilage.

Methods to Enhance Nutritional Value of Food Products

Eliminating Negative Impact During Cooking

Utilizing certain cooking methods can yield the most flavorful and healthy dishes. As proven in [12], the sous vide technology has demonstrated optimal taste qualities for chicken and vegetables, confirmed by tasting results. Additionally, steaming is considered beneficial as it preserves up to 90 % of nutrients, while braising and baking at low temperature (up to 150 °C) minimize vitamin and mineral losses. Frying in deep fat and over high heat should be avoided as it destroys nutrients and forms harmful compounds.

Another potential technology for producing high-quality dishes without losing flavor and negatively impacting the environment is cooking in an inert atmosphere. Nitrogen and carbon dioxide, already used in food packaging, can be utilized as inert gases. The technology would require the creation of cookware equipped with additional gas supply and exhaust systems, as well as filtration of outgoing gases from moisture, fats, etc. In the absence of oxygen during thermal exposure, a greater amount of elements sensitive to oxidants is preserved, emissions of oxidized compounds into the working area are reduced, and carcinogens are not formed.

Utilizing Farm Products

Due to the intensive agriculture currently practiced, the mineral composition of soils has significantly deteriorated. Fertility is often achieved through the application of only three main elements: nitrogen, phosphorus and potassium. However, with the harvest, all biogenic elements (about 80) are removed from the soil, which negatively affects the quality of agricultural products.

The use of innovative organic fertilizers from the uTerra line, as established during laboratory tests, reliably increases the content of vitamins and minerals in plants [23–28]. Crops grown on lands rich in organic matter and possessing a wide range of agronomically valuable soil microorganisms include more vitamins, minerals and antioxidants.

The presence of essential nutrients improves the taste and shelf life of products, making them not only more desirable but also economically viable.

Designing Diets Based on Personal Characteristics

When creating a balanced diet, individual factors such as age, gender, level of physical activity and overall health should be taken into account. Before using certain products (e.g., kophalhen or surströmming), consultation with a doctor or dietitian is needed. Additionally, obtaining a professional assessment of nutritional needs is recommended.

Regardless of the chosen diet plan, it is important to include foods from all major food groups. This ensures that the human body receives all the necessary vitamins, minerals and other nutrients.

Using Eco-Friendly Packaging Materials

The first packaging materials were inherently eco-friendly and natural. Over time, humanity transitioned to more convenient materials in terms of production and use, which nonetheless pose a danger to the environment (due to the formation of microplastics) and can negatively affect the quality of packaged products.

Replacing plastic, foil and various types of colored cardboard with eco-packaging made of cellulose, bioplastic and other similar materials will help preserve the taste of food and simplify the disposal of packaging waste. In some cases, the use of edible packaging is proposed [29].

Development of Nutritional Value Coefficient for Food Products

The aim of this study is to combine data on the content of vitamins, minerals, fiber, antioxidants and macronutrients found in vegetables and fruits with the GI indicator and to conduct a comprehensive assessment of their nutritional value.

By considering not only the nutritional composition of food products but also their impact on blood sugar levels, information on the speed and ease of nutrient absorption can be obtained. This data will help people make informed choices about food products based on their individual needs, whether for sports training, diets or general health improvement.

The well-known Nutri-Score system (a nutritional value labeling system that includes a five-level color scale from A to E, applied to the front of the food product packaging and complementing the existing mandatory labeling elements, such as the nutritional table) was developed by S. Hercberg with the participation of scientists from the United Kingdom, France and Belgium. It is based on the analysis of the ratio of beneficial and harmful substances per 100 g of the product. Beneficial substances include fruits, vegetables, nuts, proteins, dietary fibers and antioxidants. Harmful substances are considered to be sugar, fats, saturated fatty acids, sodium and high-calorie products [30]. This assessment is visual but quite controversial, as important food components are classified as harmful.

To calculate the nutritional value coefficient of vegetables and fruits, the authors of this article propose a methodology that differs from existing ones: it takes into account the GI and evaluates the impact of the full spectrum of nutrients, rather than a limited number of classes.

Since there is currently insufficient information about all nutrients, valuable components of products are summed according to the class to which they belong (macronutrients – in grams, microelements – in milligrams, etc.) to fully form the nutritional value index.

To calculate the nutritional value coefficient for each product (vegetable or fruit), the following data were used:

1) the total content of beneficial nutrients:

- vitamins (A, C, E, B group, etc.);
- minerals (calcium, magnesium, iron, potassium, etc.);
- dietary fibers;
- antioxidants;
- proteins, fats and carbohydrates;

2) GI.

The authors summarized the above indicators into one integral score "Content of beneficial nutrients," which includes components starting from micrograms (considering ultramicroelements). Thus, a comprehensive analysis can account for all necessary elements, even those whose biological roles are not fully understood.

For the calculation of the nutritional value coefficient, reference data on the nutritional value of various vegetables and fruits were used, and the following formula was applied:

$$\text{Nutritional value coefficient} = \text{Content of beneficial nutrients} / \text{GI}.$$

For example, let us consider the calculation of the nutritional value coefficient of an apple.

The initial data for the beneficial nutrient content of this fruit (per 100 g):

- vitamins: C – 12 mg, E – 0.4 mg, B_6 – 0.1 mg;
- minerals: potassium – 100 mg, magnesium – 20 mg, iron – 0.2 mg;
- dietary fibers: 3 g;
- antioxidants: 200 mg;
- proteins – 0.3 g; fats – 0.2 g; carbohydrates – 13.8 g.

The total content of beneficial nutrients is:

$$12 + 0.4 + 0.1 + 100 + 20 + 0.2 + 3 + 200 + 0.3 + 0.2 + 13.8 = 350 \text{ points}.$$

The GI of the apple: 40.

Substituting these values into the formula:

$$\text{Nutritional value coefficient} = 350 / 40 = 8.75.$$

Thus, the nutritional value coefficient of an apple is 8.75. Compared to other vegetables and fruits (Tables 7, 8), this is a high indicator. Consequently, the apple is an especially beneficial food product. The significant content of vitamins, minerals and antioxidants combined with a low GI makes this fruit one of the most valuable.

The data in Tables 7 and 8 allow for the evaluation of the nutritional value coefficient of fruits grown in different climate zones. Furthermore, by modifying the calculation methodology, it is possible to estimate this parameter for plants cultivated using mineral and biofertilizers.

Table 7 – Nutritional value coefficient of fruits grown in temperate climate zone

Fruit	Total content of beneficial nutrients, points	GI	Nutritional value coefficient
Apple	350	40	8.75
Pear	155.74	38	4.1
Cherry	269.54	22	12.25
Plum	193.63	29	6.68
Strawberry	290.15	40	7.25
Potato	543	80	6.79
Carrot	384.9	47	8.19
Beet	365.2	64	5.71
Cabbage (white)	283.3	45	6.3

Table 8 – Nutritional value coefficient of fruits grown in tropical climate zone

Fruit	Total content of beneficial nutrients, points	GI	Nutritional value coefficient
Mango	236.98	51	4.65
Papaya	213.88	60	3.56
Banana	433.87	51	8.51
Pineapple	196.99	59	3.34
Avocado	573.12	15	38.21
Kiwi	440.02	52	8.46
Pitahaya	329.19	48	6.86
Guava	517.9	78	6.64
Passion fruit	456.3	30	15.21

The obtained results are recommended for use in determining the dietary value of products, as the numerical value takes into account not only the presence of beneficial mineral elements and micronutrients but also their rate of absorption.

Conclusion

In this research, a wide range of nutrients found in food products were analyzed. Healthy and nutritious food is considered to contain a sufficient amount of beneficial elements, vitamins and other compounds for the body. The authors noted the poorly studied role of ultramicroelements due to their low content in food products.

Ways for increasing the nutritional value of organic products and the features of their production in an enclosed ecosystem, including in the ECH, were comprehensively considered. The application of appropriate technologies and cooking methods can reduce the loss of nutritional value of food products by 10–30 %. Laboratory research results showed that it is possible to increase the content of vitamins, sugars and essential minerals in plant products (by 20 % or more) through the use of uTerra soil fertility elixir. However, the impact of biofertilizer on the amount of micro- and ultramicroelements requires further study and may be much more significant (50 % or more) due to their active removal from the soil in intensive agriculture.

A new scale for product quality assessment was proposed; the analysis and calculation of the nutritional value coefficient of various products were conducted using the developed methodology. The nutritional value coefficient, which includes data on vitamins, minerals, dietary fibers and antioxidants, as well as the GI, is a more informative criterion than describing the content of proteins/fats/carbohydrates or each element separately. Such a comprehensive approach allows for an objective evaluation of various products and the drawing of well-founded conclusions about their health benefits.

This method of determining the value of vegetables and fruits is primarily necessary for people with pancreatic dysfunction, for whom the GI is a significant factor in choosing foods, and those who aim to lose weight. However, the coefficient considered does not play a significant role in sports nutrition.

It is known that a high content of beneficial substances in food does not always guarantee their effective absorption by the body. It is important that these substances are optimally interconnected with other nutrients and absorbed gradually, without sharp spikes in blood glucose levels. The nutritional value coefficient could take such nuances into account and provide a more accurate assessment of the quality of a product.

The implementation of a comprehensive indicator will undoubtedly make a special contribution to the overall knowledge of healthy eating. It will allow people to make informed choices about foods based on objective data and, consequently, improve their health by including the most beneficial vegetables and fruits in their diet.

Future plans include a more in-depth development of the concept of assessing the quality of food products grown in the ECH, analyzing the impact of organic fertilizers on the content of micro- and ultramicroelements and testing methods for comprehensively improving the quality of healthy food. Additionally, the proposed methodology should be improved to consider different types of diets: therapeutic, sports, daily or for healthy weight loss.

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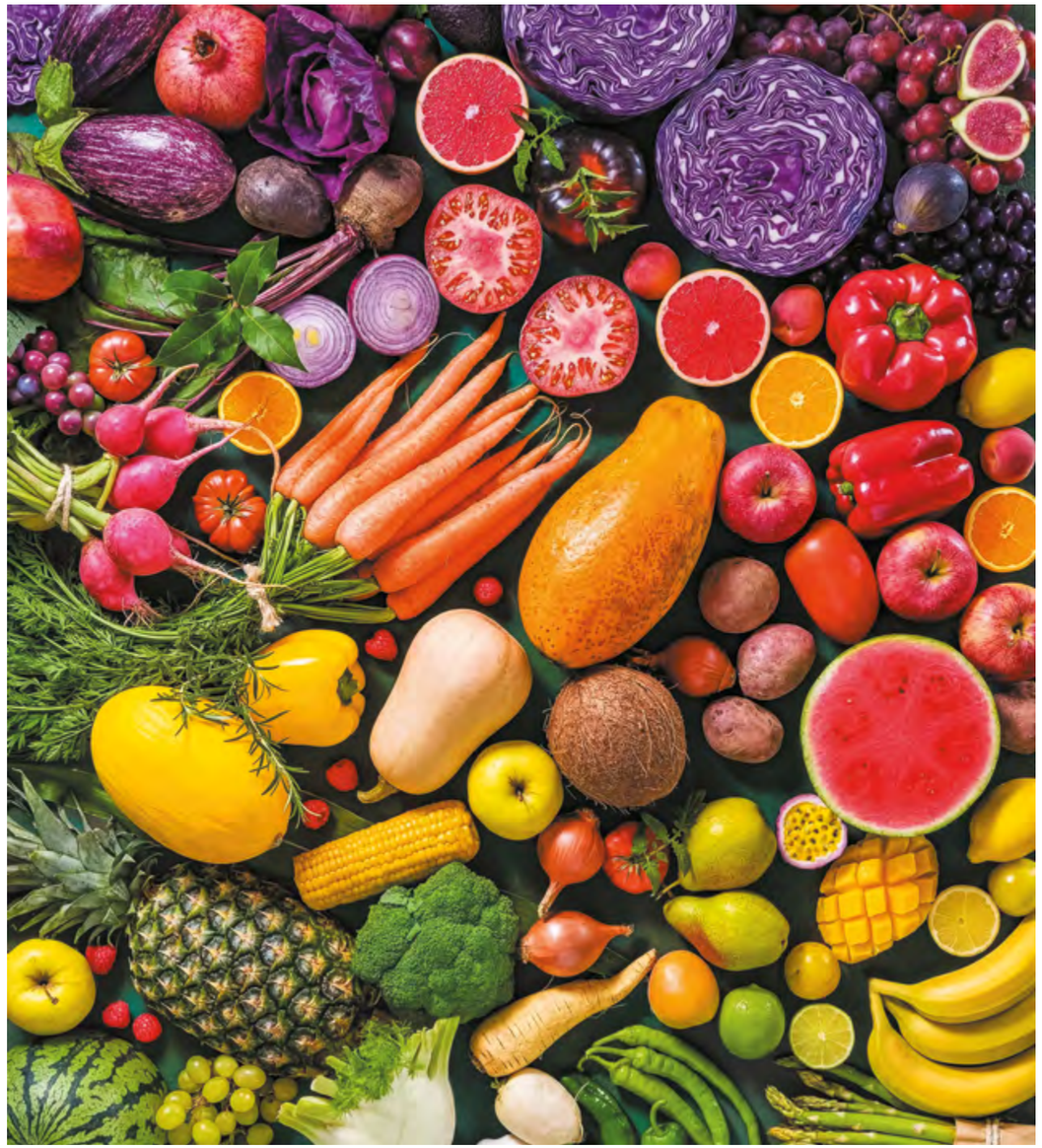

UDC 624.016+629.7

Structural Solutions for String Membrane Tent as Part of ECH-Earth Facility

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The structural design and geometric shape of any building influence its technical and economic characteristics, such as load-bearing capacity, operational suitability, wind resistance, material efficiency and others. Based on the search for optimal geometric and structural parameters, the differences between rectangular and circular designs for the EcoCosmoHouse on planet Earth (ECH-Earth) structure are discovered, with calculations of their spatial models.

The most rational layout scheme – circular membrane tent – is identified, and its technical and economic advantages are substantiated. The use of polymer film made of ethylene tetrafluoroethylene as the load-bearing material for the membrane covering is considered. Material efficiency indicators for the string membrane tent of the ECH-Earth are presented, depending on the construction region on the planet.

Keywords:
EcoCosmoHouse (ECH), EcoCosmoHouse on planet Earth (ECH-Earth), enclosed ecosystem, ETFE, membrane tent, prestressing, strings.

Introduction

Today, the concept of creating an enclosed ecosystem is more relevant than ever for advancing civilization and preserving life. Humanity faces serious threats from climate change, environmental pollution and species extinction, all of which require urgent action. Additionally, global scientific research indicates that many species in Earth's biosphere are intricately interconnected through millions of years of coevolution, making their survival dependent on each other.

Developing a biosphere-type enclosed ecosystem would enable efficient resource management, minimize organic waste and protect biodiversity. In general, creating such an ecosystem is not just timely but essential [1]. The groundwork for this concept began earlier: the near-space industrialization EcoSpace program includes components designed to merge engineering technologies, Earth's biosphere and humanity into a unified system. This involves constructing clusters known as EcoCosmoHouses (ECH) both in orbit and under Earth's harsh climatic conditions [2]. The authors have explored various structural designs for the EcoCosmoHouse on planet Earth (ECH-Earth) and continue to develop and refine their ideas. The current task is to identify the most optimal solution and move forward with practical implementation.

Feasibility Analysis of Design Solutions

An efficient large-span covering is essential for creating an enclosed ecosystem. For the sustainable and productive functioning of its flora and fauna, including microflora and microfauna, it is important to consider not only the protective properties of the shell but also the provision of adequate natural lighting and air circulation. Therefore, the future ECH-Earth must meet several requirements. These include materials that combine strength, durability and corrosion resistance to external influences, along with ease of maintenance and repair of the large-span structure's engineering systems, ensuring high living comfort for humans, animals and plants.

In reference [3], it is determined that the most cost-effective building shape for such a grand task is a torus segment constructed with arched bent pipes (Figures 1, 2). However, this load-bearing structure, which operates under compression, is highly material-intensive and expensive, particularly as the size of ECH-Earth increases. To reduce the specific cost per 1 m^2 of usable space, engineer A. Unitsky proposed an alternative solution: a large-span tent structure with a string load-bearing system and a prestressed membrane. Using the ethylene tetrafluoroethylene (ETFE) fluoropolymer for the membrane is considered the most practical approach.

Figure 1 – ECH-Earth structural solution as a torus segment (30 m in height) (option, visualization)

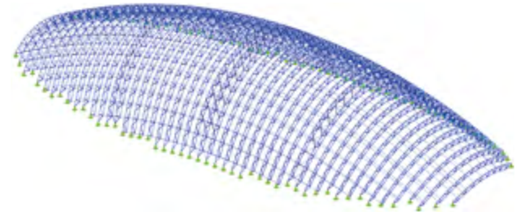

Figure 2 – ECH-Earth structural solution as a torus segment constructed with bent pipes (30 m in height) (option)

The main advantages of the ETFE fluoropolymer membrane are its light weight, strength and durability [4]. When using strings as load-bearing elements, these characteristics enable spanning significant distances (up to 500 m or more) without substantially increasing the material intensity of the structure.

The tent covering consists of several layers of ETFE, a modified copolymer originally developed by NASA for the space industry. This material is unique because it is unaffected by ultraviolet radiation and atmospheric pollutants.

Unlike glass and polyethylene, which transmit only 5 % of the sunlight spectrum necessary for plants, the maximum transparency of the ETFE fluoropolymer film is 95 % and over 90 % in the ultraviolet range (Figure 3). The full spectrum of light, especially ultraviolet, plays an important role in plant health. In the natural environment, under the influence of ultraviolet light, plants produce a greater amount of protective biologically active compounds (beta-carotene, anthocyanins and glycosides), which determine the natural color, taste and nutritional value of crops. Furthermore, ultraviolet light suppresses the development of many microorganisms, including fungi and bacteria that cause plant diseases in greenhouses [5].

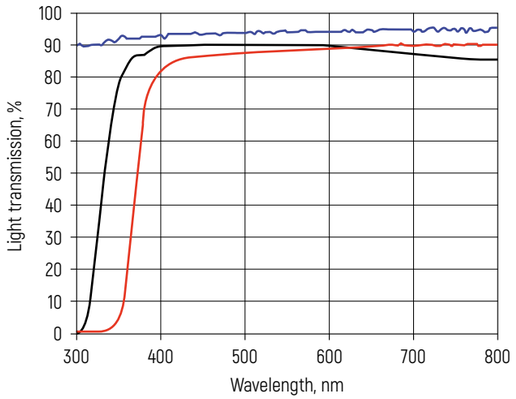

Figure 3 – Light transmission of ETFE film and similar materials [5]

The fluoroplastic film has an anti-adhesive coating, so dust and dirt do not accumulate on it. For the same reason, simple microorganisms and algae do not settle on its surface. Rainwater is sufficient to clean and wash away spores, seeds, plant pollen, any natural or technogenic contaminants [5].

The durability of the film, without significant changes in its properties, exceeds 50 years. Throughout its service life, it almost does not lose its light transmission capability, retaining at least 95 % of its original transparency. The film is highly durable and repairable; in case of damage, it can be easily repaired with special scotch tape made from the same film material.

The tent covering is a multilayer structure with air layers, which provides high thermal insulation properties. At the points where the film is attached to the strings, there are no cold bridges. The outer film is made thicker and more durable, as it withstands external atmospheric effects, while the other films are thinner and installed with less stress (Figure 4), which reduces the cost of the tent. However, in all configurations, the films are installed with prestressing and act as flat string membranes.

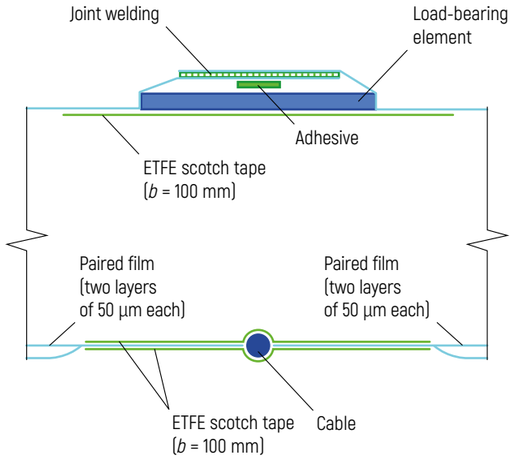

Figure 4 – Attachment node of ETFE film in multilayer covering to load-bearing elements

Let us now consider possible load-bearing structures for the ECH-Earth. Two configurations of large-span string tents have been analyzed: rectangular and circular in plan (Figures 5, 6).

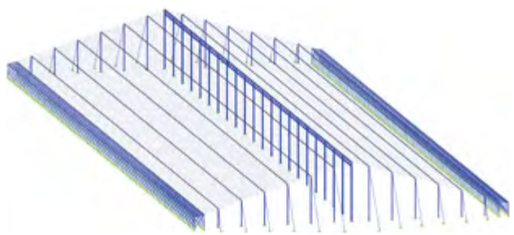

Figure 5 – General view of rectangular structural layout of ECH-Earth in plan

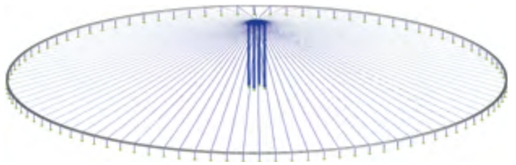

Figure 6 – General view of circular structural layout of ECH-Earth in plan

The load-bearing frame of the rectangular layout consists of a complete metal framework, covered with prestressed strings, which are made of steel strips or high-strength wires (cables) (Figure 7).

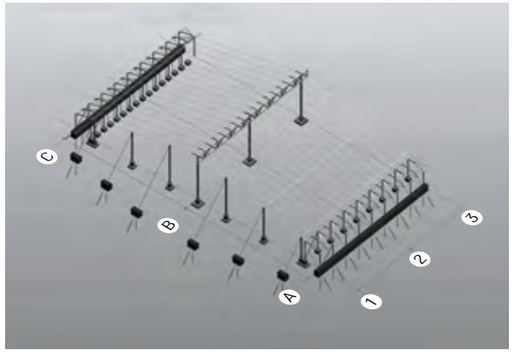

Figure 7 – General view of load-bearing structures of rectangular layout (option)

Prestressing of the strings can be performed in various ways: direct (stressing the strings using turnbuckles or winches) or indirect (lifting the central ridge truss using jacks). Figure 8 shows an option for the string stressing node using the direct method.

The most efficient foundation option for the described rectangular structure has a combined design: standalone columnar structures under the end frames and inner truss posts, along with a basement beam along the building's perimeter anchored into the ground [6]. The anchors in the tent foundation are devices designed to transfer uplift forces from the structural elements to the ground mass. This technical solution (Figure 9) eliminates the need for deep excavations and extensive earthworks, speeding up construction while ensuring it is safe, quick and cost-effective.

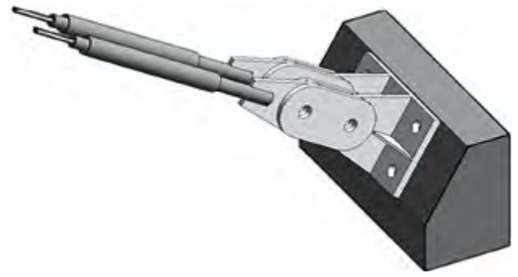

Figure 8 – Direct method string stressing node (option)

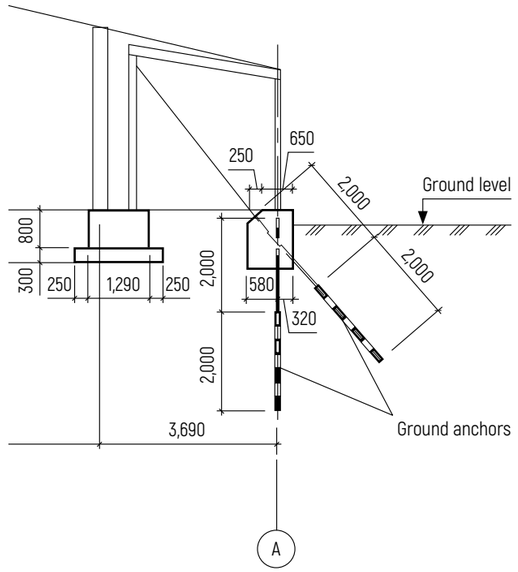

Figure 9 – Design of foundations for rectangular layout (option)

A completely different structural design is proposed for the circular structure. The tent's diameter is 180 m (area of 2.5 ha) to match the usable area of the rectangular structure. Its spatial stability and geometric immutability are ensured by a circular hanging ring beam (steel or reinforced concrete, resembling the rim of a bicycle wheel, where the spokes are the load-bearing strings) and the rigidity of central supporting columns firmly connected to the foundations.

The circular suspended roof uses a single-cord tent system with prestressed strips (strings) arranged in a circle at an incline sufficient to allow snow to slide off the membrane covering.

These steel strips support the transparent membrane. The outer load-bearing contour, subjected to compression, consists of a reinforced concrete ring [7]. Its cross section can withstand compression forces and securely hold embedded elements for further attachment of the strings (Figure 10). To accelerate construction, the ring can be prefabricated – linear segments are manufactured at a factory and assembled onsite, similar to building reinforced concrete frame structures or beam bridges.

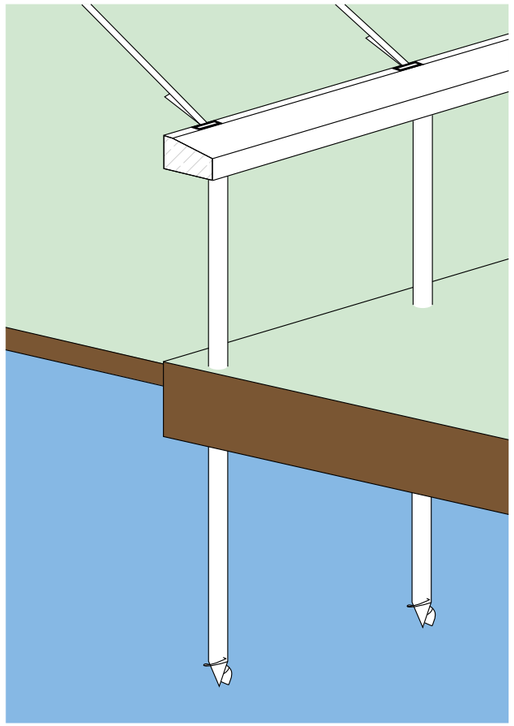

Figure 10 – Structural fragment

The central ring undergoes tension and is therefore best made from steel. The vertical load from the outer ring is transferred to the foundation through supporting structures – steel pile columns.

The foundation consists of metal screw piles installed from the ground surface (Figure 11), significantly reducing construction time of the substructure phase, without compromising the structure's overall reliability.

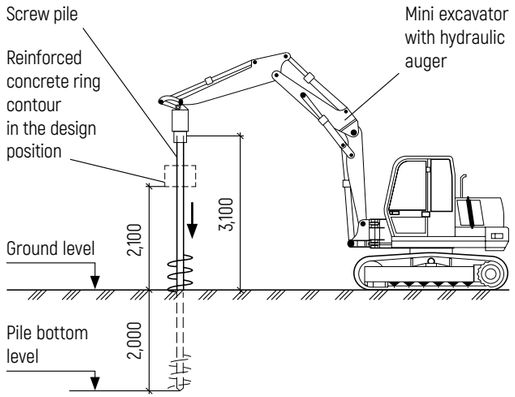

Figure 11 – Foundation construction

Stressing the strings in a circular tent structure can be done in several ways, such as simultaneously stressing all strings by lifting the central structure with jacks or stressing each string individually. The most optimal method is stressing by lowering the outer reinforced concrete load-bearing ring under its own weight (Figure 12). This approach is also less labor-intensive and ensures uniform string stressing, which positively impacts the construction process.

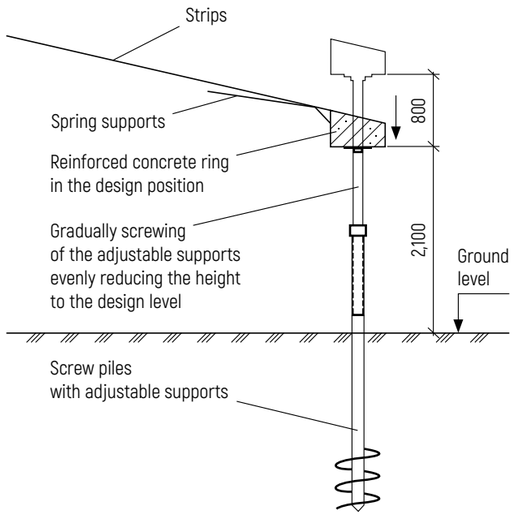

Figure 12 – String stressing
by lowering reinforced concrete load-bearing ring

The circular contour of the ECH-Earth is the most efficient design layout because it is moment-free, ensuring optimal crosssections for the structural elements. When dealing with forces in the load-bearing components of a circular tent, it is most practical to utilize the properties of traditional construction materials. Additionally, in the case of asymmetrical loading on the suspended roof, tension redistributes among all stressed elements, factoring in the bending stiffness (horizontal displacement) of the central columns.

Let us now proceed with calculating the proposed structural layouts.

The circular shape significantly reduces the overall aerodynamic drag coefficient in crosswinds, regardless of wind direction [8]. Wind flows were numerically simulated using the RWIND 2 program, with action isofields shown in Figures 13–17.

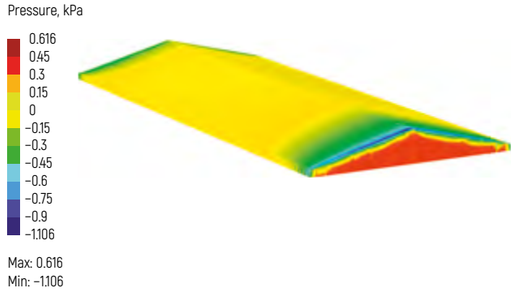

Figure 13 – Pressure isofields on the surface of rectangular layout
(the direction of the oncoming wind flow
is parallel to the long side of the structure)

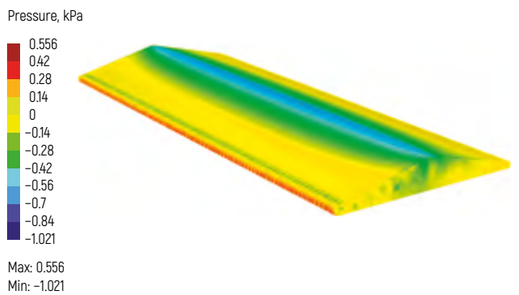

Figure 14 – Pressure isofields on the surface of rectangular layout
(the direction of the oncoming wind flow
is parallel to the short side of the structure)

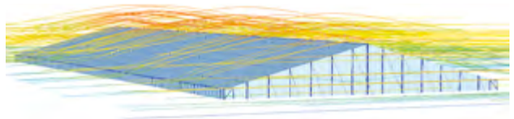

Figure 15 – Graphical representation of the wind flow envelopment
of the structure rectangular in plan

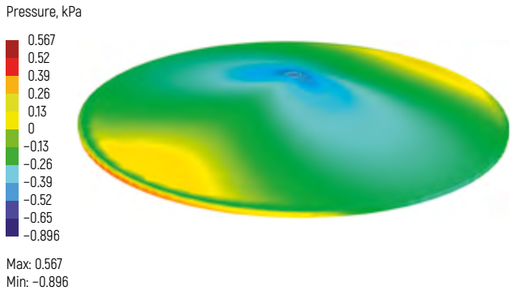

Figure 16 – Pressure isofields on the surface of circular layout

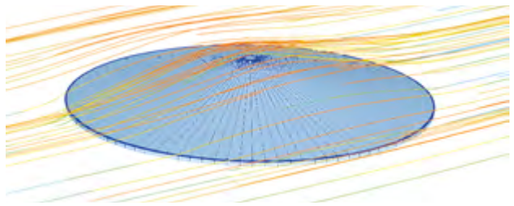

Figure 17 – Graphical representation of the wind flow envelopment
of the structure circular in plan

As shown by the pressure isofields and the graphical representations of wind flow patterns, the circular tent has a more streamlined shape and, consequently, a lower overall aerodynamic drag coefficient. Due to this shape, the surface lacks corners, breaks, protrusions and flat slopes, preventing snow accumulation driven by wind. Therefore, the snow load can be calculated without considering snowdrifts. Moreover, the well-known self-cleaning properties of ETFE film ensure that dry snow will slide off and be blown away by the wind, even at an incline of around 5 %. Melted snow will also slide off the conical roof with only minimal accumulation (20–30 mm). Thus, only a portion of the standard snow load needs to be considered, significantly reducing the material requirements and cost of the circular tent's load-bearing structure.

The results of calculations for various ECH-Earth tent design layouts are summarized in the Table below. The analysis shows that the cost of load-bearing structures for string tents is significantly lower than that of other design layouts. A tent with a circular base is more cost-effective due to a number of factors mentioned above.

It is important to note that it is not only the economics that dictate the clear advantages of the circular base of the ECH-Earth over the rectangular one. The perimeter of a circle is smaller than the perimeter of a rectangle with the same area, meaning that this solution is more efficient in terms of material consumption and energy costs associated with maintaining the microclimate of a warm contour with a smaller perimeter, both in summer cooling and winter heating of a biosphere-type enclosed ecosystem.

The flat roof of a rectangular tent often leads to flutter (vibrations during gusty winds, whose amplitude at the specified spans can reach several meters). Moreover, the ends of the rectangular tent will experience even higher wind loads than the roof, requiring additional reinforcement.

In the rectangular tent, the outer contour experiences greater horizontal shearing forces from string stressing and requires more massive foundations to transfer these forces. The circular contour is moment-free – the external self-supporting ring, working in compression, compensates for the stress in the strings and does not transmit it to the foundation, which is an indisputable advantage.

Conclusion

The feasibility analysis showed that the optimal design solution for the ECH-Earth is a circular tent with flat load-bearing strings (steel strips) and a multilayer transparent coating made of ETFE fluoropolymer, also constructed as a flat string – membrane. This tent has low material consumption and cost, while providing increased load-bearing capacity under the calculated loads (dead weight, lateral wind and snow load).

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Table – Comparative analysis of material consumption and construction costs (for the new design layouts, rectangular and circular in plan, in June 2024 prices)

Indicator	A 30-meter-high torus segment (constructed from individual trusses)	Large-span string tent rectangular in plan	Large-span string tent circular in plan
Per 1 m^2 of area			
Steel structures mass, kg	60	20.9	12.7
Cost of steel structures, BYN	574	166	102
Coating, m^2	1.3	1.03	1.03
Per 1 m^3 of building volume			
Steel structures mass, kg	4.11	1.6	1.4
Cost of steel structures, BYN	39.1	12.6	11.2
Coating, m^2	0.09	0.08	0.11
Total cost of steel structures (tent with an area of 2.5 ha), BYN (USD)	12,362,940 (3,757,733)	4,152,879 (1,277,809)	2,595,398 (798,584)

UDC 725.8.012+629.7

Modeling Closed Biospheric Space in Translucent Film-Coated Tent

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The characteristics of a new living environment (uCity) were considered, focusing on organizing inhabited spaces based on autonomous biospheric equilibrium and the development of universal closed biospheric complexes designed as tent-like structures to provide essential living conditions with controlled climate parameters. Methods for simulation modeling of this space were analyzed. The study highlights the benefits of utilizing artificial climate-controlled habitats in extreme areas, such as the Arctic, tropical deserts and in orbital EcoCosmoHouses. Innovative construction techniques for erecting tent-like spatial structures to study sustainability and self-sufficiency of biospheric habitats were proposed.

The challenge in this article lies in identifying universal engineering and technological solutions within economically feasible limits. This involves examining acceptable habitat parameters that support dynamic development and maintenance of biological homeostasis within the constructed biospheric model.

Keywords:
biological homeostasis, biospheric space, cryptoclimatic complex, EcoCosmoHouse (ECH), film-coated tent, linear type of settlement, uCity, uNet.

Introduction

Modeling closed biospheric spaces with a subtropical climate represents a cutting-edge area of research aimed at creating complexes characterized by a sustainable and self-sufficient living environment. Innovations in this field open up opportunities for the development of extreme territories on Earth and near space, offering alternatives to traditional methods of ecosystem management [1].

Engineering design and the development of related technologies play a pivotal role in achieving these objectives, enabling adaptation to various environmental parameters – from polar regions to orbital stations. The success of such projects depends on numerous factors, including the precision of mathematical modeling, resource efficiency and the ability to maintain the stability and resilience of the internal environment, making the research outcomes critically important for the future of humanity. The creation of operational simulation models of closed biospheric spaces allows for identifying and resolving issues related to their stability and resilience before the object is put into operation under real-world conditions.

Key Principles of Modeling Biospheric Spaces

Modeling closed biospheric spaces with a subtropical climate, which is considered the most comfortable for long-term human habitation, is a complex and multifaceted process requiring profound knowledge in ecology, biology, engineering and systems analysis. This research area is rapidly developing in connection with the planning of extended space missions and the search for sustainable development solutions for Earth's civilization. The primary goal of modeling closed biospheric spaces is to create a controlled habitat capable of sustaining life under conditions as close to natural as possible, while remaining isolated from external influences.

To better understand the principles of modeling biospheric spaces, we will review the existing approaches to addressing this challenge.

A critical first step is the careful selection of biosphere components, including the types and quantities of plants, animals and microorganisms necessary to maintain the exchange of matter, energy and information within the closed system. At the same time, maintaining a balance between the production and consumption of limited resources is crucial, requiring precise modeling and forecasting of all processes occurring within the biospheric environment.

The second significant focus is on developing mathematical models to understand the dynamics of biospheric processes and predict their behavior under various conditions. These models are based on principles of system dynamics and are similar to the Gaia project proposed by N. Moiseyev and his colleagues [2], where Earth's biosphere is considered a single self-regulating system. In this context, N. Moiseyev stated that the first essential step in implementing such ideas is the ability to organize a series of alternative calculations. It is vital for the expert to understand the nature of the studied process, the degree of its "controllability," the nature of its limits (sets of attainability), i.e., to organize a series of machine-based experiments with the model. For this purpose, models must be created that simulate reality and the studied process [3].

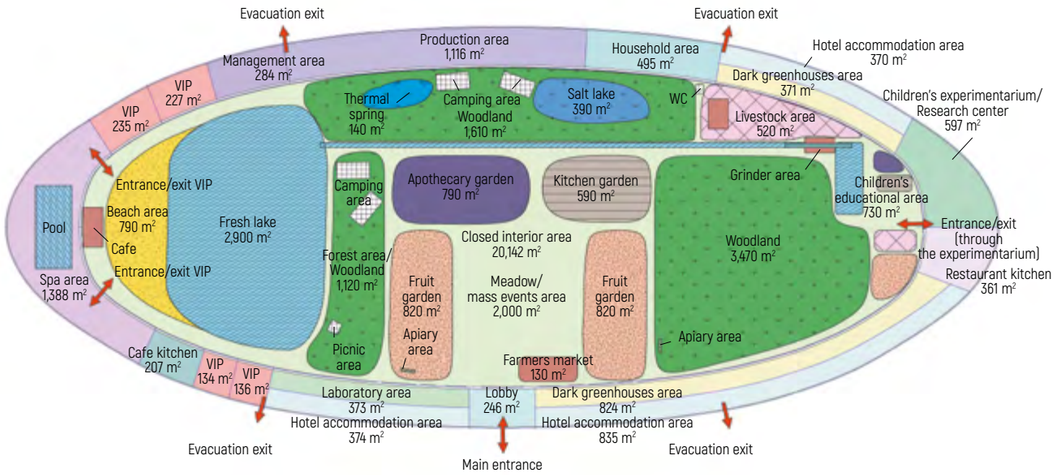
Furthermore, the use of simulation modeling in modern ecological research allows for a deep understanding of the essence of the studied object or phenomenon within the coevolution of the biosphere and human society. This approach facilitates a better understanding of the complex interactions between biosphere components and enables the development of more effective and reliable life-support systems [4].

An essential part of modeling is the architectural design of closed spaces, which must account not only for functional but also for psychological aspects of living in an isolated environment. Architectural solutions include areas for rest, work, education and social interactions as well as the integration of natural elements to create a more natural and healthy atmosphere.

To save Earth's biosphere from further degradation, it is necessary to restore the natural conditions created to support healthy life. At the same time, the development of technogenic civilization must occur without harming all living things on the planet. One of the most popular concepts in this field is the ecohouse, featuring a renewable energy system and zero environmental impact. Such design elements form the foundation of the linear cities (uCities) – cluster-type settlements interconnected by the uNet international transport and infrastructure network [5]. In the near future, these will become cities of a new engineering civilization, capable of wisely and efficiently utilizing fertile land and developing significant territories without damaging the planet's ecosystems.

In this study, the conditional characteristics of the EcoCosmoHouse on planet Earth (ECH-Earth), depicted in Figure 1, were adopted as a model of a closed biospheric space [6, 7].

a)



b)

Figure 1 – Variant of ECH-Earth: a – general view (model); b – layout scheme

The ECH-Earth is a prototype of the EcoCosmoHouse (ECH) – a self-sustaining, closed residential settlement designed for human habitation and work in near-Earth orbit.

The chosen model offers key advantages: its parameters allow for the simulation of a planetary biosphere, encompassing a diverse range of flora and fauna from Earth's most life-friendly climatic zones, as well as microflora and microfauna, i.e., soil biogeocenosis, including thousands of species of agronomically valuable microorganisms. These conditions are equivalent to those on Earth, ensuring a comfortable atmosphere in terms of pressure, composition, humidity and temperature as well as an optimal day-night and annual cycle and natural lighting.

Thus, the study of closed biospheric environments represents a promising field that brings together scientists from various disciplines in the search for solutions to sustain life with limited resources. This approach not only expands possibilities for space exploration but also enhances quality of life on Earth by fostering the development of resilient and self-sufficient ecosystems.

Analysis of Literature on Closed Biospheric Systems

The term "biosphere" was first introduced in 1875 by Austrian geologist E. Suess. In 1926, Russian scientist V. Vernadsky published a book describing the biosphere as a self-sustaining ecological network of life that forms the outer shell of the planet [8].

Closed biospheric systems were explored in various research projects, including the famous Biosphere 2 experiment [9], conducted in the early 1990s in Arizona, USA. This program aimed to study the possibility of sustaining life in an isolated environment that simulated various Earth biocenoses (Figure 2). According to the scientists' scenario, a crew of eight volunteers was to remain inside the biosphere for an extended period, completely cut off from the outside world, while providing for all their needs within the enclosed ecosystem. The project, envisioned as a fusion of ecology and technology in a new format, received extensive publicity and significant funding. However, the results were disappointing due to inadequate scientific planning and the lack of a reliable system for modeling an enclosed ecosystem. Over two years, the eight participants cultivated papaya, beets, bananas, rice and other crops. Despite the extinction of some plant species, the ecosystem remained functional, though it did not yield the expected results. Ultimately, the experiment was prematurely terminated.

One of the study's major flaws was the failure to account for and properly evaluate numerous simultaneous processes occurring within the enclosed system. This made it impossible to distinguish between causal relationships and mere coincidences. Another significant drawback was that only a small portion of the data obtained from the unsuccessful experiment was analyzed and published.

Another example is the Mars 500 project (Figure 3), conducted in the early 2000s to simulate the conditions of a long-duration spaceflight in preparation for a mission to Mars. The program was organized by the Institute of Biomedical Problems of the Russian Academy of Sciences [10].

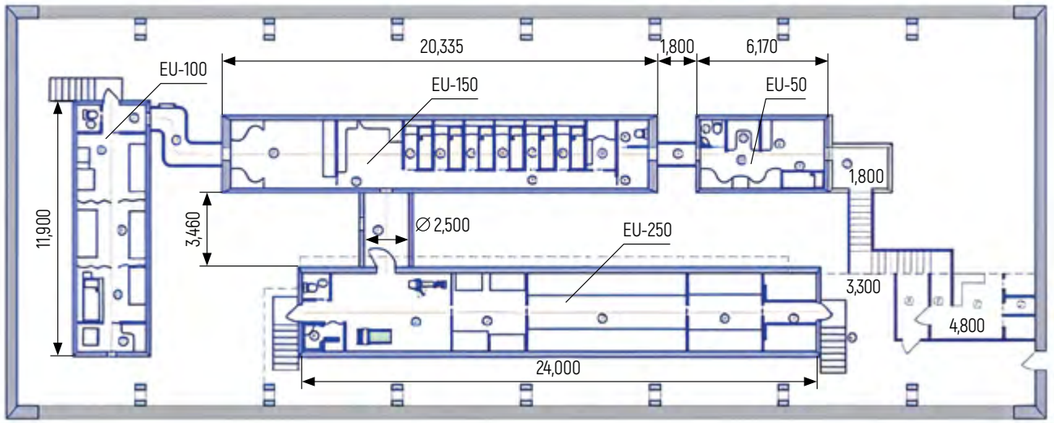
The Russian scientific institution aimed to test and verify the technical and operational characteristics of closed-module systems to assess their suitability for crewed missions. A specially selected crew of six participants conducted tasks under conditions as close to real spaceflight as possible. Through a series of scientific experiments taken place from 2007 to 2010, detailed data were obtained in the following areas:

- clinical and physiological aspects;
- psychological aspects;
- biochemical and immunological aspects;
- microbiological and sanitary-hygienic aspects;
- operational, technological and biological aspects.

The experimental program included more than 70 different scientific studies, the results of which were crucial for the further preparation of the Mars expedition and are therefore applicable to the organization of the biospheric environments we are interested in.

Figure 2 – Biosphere 2 experimental complex (Arizona, USA, 1991)

a)



b)

Figure 3 – Mars 500 experimental complex (Russia, 2007–2011): a – external view of the modules; b – module layout scheme

The examples discussed focused primarily on the problem of extended human habitation in a closed autonomous environment. When modeling biospheric spaces, it is necessary to conduct equally thorough research into the living environment being created, considering all its interrelationships.

In systems like those described, the primary focus should be on maintaining the circulation of matter and energy, which will ensure the sustainability of life without external intervention. For satisfactory predictions regarding the state of closed biospheric objects in a broader context, it is essential to draw on the experience of studying the behavior of relatively enclosed ecological systems in nature, where certain patterns have been established, characterized by two distinct properties: resilience and stability.

Resilience defines the constancy of relationships between living organisms within the system and measures the system's ability to maintain life despite changes in its variables and parameters. On the other hand, resilience refers to the system's ability to return to equilibrium after a temporary disturbance. The speed of this process and the minimal fluctuations characterize the system's stability. Research has shown that the more species of living organisms present in an ecosystem, the more stable equilibria it has. The population of organisms may fluctuate significantly, but the overall resilience of the system will be higher. At the same time, instability in population numbers can sometimes lead to increased species diversity and spatial heterogeneity, which in turn enhances resilience [11].

A special place in the design and construction of enclosed biospheric systems is occupied by the relevant developments from the Soviet era during the Arctic exploration as well as contemporary and international experience in implementing such projects. When systematizing the typological solutions for such construction, the term "cryptoclimatic complexes" [12] has entered scientific usage, encompassing the full range of structures with adjustable climate parameters. An analysis of examples of designing and building objects, integrated with systems for servicing, leisure and human interaction, led to the creation of a consolidated classification of possible cryptoclimatic complexes (Figure 4) [12].

To form a living environment for people, requirements have been developed for the quality and typology of residential buildings in Arctic cities, with groups of factors being defined. The most important of these is the natural and climatic parameters of the region. The characteristics of settlement in the Far North, along with the specifics of the sociodemographic structure, also have a significant impact. Extreme winter frosts, substantial annual temperature contrasts during key seasons (with a difference of up to 100 °C) are exacerbated by strong winds and snowdrifts. The presence of polar day and polar night disrupts human biorhythms. The polar night induces psychological depression, while the polar day leads to insomnia and increased fatigue.

The cryptoclimatic complexes listed in the consolidated classification are designed to mitigate regional peculiarities and provide the most comfortable living conditions. Services in the areas of social and household support and leisure will be available to people of all ages and social groups, as these facilities are focused on neighborhood interaction and hosting guests.

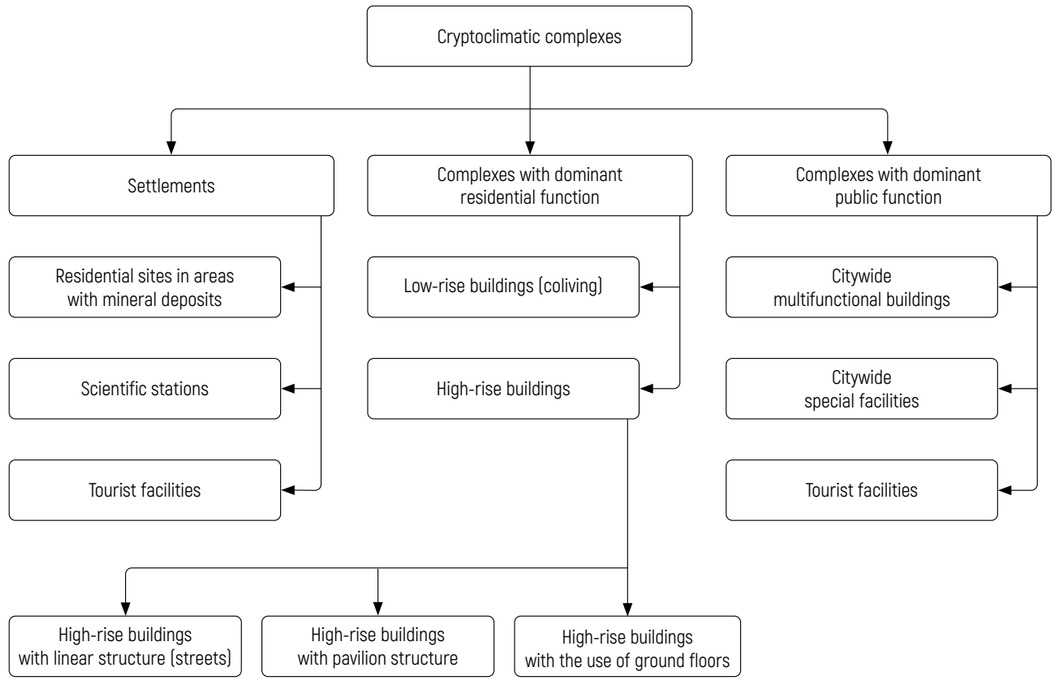


Figure 4 – Consolidated classification of cryptoclimatic complexes

An example of the implementation of these ideas is Poluy experimental residential complex, designed in 1970 by the Russian institute LenZNIIEP (Figure 5) [12]. It consisted of two parallel buildings, with a courtyard – a winter garden – located between them, featuring a shared translucent coating. The garden was conceived as the core of the socio-domestic organization and spatial composition of the entire complex. The proposed layout aimed to provide direct sunlight to the rooms and minimize heat loss due to the significant reduction in the surface area of external walls.

Among the cryptoclimatic complexes, one can include the Ny-Ålesund research village, located on the Spitsbergen archipelago (Norway), which includes residential areas with rooms for scientists, rest zones, kitchens as well as technical facilities with a garage, workshops and engineering equipment for heating, water supply and autonomous sewage systems [12].

In the cryptoclimatic complex built in Kiruna (Sweden), vertical zoning of the space was implemented, where the first floors and ground-level areas are covered to create an inner courtyard, and residential buildings are situated above the public center and connected by stairs [12].

Research shows that cryptoclimatic complexes should not be isolated objects. To support and serve the populations of Arctic cities, it is necessary to develop a region-wide urban infrastructure system that will ensure comfortable living conditions and attract new residents [12].

Summarizing the overview of Arctic projects, one can identify the advantages of using residential systems with artificial climates in extreme conditions of the Arctic and apply them to any spaces where suitable ecosystems need to be created for human habitation.

Thus, the goal of this work is to search for universal engineering and technological solutions within an acceptable range of economic indicators, so that the created biospheric space model can be used to study the permissible parameters of the living environment in the dynamics of its development, while maintaining biological homeostasis.

Experimental Studies on Use of Pilot Tents for Validating Developed Models

Under the guidance of A. Unitsky, the task of optimizing the engineering, structural and economic indicators of the designed biospheric tents is being addressed at Unitsky String Technologies Inc. (Minsk, Belarus). This will allow their use in urban planning, organic agricultural production, industry, energy and transport.

To validate the developed models of closed biospheric spaces, experimental construction of several structures simulating the conditions of cryptoclimatic complexes will be required. These buildings are tent-shaped, have a translucent film coating and are equipped with all the necessary engineering systems to maintain the appropriate climatic parameters inside the complex.

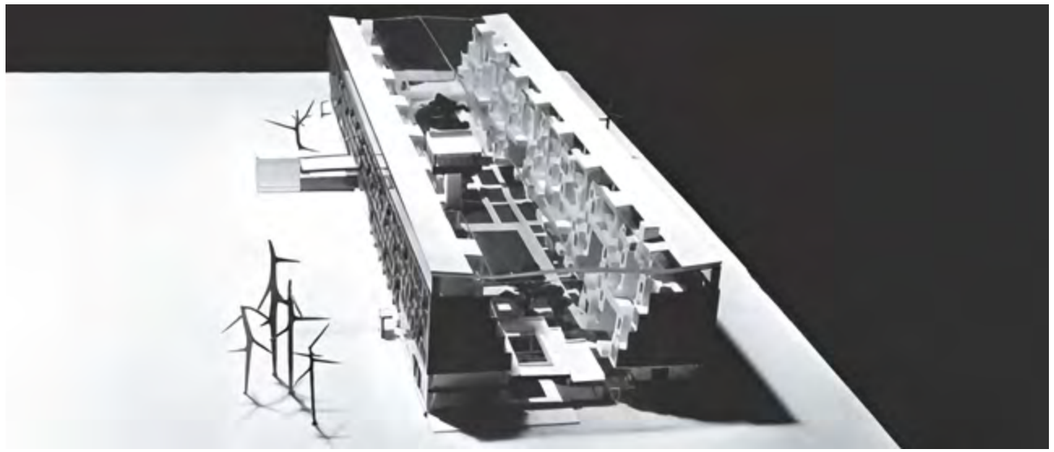


Figure 5 – Poluy experimental residential complex (USSR, 1970)

Tents have been created by humans since ancient times. In various shapes and sizes, they have always been used as shelters throughout history. The culture, climate and materials used were the factors determining the choice of form and design of tent structures. The development of the textile industry in the 19th century and the study of such structures in the early 1950s revived this type of construction. Among all types of tents, we are interested in configurations and sizes united by the main function – an internal enclosed ecosystem of a biospheric type with natural climatic conditions ideal for the life of humans, animals and plants, but with minimal maintenance costs and an acceptable construction cost.

This work focuses on two types of tents, differing in shape and volume of internal space: rectangular and circular in plan. An important component of the success of the pilot project is its practical use even at the experimental stage. Thus, the constructed building will not only provide space for scientific research but also allocate sufficient area for commercial purposes. Additionally, a greenhouse will be organized as a public facility.

The principle for constructing the volume of each selected tent is the same: the central part, supported by towers and prestressed steel strings (strips, ropes, wires), is covered with a translucent film membrane made of ethylene-tetrafluoroethylene (ETFE), and the perimeter of the tent is surrounded by an insulating barrier which includes entrances, evacuation exits and air intake locations.

The polymer ETFE film coatings possess useful and unique properties:

- transparency in the visible and UV spectra;
- self-cleaning surface;
- long service life (30–50 years, provided there is no mechanical damage);
- repairability;
- energy efficiency;
- chemical inertness;
- low weight of 1 m^2 of coating;
- anti-drop effect;
- ability to span large distances;
- fire safety.

The relatively low weight of ETFE film, when compared to glass, allows for the creation of lightweight, multilayered roof structures with large spans and acceptable thermal insulation properties without cold bridges. These qualities of the material provide the possibility to design tents of various configurations with a wide range of functional zoning of the internal space.

Employees of Unitsky String Technologies Inc. have presented predesign proposals for placing a biospheric tent in the territory of Unitsky's Farm Enterprise (Maryina Gorka, Belarus). Among many volumetric-planning solutions, two proposals for organizing the tent's space have been explored. The basic structural solutions for the tents with rectangular (Figures 6–11) and circular (Figures 12–17) floor plans have been developed. Both options are designed as greenhouses with a subtropical climate and are intended for the integration of efforts from various company departments in the design, construction and operation of such inhabited spaces. The scientific and research objectives in this experiment are harmoniously combined with the practical use of the unique structure. Each of the tents under consideration can serve as a venue for various events (conferences, forums, exhibitions, educational tours, wedding ceremonies and other celebrations) as well as a place for recreation and entertainment.

The functional part of the rectangular tent (Figure 7) is represented by various zones:

- greenhouse sectors with fruit-bearing and decorative plant cultures. These are thematically diverse and are arranged in a scattered manner, creating a unique perception scenario for visitors to the facility;
- public modules. Located between the plant cultivation zones, they are intended for organizing large-scale events, either as a single group or as smaller groups (with the capacity for about 1,000 visitors). The transformable space allows for year-round celebrations of varying participant numbers and themes, providing qualitative advantages derived from the functional content of the facility (for example, a conference or banquet surrounded by water and greenery, with the corresponding atmosphere and mood);
- catering areas. In addition to their primary function, these spaces are also designed to broadcast and view events, both those taking place within the greenhouse and external ones (such as sports competitions).

The 48 × 108 m structure is constructed using a metal frame, with a 12 m spacing between the middle columns and a 3 m spacing between the outer columns. The rafter structures consist of trusses with parallel chords on the middle columns, while bent-welded profiles with a square cross section are used on the outer columns. The coating is designed using prestressed strips with a 1.5 m step, with the prestressing force for the main mesh strips set at 20 kN. The prestressing of the strips can be implemented in several ways: using temporary devices (jacks, turnbuckles, winches, etc.) or by lifting the ridge truss.

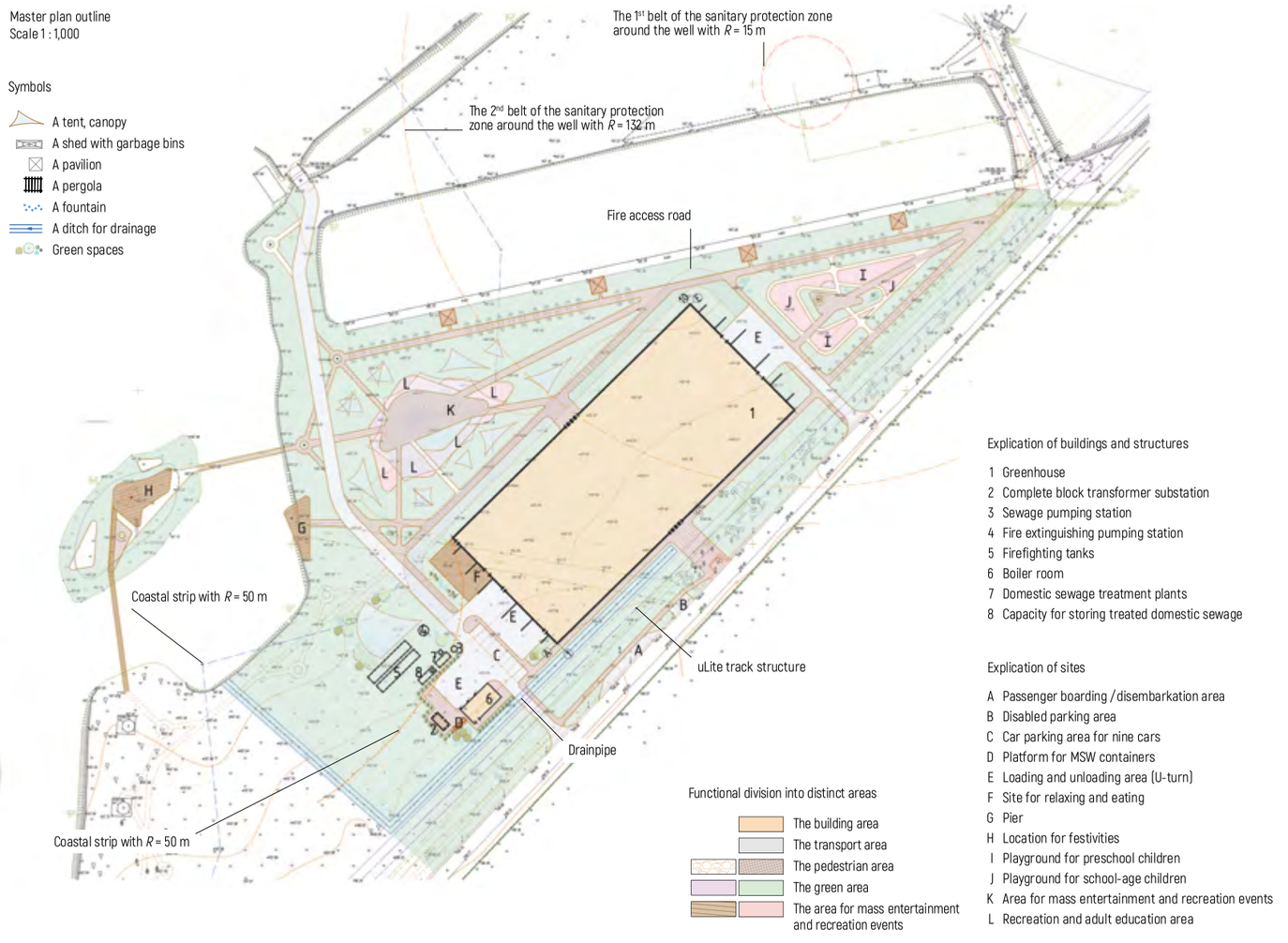


Figure 6 – Layout of the rectangular tent (greenhouse)

Figure 7 – Functional zoning layout of the rectangular tent (greenhouse)

Figure 8 – Top view of the rectangular tent (greenhouse) (model)

Figure 11 – Quiet rest area inside the rectangular tent (greenhouse) (model)

Figure 9 – View of the rectangular tent (greenhouse) from the local roadway (model)

Figure 10 – View of the public area inside the rectangular tent (greenhouse) (model)

The greenhouse, depicted in Figures 12–17, is a single-story cirular building with a tent structure, having a diameter of 91.7 m. Inside the tent, there are sectors for cultivating fruit and ornamental plants, and there is also the possibility to allocate areas for public events.

The zones of the circular greenhouse are thematically diverse and arranged in a scattered manner, creating unique interaction scenarios between the plant cultures. An important feature of the greenhouse is the decorative pond, which complements the plant world with aquatic and riparian species, while also ensuring a comfortable humidity and temperature conditions inside the structure. The external attraction – a slide – provides an optional opportunity for potential visitors to experience an adrenaline rush by descending from the upper level of the greenhouse to the ground level along a long chute. Auxiliary zones of the facility are intended for the storage of equipment and machinery as well as for housing the water treatment unit necessary for irrigation and filling the pond. Ventilation equipment is installed on the technical floor of the central supporting tower.

The circular shape of the tent offers certain advantages over a rectangular design in terms of the efficiency of space usage and compact placement on the site. While the building's area is larger, the perimeter is shorter, resulting in significant savings in structural materials. Moreover, innovative energy solutions have been implemented in this design: heating during cold periods and cooling in the presence of excess heat are achieved by circulating water from a nearby artesian well through heat exchangers built inside the supporting metal columns of the central tower. The pipeline system ensures the discharge of excess heat into the ground under the floor slab to store the accumulated heat for use in winter [13].

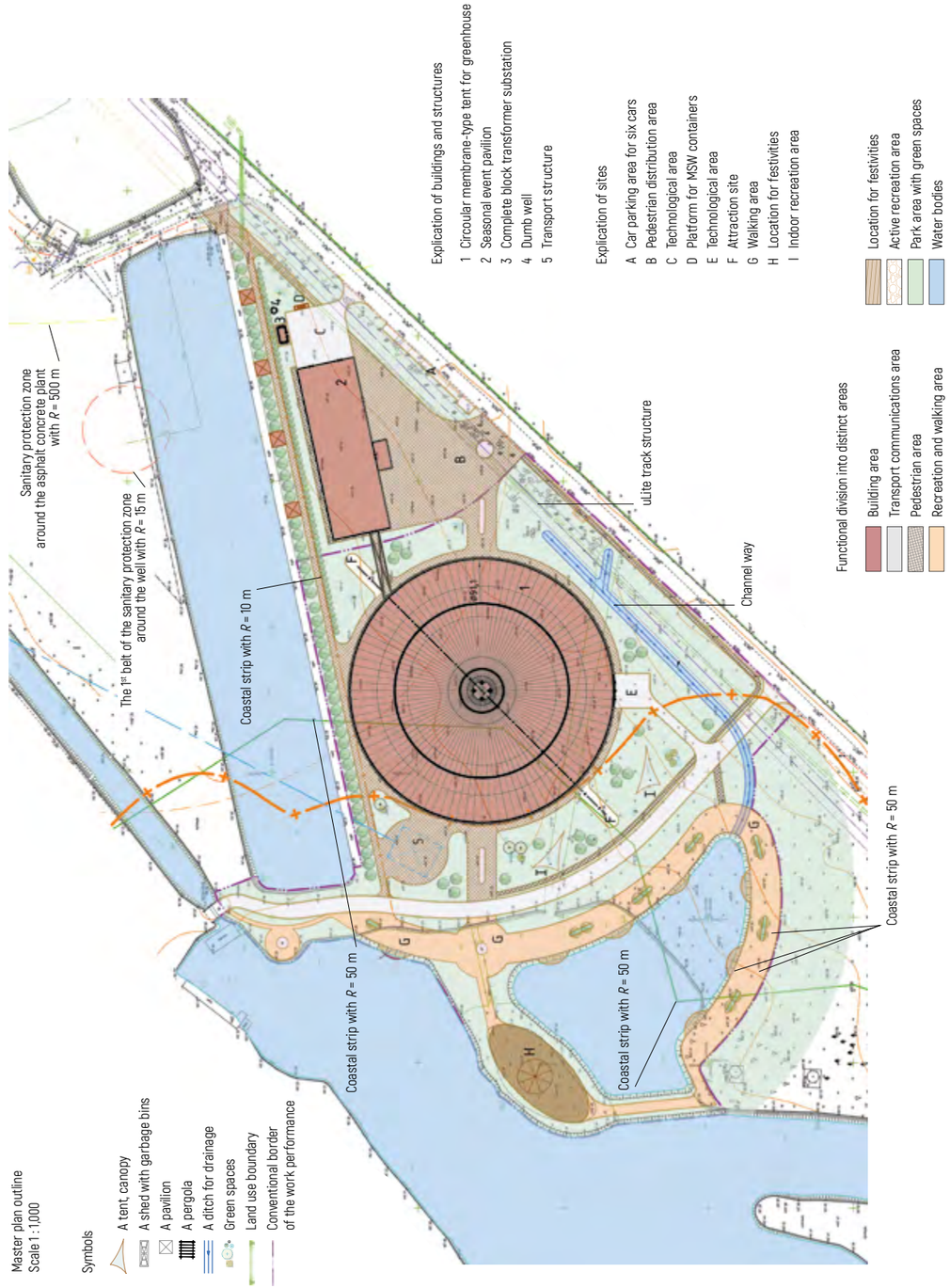


Figure 12 – Layout of the circular tent (greenhouse)

Figure 13 – Top view of the area for the circular tent (greenhouse) (model)

Figure 16 – View of the circular tent (greenhouse) from the local roadway (model)

Figure 14 – View of the circular tent (greenhouse) from Lake Nadezhda (model)

Figure 17 – Interior view of the circular tent (greenhouse) (model)

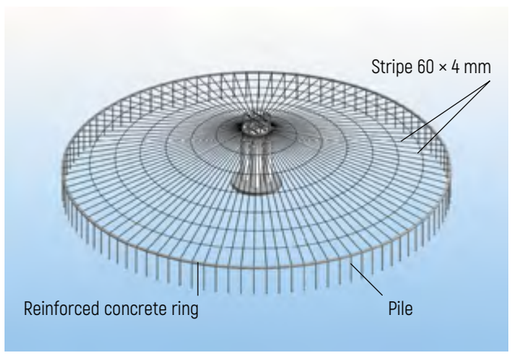


Figure 15 – General view of load-bearing structures of the circular tent (greenhouse) (model)

The spatial stability and geometric invariability of the tent structure are ensured by the combined work of the circular, plan-hanging disk coating and the rigid supporting elements (Figure 15). The main load-bearing structural element is the circular hanging cover in the form of a single-chord tent system, consisting of radially arranged stressed elements that connect to the support rings – internal and external. The stressed elements of the structure are the strings (steel strips), whose shape stability is ensured by their fixation in an orthogonal direction with stabilizing elements arranged in a circular pattern in plan.

To reduce the impact of snow on the coating, further research is needed to determine the critical angles for snow and ice sliding off the membrane roof.

Preliminary calculations of economic indicators suggest that the use of tents with an original design, featuring translucent film coatings and developed by Unitsky String Technologies Inc., can significantly increase the effectiveness of capital investments in the creation of closed biospheric complexes due to the relatively low construction cost per 1 m^2 of the building.

For comparison, similar facilities in terms of functionality and construction materials have been selected: the Leaf greenhouse (Winnipeg, Canada) and the Khan Shatyr Entertainment Center (Astana, Kazakhstan). In both projects, as in our case, a polymer ETFE film was used as the translucent coating. The comparative investment efficiency indicators are provided in the Table below.

Table – Comparative indicators of efficiency of investments related to construction of various tents

Facility	Usable area, m^2	Construction cost, mln USD	Cost of 1 m^2, USD	KPI of investment efficiency
The Leaf greenhouse (Winnipeg, Canada)	120,000 [14]	95 [14]	790	1
The Khan Shatyr Entertainment Center (Astana, Kazakhstan)	127,000 [15]	150 [15]	1,180	0.67
Rectangular tent (greenhouse) at Unitsky's Farm Enterprise (Maryina Gorka, Belarus)	5,183	3.912	755	1.05
Circular tent (greenhouse) at Unitsky's Farm Enterprise (Maryina Gorka, Belarus)	6,500	1.966	302	2.62

The construction of the pilot tent is an experiment that, during its operation, allows for testing original structures. Furthermore, it provides a unique platform for conducting research in a closed biospheric space to validate the developed models of universal engineering and technological solutions within an acceptable range of economic indicators, as well as to study the dynamic parameters of the living environment while maintaining its biological homeostasis.

The general direction of civilization development can be adjusted by changing the technocratic vector of outdated technologies, driven by sectors such as food, communications, energy and living infrastructure, towards an innovative strategy for transitioning local (cluster) techno-consumer societies to a new qualitative state – socio-technogenic society – through the creation of a new global eco-infrastructure [5].

Conclusion

Modeling closed biospheric spaces with a subtropical climate in tents featuring translucent film coatings is a relevant and promising direction in modern science. Thoughtfully designed research topics in this field, applied methods and obtained results can be used to develop residential systems with artificial climates in the Arctic, tropical deserts and orbital ECH.

It is expected that the presented original structural and engineering solutions will help simulate and better understand the processes occurring in closed biospheric spaces with a subtropical climate as well as optimize their operational conditions.

The described modeling options for closed biospheric spaces gain particular significance in the context of building the General Planetary Vehicle and creating the transport, infrastructure and industrial complex "Orbit" in Earth's orbit, with the ECH as the main component. It is through simulation modeling of the inhabited space that all necessary parameters for long-term and comfortable human existence in space – under conditions different from those on Earth – can be fully considered.

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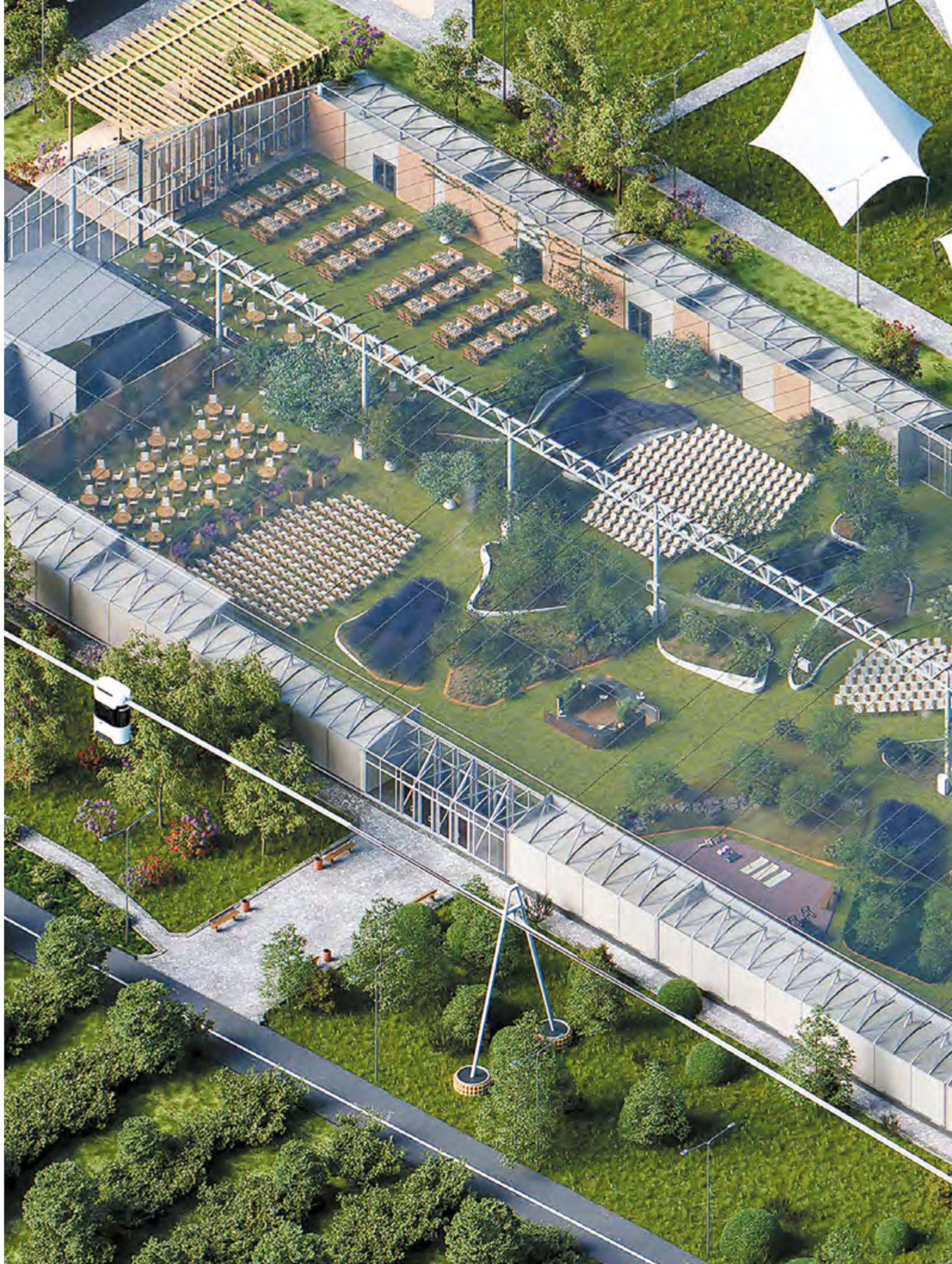

Section

SOCIAL, LEGAL, POLITICAL AND FINANCIAL ASPECTS OF HUMAN CIVILIZATION DEVELOPMENT ON EARTH AND IN SPACE

UDC 524.8+008.2+629.7

Extraterrestrial Engineering Civilizations and Space Civilization Panspermia

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Humanity has long dreamed of interstellar travel, but these aspirations often remain within the realm of imagination, rather than evolving into practical engineering solutions grounded in the physical laws that govern our home – the Universe. This vast expanse includes galaxies, stars, planets and life as we know it on Earth. It is likely that representatives of extraterrestrial civilizations on distant exoplanets share similar dreams. Modern researchers categorize these civilizations based on the amount of energy they consume. However, consumption – whether of space, time, energy or resources – is unlikely to drive the development of engineering civilizations. Only those civilizations capable of transcending the gravity wells of their home planets can engage in space exploration, including the ventures into the depths of the cosmos.

This article demonstrates that near-light speeds are unattainable for space missions carrying "Noah's" Arks with enclosed biosphere-type ecosystems. These missions are essential for relocating terrestrial life – particularly intelligent life – to exoplanets in other star systems. Even if we could travel to exoplanets within a 100-light-year radius at a velocity of 1,000 km/s, the journey would take thousands, if not tens of thousands, of years. The paper also explores the challenges of civilization panspermia, addressing various security factors: physical, energetic, technological, resource-based, biospheric, nutritional and social.

The study substantiates that all advanced civilizations capable of panspermia and interstellar travel belong to a single category – engineering civilizations. They can theoretically progress through six levels of socio-technological development. Currently, Earth's engineering civilization is at Level I, with the potential progression to Level V over billions of years of evolution. However, Level VI is likely unattainable for humanity. The Universe itself may have been created by a Level VI civilization existing in the Multiverse. It is conceivable that our Universe with its fine-tuning represents an engineering civilization of the highest level, one able to navigate singularity and the Big Bang without experiencing collapse.

Keywords:
enclosed biosphere-type ecosystem, extraterrestrial civilization, fine-tuning, galaxy, gravity well, interstellar travel, panspermia, space Ark, star system, the Universe.

Introduction

Hypothetical intelligent civilizations that have emerged and developed (or developed in the past) beyond Earth are referred to as "extraterrestrial civilizations" [1]. This concept is used in fiction, ufology and the scientific discourse. The existence of extraterrestrial civilizations (as well as their absence) has not been scientifically or experimentally proven; however, statistically, it remains a plausible possibility.

Ancient philosophy postulated the impossibility of other inhabited worlds, as the Earth occupied the central position in the cosmos. However, in the 17th century, the idea of searching for extraterrestrial civilizations gained substantial support within scientific communities, largely due to Galileo's invention of the telescope and Copernicus's heliocentric model. As our Blue Planet was demoted to the status of one among many other planets, the hypothesis of life beyond Earth began to be perceived as logically inevitable. With the exploration of the Solar System, the potential for extraterrestrial civilizations was increasingly projected farther into the depths of space.

The hypothesis of other habitable worlds stems from our understanding of the natural origins and subsequent evolution of life on Earth. If the emergence of life, and subsequently intelligent life, is a natural process, then why could this not occur in any other location within the Universe where suitable environmental and climatic conditions exist? Contemporary assumptions suggest that other planets in the Solar System likely do not harbor intelligent life, yet extraterrestrial civilizations may well exist in other star systems – on exoplanets.

The age of Earth (approximately 4.5 bln years) constitutes less than a third of the estimated age of our Universe (around 13.8 bln years) since the Big Bang, if such an event indeed occurred. This circumstance has fueled notions of older and more advanced civilizations than our own human civilization. Research conducted in the late 20th and early 21st centuries casts doubt on the assumptions regarding the existence of extraterrestrial civilizations. The Sun is classified as a third-generation star, having formed from the remnants of supernova explosions of second-generation stars. These, in turn, originated from the remnants of first-generation stars, which emerged shortly after the Big Bang. Consequently, planets orbiting first-generation stars lacked heavy chemical elements essential for the emergence of life. For instance, over 80 chemical elements from the periodic table participate in the homeostasis and metabolism of living organisms on Earth, with approximately 50 tln cells in the human body alone. Second-generation stars similarly did not possess heavy elements, and the formation of first- and second-generation stars, culminating in their supernova explosions (where heavy elements are synthesized), requires not just millions but billions of years.

Furthermore, in the early stages of the Universe's development, when stellar systems were still closely clustered together, the surfaces of potentially habitable planets were constantly sterilized due to catastrophic astronomical events, such as powerful gamma-ray bursts from nearby stars. This phenomenon affected not only systems near the galactic core but also planets on the outskirts of galaxies – similar to Earth – that were exposed to intense gamma radiation from neighboring galaxies, effectively annihilating any nascent life.

It is important to note that planets capable of supporting life remain within the habitable zone for relatively short periods in cosmic terms [2]. Both stellar processes and atmospheric and geochemical phenomena observed on planets can lead to rapid heating, making them similar to Venus rather than to Earth, or rapid cooling, resulting in the freezing of all liquid, as seen on Mars. In this context, intelligent life cannot intervene in these natural processes occurring on planets that obstruct the genesis of life, as intelligence cannot precede the emergence of life itself.

Types of Extraterrestrial Civilizations and God

In 1964, the Soviet scientist N. Kardashev proposed a method for measuring the level of development of intelligent civilizations based on the amount of energy they utilize for technological needs [3].

According to the Kardashev scale, a Type I civilization harnesses the energy resources available on its home planet, a Type II civilization utilizes the energy of its star, and a Type III civilization taps into the energy of its galaxy. Then the scale was expanded to include even more hypothetical civilizations, such as Type IV, which would use the resources of the Universe, and Type V, capable of manipulating the cosmological Multiverse. Additional criteria have also been proposed, including "mastery" over a planet, star system or galaxy (achieving complete control over the processes occurring within them) and the quantity of information controlled by the civilization.

Science fiction writer H. Kautz reworked the Kardashev scale, introducing new types of civilizations [4].

A Type 0 civilization is preindustrial (the first stage of cosmic expansion) and utilizes only a fraction of the available energy resources of its planet. A close analogy is humanity

in the 21st century. Many civilizations of this type self-destruct during their transition to a new level of technological development, a fate that could also befall our civilization within this century.

A Type I civilization exhausts its planet's energy and mineral resources entirely. Neighboring planets are colonized, becoming part of its resource base. This stage may pose a trap for such a civilization, as it risks entering a state of self-sufficiency, directing all available resources towards virtual development, including information technologies, rather than pursuing further physical (material) expansion.

Type II civilizations are exceedingly rare. Typically, they have existed for millions of years, utilizing all the energy and resources of their stellar system. These civilizations are interstellar travelers and have colonized planets in other star systems within their galaxies. They have outgrown their youthful phase, overcome turbulent periods and have significant potential for continued sustainable development.

A Type III civilization has the capability to consume the energy of an entire galaxy. Achieving this level is practically unattainable for a single technological species; it would require the unification of multiple civilizations within the galaxy.

A Type IV civilization utilizes all available energy from galactic superclusters, while a Type V civilization harnesses the energy of the entire Universe.

A Type VI civilization could potentially consume energy from multiple Universes, alter the physical laws within them and even prevent the heat death of its home Universe, allowing it to exist indefinitely.

Given that humanity is currently at a Type 0 level, we struggle to comprehend more advanced civilizations and predict their behavior. Consequently, both the Kardashev and Kautz scales may not accurately reflect the realities of what will occur with advanced civilizations.

Contemporary scientific perspectives view these scales as hypothetical and highly speculative. The level of technological development cannot be reduced solely to a civilization's energy consumption and resource utilization nor its control over information. These attributes reflect a sort of consumerist model of civilizations at planetary, galactic and universal scales. However, "consumption" serves merely as a broad quantitative macroeconomic indicator of a consumer-driven civilization, failing to account for qualitative factors – particularly the social and technological development levels of the civilizations themselves. Nonetheless, the Kardashev scale has been employed by Earth astronomers to search for civilizations in neighboring galaxies.

Moreover, according to this scale, supermassive black holes – ranging from millions to billions of solar masses – found at the centers of many galaxies, including our Milky Way, are also considered Type III civilizations. These black holes utilize their immense gravitational fields to assemble star systems into a galaxy (isn't this akin to intelligent design?), subsequently consuming all available energy and mineral resources for their growth and development. Such black holes can absorb not only star systems but also small galaxies.

Following this logic, the singular state preceding the Big Bang, in which our Universe existed before its expansion began, could be classified as a Type VI civilization. In this singularity, all the energy and matter of the future Universe were concentrated, and it is here that the physical laws of a prior state from one of the preceding universes within the Multiverse could have been altered, reset or rewritten. Under these new laws (which cannot be changed), not only our earthly civilization but also civilizations of Types I–V, if they exist somewhere, would be compelled to evolve. In this context, a Type VI civilization aligns with the concept of "God" – a powerful supernatural entity that creates and organizes the world, granting existence, measure, meaning and law to things, beings and individuals [5]. This civilization likely performed the fine-tuning of our Universe [6]. Thus, a believer might assert, "Our World was created by God," and would be justified in this claim. Similarly, a materialist Engineer might say, "Our World was designed by a Creator – an engineering Supercivilisation."

Engineering Type of Civilizations

The type of civilization should not be defined by the amount and content of resources, energy or space it consumes nor by what it has mastered or produced. It should be evaluated through qualitative indicators rather than quantitative ones. In fact, all the civilizations described above can be categorized under one type: the engineering civilization, which includes our own Earth's human civilization – a global human society. This society has been shaped by thousands of generations of engineers, and not philosophers, artists, poets, bureaucrats, bankers or oligarchs, who are more the consequence than the cause of civilizational development, beginning with the invention of the first fire.

The first fire was ignited by a primitive human engineer. It was not initiated by bees, ants or dolphins, which also possess their own social structures and can be considered civilizations, albeit not engineering ones. These creatures lack engineering technologies, innovations, inventions, science and the derivatives thereof, such as philosophy, art, medicine, education, buildings, infrastructure, energy production, agriculture, communication, the internet, computers, smartphones, automobiles, aircraft, rockets and all the millions of engineering solutions realized in metal, concrete and composites that characterize Earth's human civilization. There is also no result of multimillion engineering – the Earth's industry. Moreover, there is no launch vehicle that has enabled humanity to escape from the Earth's gravity well [7]. For instance, a monkey cannot achieve this because such a "well" is exceedingly deep. One must either climb slowly to infinity or leap with a second cosmic velocity of 11,180 m/s.

Consequently, this study focuses exclusively on extraterrestrial engineering civilizations that have managed to rise from their planetary gravitational depths into space, thereby achieving further socio-technological development. These civilizations have been able to open their own Petri dish of civilization – pushing their engineering technologies beyond the confines of their planetary cradle. It is well-known that even the hardiest mold, placed in a closed Petri dish, will inevitably degenerate, extinguish and ultimately perish after exhausting all finite resources and contaminating the limited space with waste products.

From this, an important conclusion emerges that futurists and science fiction writers often overlook when forecasting the development of extraterrestrial civilizations: all they will possess engineering intelligence (not merely intelligence) because their development is grounded in scientific knowledge of our material world – rooted in the laws of physics (rather than philosophy or art), where the foundation of all is precise engineering calculations and the optimization of technological solutions and processes. Therefore, the amount of energy consumed, as proposed in the Kardashev–Kautz scale, is unlikely to be the primary driver of development for such extraterrestrial civilizations. So, what then will be the main driver?

Astroengineering Technological Structures

To fully harness the energy of a star, the American physicist F. Dyson proposed the construction of a relatively thin spherical shell at a large radius around it – approximately equal to the radius of planetary orbits – rotating at orbital speed [8]. The primary reasons for constructing such a sphere effectively echo the ideas posited by K. Tsiolkovsky in 1895, who suggested its creation for a chain and rings of space settlements around the Sun [9].

According to engineering calculations, the construction of a Dyson sphere around the Sun would require structural materials with a total mass roughly equivalent to that of the largest planet in the Solar System – Jupiter. In this configuration, centrifugal force reaches its maximum at the equator and becomes zero at the poles of the rotating Dyson sphere, where gravitational forces from the central star are unopposed. Consequently, such a sphere would inevitably be destroyed by the immense gravitational pull of the Sun. This is not only due to the current lack of (and the improbability of future development of) materials with tensile strengths thousands of times greater than steel but also because a gigantic hollow sphere with a diameter of approximately 300 mln km would operate under compression (similar to a dome of variable weight), causing its thin-walled structure – even with a thickness of 1,000 km – to lose stability.

Thus, the colossal astroengineering structures purported to be constructed by Type I–V civilizations cannot be detected by us, a Type 0 civilization, as their creation is infeasible both from the standpoint of the physical laws governing our actual Universe (as opposed to a virtual or digital one) and due to the lack of necessity for such constructions among intelligent engineering civilizations, regardless of their level of advancement.

However, linear astroengineering structures built along the equator are not only feasible according to the laws of physics but also necessary for achieving plans for civilizational expansion – from the planet to near space and subsequently from the stellar system to the galaxy. One such solution is a General Planetary Vehicle (GPV) encircling the Earth at the equator, capable of ferrying up to 10 mln passengers and 10 mln tons of cargo in a single trip [10–12]. Importantly, this system operates entirely on electric energy, ensuring environmentally friendly transportation. Moreover, the cost of geocosmic transportation is approximately 1,000 times lower than that of conventional launch vehicles.

Engineering is fundamentally tasked with enabling *Homo sapiens* to create new, more complex and efficient things rather than merely consuming existing, simpler ones. This pursuit embodies the essence of life and its rational component, opposing the second law of thermodynamics concerning inert matter: the increase of entropy [13], or chaos. According to the second law of thermodynamics, a broken cup cannot spontaneously restore itself; however, a rational being equipped with engineering skills can reassemble it from shards or produce a new cup identical to the original. This process involves directing not just lifeless energy

but energy structured into a complex rational engineering process. Therefore, any engineering civilization can be characterized as a Creator Civilization (rather than a Consumer Civilization), with the primary goal of transforming the maximum amount of simple inorganic matter from the Universe into hypercomplex organic substances. In essence, the phenomenon of rational life can be viewed as a form of civilizational panspermia [14]: reconstructing as many "new cups" as possible from the "broken cups" of the Big Bang, defying the second law of thermodynamics, within our vast Universe.

Civilizational Expansion: Objectives and Imperatives

The fundamental aim of living organisms, as encoded in their genetics, is not mere consumption but creation – the transformation of simple nonliving matter into intricate organic structures. Therefore, once life emerges, it should not vanish; this drive for continuity is ingrained at the genetic level in the core instinct of any living being – the preservation of its lineage.

Life – comprising DNA molecules, cells, tissues, organs and systems – represents the pinnacle of engineering. It suggests that a Creator (potentially a Type VI supercivilisation) has harnessed all principles of physics (both quantum and relativistic), chemistry (both inorganic and organic), energy management, materials science, design and construction (spanning scales from nanometers to tens of meters, i.e., from the size of proteins and DNA molecules to that of dinosaurs and whales), mathematics and various other facets of our tangible micro- and macro-worlds.

Consider, for instance, the biochemical metabolism occurring within any living cell in the Earth's biosphere. Each cell hosts thousands of simultaneous biochemical reactions involving diverse organic substances, including the synthesis of DNA. A launch vehicle, often hailed as a marvel of modern engineering, executes merely a single chemical reaction – the combustion of fuel. Moreover, a rocket cannot replicate itself or any of its components, such as a jet engine or control system, while a living cell possesses that capability. This disparity underscores that even a single structural component of a cell – the DNA molecule, which consists of tens or hundreds of billions of atoms arranged in complex spatial configurations – is millions of times more intricate than any rocket and thousands of times more so than the entire terrestrial industry built by countless generations of engineers.

The life processes within each cell utilize over 80 chemical elements from the periodic table. Within these cells, one can find networks akin to roads, bridges, power stations, workshops, factories, machines, assembly lines, technological processes and intelligent management systems. Thus, terrestrial life can be viewed as an engineering endeavor, and its Creator – whether conceived as Nothing, Chance, a Highly Advanced Civilization or God – certainly embodies the essence of an extraordinary Cosmic Engineer.

During the singularity and the ensuing Big Bang, a fine-tuning of the Universe's physical laws occurred – establishing the "physical genes" of its programmed evolution. The objective of this tuning is the emergence of Intelligent Life, which, regardless of its random origins, will propagate its advancements throughout the entirety of the nonliving material Universe. Consequently, the aim of extraterrestrial civilizations will not lie in the relentless consumption of energy and resources but in the expansion of the Civilizational Habitat, first to neighboring star systems, then to their home galaxy and ultimately beyond to adjacent galaxies and their clusters.

Interstellar Flights: Key Challenges and Engineering (Technological) Solutions

Interstellar journeys must adhere to the fundamental physical laws of conservation: mass, energy, momentum, angular momentum and motion of the center of mass, all established during the Big Bang. For instance, consider an interstellar Ark with a mass of 200,000 tons accelerated to a speed of 100 km/s. This would require an immense amount of energy, calculated as follows:

- kinetic energy: 10^{18} J. For context, this is equivalent to the energy released by burning 21 mln tons of gasoline in the presence of 71 mln tons of oxidizer (oxygen), totaling 93 mln tons of chemical fuel;
- momentum: 2×10^{13} kg·m/s. To put this into perspective, this amount of momentum is similar to that of a train weighing 800 mln tons traveling at 90 km/h.

Both kinetic energy and momentum must be imparted to the spacecraft at two critical stages: during the initial acceleration phase within our Solar System and again during deceleration as it approaches the target star system and exoplanet, which will serve as a new home for Earth's life.

Launching from Earth's orbit – specifically from the Lagrange points L_4 or L_5 in the Sun–Earth system [15] – would be the most efficient approach. Here, we could establish a space industry supported by the planet's resource and energy base. Arriving is also intended to Lagrange points in the star–exoplanet system, where the Ark's engineering crew should build an industrial, resource and energy base for colonizing the exoplanet. This new world would ideally become a second home for Earth's life and humanity. After all, what would motivate astronauts to embark on such a monumental journey if not the prospect of establishing a sustainable colony? The Lagrange points are expansive zones; they span millions of kilometers, allowing for the potential placement of thousands of astroengineering structures, each serving diverse functions.

Equipping a space mission involves addressing numerous challenges, both engineering-related (design, technology, energy, resource management, flight safety, in particular space radiation and dust hazards, meteorite threats, etc.) and sociobiological. Key questions are: How many species of Earth's billions should be included in the mission, and in what quantities? Simply sending two of every kind would be insufficient. What type of enclosed biosphere-type ecosystem should the spaceship maintain? Additionally, how should we structure the crew, which will undergo multiple generational changes over thousands of years? The mission's objective extends beyond mere flight; it encompasses the colonization of an exoplanet. Therefore, how can we create a closed society that is far more complex than tribal structures, such as those of Amazonian indigenous peoples, ensuring not only survival but also development and progress throughout the journey and into the colonization phase?

Space Ark

The Ark is more than just a spaceship; it is an immense engineering marvel – an advanced biosphere designed to safely preserve Earth's life forms, including humans, and transport them to distant exoplanets that are light-years away. This ambitious endeavor is feasible only within an EcoCosmoHouse (ECH), a self-contained biosphere-type ecosystem [16].

The ECH-Ark serves as a miniature version of Earth's biosphere, representing the most sophisticated autonomous vehicle capable of sustaining life for thousands of years. It is equipped with its own energy systems, engines, fuel reserves and nonrenewable resources that do not participate in the biospheric cycle. Furthermore, the Ark includes essential engineering infrastructure, a repair facility, living quarters, production areas and agricultural systems. It supports a diverse range of activities, encompassing agro- and aquaculture as well as housing flora, fauna and fertile soil. Additionally, the Ark functions as a complete society, featuring a kindergarten, school, university, medical facilities and a variety of workplaces that cater to hundreds of specialties.

Ark Structure

The Ark's hull is designed in the shape of a spindle (Figure 1), measuring between 500 and 2,000 m in length and 200 to 500 m in diameter, accommodating a crew of 1,000 to 10,000 individuals. For our further studies, we will focus on the minimum size and biospheric capacity of this spaceship.

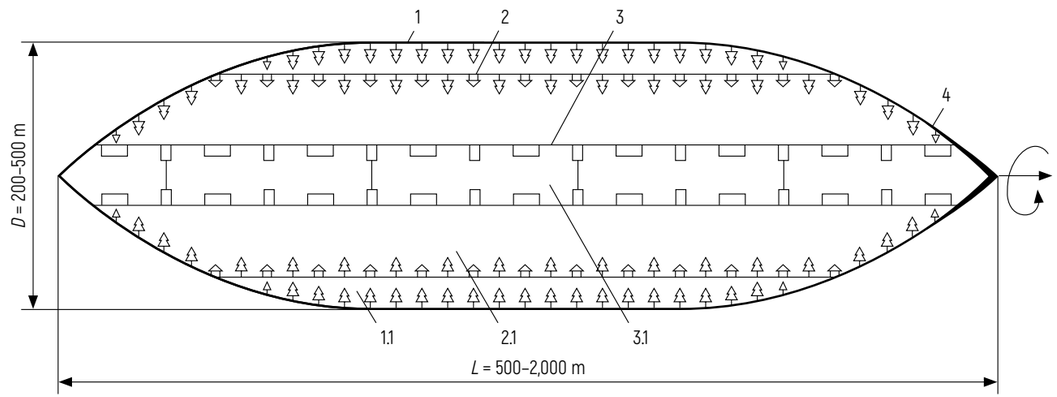

Figure 1 – Longitudinal section of the Ark (option):
1 – outer (protective) shell, 1.1 – biospheric (natural) compartment;
2 – living compartment shell ("floor"), 2.1 – living compartment and agricultural zone;
3 – production compartment shell ("floor"), 3.1 – production compartment; 4 – frontal armor protection

The Ark comprises three primary zones.

Zone 1.1: biospheric (natural) compartment. This area is a natural habitat devoid of human presence, featuring untouched terrestrial and aquatic flora and fauna. Its primary function is to generate the essential oxygen for the biosphere while absorbing excess carbon dioxide. For instance, the annual oxygen requirement for 1,000 people aboard the Ark would be approximately 180 tons.

Zone 2.1: living compartment and agricultural zone. This area serves as the living quarters for humans, where organic food is cultivated and economic activities are carried out by the crew.

Zone 3.1: production compartment. This area is designed for microgravity and weightlessness along the Ark's rotation axis, with the option for a deep vacuum facilitated by a technological vacuum chamber connected to the surrounding space. It houses production and repair facilities, a robotic machine park as well as various scientific, power and other equipment.

Assuming a total mass of 200,000 tons, or 200 t/person (excluding fuel and accounting for the working mass needed to create a braking impulse), the approximate composition of a fully leaded ark includes:

- air: volume of 12 mln m^3 (12,000 m^3/person), mass of 15,000 tons (15 t/person, with 3 t/person of oxygen);
- water, including fresh and saltwater, groundwater and technical water: 25,000 tons (25 t/person);
- fertile soil (biohumus) and living organisms, encompassing flora and fauna, including humans: 45,000 tons (45 t/person);
- supporting structure: 25,000 tons (25 t/person);
- protection against space radiation and meteorite impacts: 35,000 tons (35 t/person);
- equipment: power, production, operational, engineering networks, etc. – 40,000 tons (40 t/person);
- miscellaneous: 15,000 tons (15 t/person).

The Ark should also carry a stock of nuclear fuel (several tens of tons of plutonium-239) and several hundreds of thousands of tons as a working mass for creating a braking impulse upon reaching the exoplanet (see below).

To simulate Earth's gravity (acceleration of gravity is 9.8 m/s^2), the Ark's "spindle" must be rotated around its longitudinal axis at a circumferential velocity of 31 m/s, completing one revolution every 20 s. A thick layer of fertile soil, several meters deep in some areas, will cover the inner surface of the ECH. This soil is essential for planting gardens and forests and will host soil biota, forming a biogeocenosis that underpins the fertility of any terrestrial ecosystem. Additionally, it will provide extra radiation and meteorite protection.

Let us now identify the most pressing engineering challenges and explore potential strategies to address them, which is crucial for ensuring the safety of interstellar travel within the mission of civilization panspermia.

Ark Security

The safety of the Ark extends beyond the challenges of high-speed movement through outer space, which is fraught with various threats such as cosmic radiation, dust and meteorite impacts. Equally important is the need to mitigate risks that have historically accompanied the development of human civilization on Earth. These include civil unrest, dictatorships, revolutions, wars, pandemics and a consumerist mindset that prioritizes pleasure and profit over well-being. In an enclosed ecosystem, these issues can threaten not only the environment but also the human society residing within it – a microcosm of civilization. Therefore, it is imperative to consciously eliminate such dangers at every level. To achieve this, the Ark must ensure multiple forms of security: technological, social, energy, food, resource, information, etc. This comprehensive approach will support the engineering-oriented (not only biological) civilization embarking on a multi-millennia journey, safeguarding both the ecosystem and the society it nurtures.

Physical Security. The primary concern for physical safety during such a long-duration flight is protection against radiation and meteorite impacts. For instance, a 100 kg meteorite traveling at 20 km/s possesses a kinetic energy of 2×10^8 J, equivalent to the explosive energy of 4,800 kg of TNT. At a speed of 100 km/s, this energy rises to the equivalent of 120 tons of TNT. A collision with such a space object could be catastrophic for the entire expedition.

While the probability of such collisions is not negligible, the space Ark must be equipped with robust armor made from minerals, several meters thick, particularly at the bow. In this context, thickness is more critical than mass, so the ship's shell should utilize a lightweight porous structure. This armor will not only provide protection but will also serve as a mineral reservoir, which will be essential during the lengthy voyage. The pores can be filled with water, necessary for maintaining the Ark's biosphere, while also offering additional radiation shielding. Moreover, the content of the armor can be repurposed as a working mass for creating a braking impulse, allowing the Ark to decelerate from interstellar to planetary orbital velocities upon reaching its destination.

To achieve this, it is proposed that mineral waste generated by the Lagrangian industry in Earth's orbit – specifically, the space industry operating at the Lagrange points of the Sun–Earth system – be immediately processed and stored as protective armor for the future interplanetary vessel. This industry could feasibly produce enough materials in just one year to equip thousands of such "Noah's" Arks for journeys throughout our Milky Way galaxy.

To further reduce the thickness and mass of the armor, especially at the nose of the Ark, it could be enveloped in a cocoon of fine mesh, for example, with a grid size of 10 × 10 mm, positioned several tens of meters away. If a meteorite were to strike this mesh at high speed, it would create a hole and fragment into smaller pieces, ensuring that only tiny fragments, each weighing no more than 10 g, would reach the Ark's hull. For enhanced effectiveness, multiple cocoons could be employed, with mesh sizes decreasing progressively as they approach the hull.

Energy Security. At the outset of a mission, resources from a spaceport located at the Lagrange point of the Sun–Earth system can be utilized for acceleration. However, for braking at the journey's end, the Ark must carry its own energy resources. Without these, the mission of space expansion could fail, leaving the ship to drift endlessly through the Universe until it is inevitably consumed by a black hole.

Interstellar flights require exceedingly high speeds (by Earth standards). For instance, to reach the nearest star, Proxima Centauri, which is 4.244 light-years away, the journey would take approximately 12,800 years at a speed of 100 km/s.

At the spaceport, the Solar System's resources should be harnessed to accelerate the Ark. This could include using a specialized tugboat, similar to the first stage of a launch vehicle. When accelerating a spacecraft weighing hundreds of thousands of tons, gravitational maneuvers around the giant planets Saturn and Jupiter can significantly increase speed – up to 50 km/s – without consuming additional fuel [17]. A similar maneuver can be employed at the journey's end to decelerate the spacecraft, provided there are giant planets at the destination.

Let us examine the final phase of the Ark's journey to deep space, focusing on braking near an exoplanet. The maximum change in velocity, as determined by K. Tsiolkovsky's formula (which describes the motion of a body with variable mass), is constrained by the exhaust speed of the working mass (the kinetic jet) and the energy available on board.

Table 1 outlines the mass-energy characteristics of the Ark with a dry mass M_1 = 200,000 tons (excluding the mass of the working mass M_2 and fuel M_3) at various velocities of the working mass exhaust V_r and changes in the ship's velocity v_{max}. Notably, when $V_r = v_{max}$, the mass of the working mass M_2 remains constant at 340,000 tons for a ship with the mass of M_1 = 200,000 tons.

However, if the ratio $v_{max} / V_r = 10$ is applied to achieve a speed of v_{max} = 50 km/s (with V_r = 5 km/s), the necessary mass of the working mass M_2 increases by a factor of 13,000, while energy consumption E_T escalates by a factor of 130 compared to a scenario where $v_{max} / V_r = 1$ (i.e., v_{max} = = 50 km/s and V_r = 50 km/s). In this situation, the onboard energy reserve $E_T = 5.5 \times 10^{19}$ J (considering only the kinetic energy of the jet, excluding heat losses) equates to the energy produced by burning 1.2 bln tons of gasoline and 4 bln tons of oxidizer (oxygen). Moreover, this fuel must be transported, initially accelerated to 50 km/s alongside the ship, in order to facilitate braking after thousands of years upon reaching the exoplanet. Clearly, chemical fuel jet engines are not suitable for interstellar travel.

Table 1 – Mass-energy characteristics of the Ark

v_{max}, km/s	V_r, km/s	v_{max} / V_r	M_1, tons	M_2, tons	$M_1 + M_2$, tons	E_T, J
50	5	10	200,000	4.4 bln	4.4 bln	5.5×10^{19}
50	50	1	200,000	340,000	540,000	4.3×10^{17}
100	100	1	200,000	340,000	540,000	1.7×10^{18}
1,000	1,000	1	200,000	340,000	540,000	1.7×10^{20}
10,000	10,000	1	200,000	340,000	540,000	1.7×10^{22}
100,000	100,000	1	200,000	340,000	540,000	1.7×10^{24}

Therefore, the most energy-efficient interstellar flight occurs when the condition $v_{max} / V_r = 1$ is met. This approach should be prioritized by advanced extraterrestrial civilizations engaged in deep space exploration.

To achieve 1/3 the speed of light (100,000 km/s), the mass of the working mass would still be 340,000 tons. However, due to the high velocity of the jet exhaust (100,000 km/s), the Ark, with a curb weight of $M_1 + M_2$ = 540,000 tons, would require fuel with an energy capacity of 1.7×10^{24} J. This amount of energy is equivalent to the calorific value of 36 tln tons of gasoline and 120 tln tons of oxygen, totaling 156 tln tons of chemical fuel. Alternatively, it could be represented by about 20 mln tons of plutonium-239, the most energy-dense fuel known to humanity. In this scenario, the Ark's curb weight would increase to an astronomical 20.3 mln tons due to the fuel mass M_3 that will be 37 times greater. What propulsion system should be used and where to store tens of millions of tons of radioactive fuel in a relatively small Ark?

This challenge raises significant engineering concerns. Consequently, near-light interstellar travel in our Universe appears to be unfeasible, despite the notions presented by science fiction writers and philosophers. The hurdles lie not only in the exorbitant energy demands but also in the unrealistic nature of the required technology, even in future scenarios. It is clear that the Ark would need a power plant – potentially nuclear, thermonuclear or a hypothetical *X*-nuclear reactor – with an efficiency factor of about 50 %. Given that half of the energy produced would be lost as waste heat, the fuel reserves would need to be doubled, resulting in 40 mln tons of plutonium-239, vastly exceeding the total nuclear fuel supply available on Earth. This electrical energy would be directed to an ion jet engine, accelerating a working mass to speeds of 100,000 km/s using an electromagnetic field.

If the braking process at the journey's end were to take a year, the required power for the ion jet engine would be $N = 1.7 \times 10^{24}$ J / 31,536,000 s = 5.4×10^{16} W = 54 tln kW, not accounting for the energy needed to decelerate the fuel itself with a mass of 40 mln tons, i.e., for a hypothetical case when this fuel does not actually have any mass.

Imagining an engine of such electrical capacity within a small Ark is challenging, especially since this power would also generate significant waste heat with nowhere to dissipate it, given the surrounding vacuum. Even if the Ark were to accelerate and decelerate over a millennium, a power plant capable of producing 54 bln kW – 25 times the output of all the world's power plants combined – remains unimaginable, particularly given the immense heat generated. In such a scenario, the Ark and its contents would likely melt and vaporize within moments.

Thus, from an engineering perspective (rather than purely scientific), a starship would need to accelerate for approximately 100,000 years and decelerate for an equal duration. This renders the benefits of achieving higher speeds in real interstellar travel within our physical Universe largely meaningless. These challenges are not only apparent to engineers on Earth but likely understood by extraterrestrial engineers who may have long ago planned or executed a journey to the exoplanet we call Earth, at speeds that are physically reasonable.

High exhaust velocities of substances pose significant engineering issues and are currently achievable only in theory. Therefore, it is essential to consider a more practical gas-phase nuclear jet engine, which can achieve a maximum jet exhaust velocity of 50 km/s [18]. For this discussion, we will use plutonium-239 as a hypothetical space fuel, which has an energy content of 8.36×10^{13} J/kg. Notably, 1 kg of plutonium-239 is equivalent to the calorific value of 1,770 tons of gasoline and 6,000 tons of oxygen [19].

A gravitational maneuver around giant planets can reduce the Ark's speed at the end of its journey from 100 to 50 km/s. To decelerate effectively from this speed, approximately 340,000 tons of working mass and 5.2 tons of plutonium-239 would be required, providing a total energy efficiency of 4.3×10^{17} J.

Assuming an energy requirement of 5 kW/person aboard the Ark, the total energy needed to sustain 1,000 inhabitants during a 12,800-year journey to the nearest star would amount to about 2×10^{18} J, equivalent to 24 tons of plutonium-239. Including a 20 % reserve, the total nuclear fuel needed would be approximately 35 tons, which is feasible. Given that plutonium-239 has a half-life of 24,100 years, it will also need to be produced onboard from uranium-238 (which has a half-life of 4.5 bln years) using a fast neutron reactor within a closed nuclear fuel cycle [19].

Thus, the energy component of the Ark should consist of roughly 340,000 tons (with the total mass of the ship at 540,000 tons), primarily made up of the working mass. Water is a reasonable choice for this purpose, as it can serve multiple functions: it will support biospheric processes, replenish freshwater and seawater reserves and function as a cooling and heating agent. Additionally, water can provide protection against meteorites and radiation. The optimal storage for water would be within the porous armor of the spacecraft, which would have an average thickness of several meters. This configuration allows for easy removal and replenishment of water, enabling its participation in the Ark's biospheric water cycle.

The most promising propulsion system for interstellar travel is the ion engine – an electric rocket engine that produces thrust by accelerating ionized gas in an electric field to speeds between 50 and 210 km/s [20].

Within a 10-light-year radius of Earth, there are 11 stars, and traveling to these at a speed of 200 km/s would take up to 15,000 years. The working mass for this journey would also be 340,000 tons, but the amount of plutonium-239 needed for braking at the exoplanet would need to be four times greater than that required for a speed of 100 km/s, resulting in 21 tons of nuclear fuel.

Due to the low thrust and power output of ion engines, the Ark would require several years – possibly even decades – to accelerate and decelerate effectively.

During long-duration flights, consistent lighting of the Ark's interior is crucial for maintaining the metabolic processes of its enclosed biosphere-type ecosystem. Thus, ensuring stable and high-quality lighting becomes one of the critical onboard energy technologies.

The recoverable reserves of nuclear fuel on Earth – specifically, uranium-238 (approximately 5 mln tons) and thorium-232 (which is 2.7 times more abundant) – offer a total calorific value about 30 times higher than all fossil hydrocarbons combined (oil, coal, gas). These resources could potentially equip tens of thousands of Arks for travel at 100 km/s or several Arks for speeds of 1,000 km/s, acknowledging that energy consumption for the latter would be two orders of magnitude greater.

If, in the future, jet engines capable of achieving high exhaust velocities (e.g., 1,000 km/s) are developed, the mass of the Ark could be significantly reduced. In the scenarios described, the working mass of 340,000 tons could be diminished. For instance, only 100,000 tons of working mass would be necessary for the Ark to reach a speed of 405 km/s, and a mere 50,000 tons – 6.8 times less – would suffice for a speed of 223 km/s.

Technological Security. Humanity currently lacks experience in creating materials, components and devices with lifespans exceeding 1,000 years. In today's consumer-driven society, the prevailing approach is to minimize product longevity, encouraging consumers to purchase slightly modified versions of the same item, thereby maximizing profits for manufacturers. In contrast, Live Nature operates on a fundamentally different principle: any mother, whether a bacterium or a human, brings forth offspring not for profit but for survival. This necessitates the incorporation of biosphere-inspired engineering technologies within the Ark, which should possess self-repair capabilities, the ability to reproduce (through the division of technological "cells") and other adaptive characteristics, all while fostering technological advancement rather than regression. This mirrors the evolutionary trajectory seen in Live Nature, moving from simple to increasingly complex systems.

While engineering technologies can function in darkness, life cannot thrive without light; both flora and fauna depend on it. Therefore, an analogue of the Sun is essential within the Ark. It is important to note that there are no everlasting light sources; if power is cut, the Ark would be plunged into darkness, leading to the demise of all living organisms except for certain protozoa. Consequently, the production and repair of critical power equipment, lighting systems and other essential devices are vital technologies. Without these, the mission of panspermia would be rendered impossible.

Upon arrival at the exoplanet star system – specifically at the Lagrange points rather than the exoplanet itself – the Ark will require landing modules capable of both landing on the planet and returning to escape its gravitational pull. Thus, these modules, along with reserves of fuel and other working materials, must be included aboard the Ark.

It is unlikely that the exoplanet will be immediately suitable for habitation by Earth organisms, particularly regarding its atmosphere, which must contain approximately 20 % oxygen and 80 % inert gases to support metabolism. Adjusting the atmospheric composition of an exoplanet may take millennia, so the Ark's crew should prioritize establishing a space industry using local raw materials and energy sources from the nearby star at the Lagrange points of the star–exoplanet system. Only after this should they begin the process of developing the exoplanet. Moreover, the basic engineering technologies and equipment necessary for the mission must also be transported from Earth aboard the Ark. Extracting raw materials from the planets within the star system is likely to be highly energy-intensive; the more massive a planet, the more challenging it is to land on and take off from it. Therefore, mineral resources should ideally be sourced from local asteroids and smaller celestial bodies.

Biospheric Security. As the aim of interstellar flights is to extend humanity and Earth life into the depths of space, it is essential to utilize the ECH-Ark rather than a conventional spacecraft [10, 16]. This Ark will replicate the optimal

conditions of Earth's biosphere for several thousand inhabitants, creating a small, rural-style community complete with all necessary natural elements: atmosphere, diverse landscapes, living organisms, soils, biogeocenoses, aquatic ecosystems and more. The Ark will be designed to provide the most comfortable conditions possible, including optimal gravity through centrifugal forces, natural spectrum lighting and a well-balanced atmosphere (with ideal composition, temperature, pressure, humidity and oxygen levels), etc.

The crew of the Ark will spend thousands of years within an enclosed ecosystem, characterized by a natural cycle of substances and energy as well as an optimal subtropical climate conducive to human habitation. This environment will support a genetically diverse population, featuring millions of carefully selected species from the billions (if not trillions [21]) of organisms on Earth, representing all kingdoms of Live Nature: bacteria, viruses, fungi, plants and animals.

To achieve this, the Ark must model a miniature version of Earth's biosphere – the cradle of humanity with a rich evolutionary history spanning billions of years, including the precursors to *Homo sapiens*, and recorded in our genes. It should encompass the diverse flora and fauna of Earth's climatic zones that are favorable for human life, reflecting our deep-rooted origins. For instance, the ancient ocean's mineral composition resonates in our blood, highlighting the need for a representative ecosystem. Additionally, the Ark should include soil biogeocenosis containing thousands of species of agronomically valuable associations of aerobic and anaerobic microorganisms. This soil will not only be more fertile than rich chernozem but also serve as an "engineer of fertility," housing at least 100 earthworms per 1 m^2.

Healthy soil acts as the immune system of Earth's biosphere, ensuring the well-being of all living organisms, including humans. A kilogram of such soil hosts about one trillion of microorganisms. Without this, creating comfortable and safe conditions for the Ark's flora and fauna – along with the crew and the vital microflora and microfauna in both soil and water – would be impossible.

The food chain within this biospheric cycle begins and ends in the soil. For example, the human immune system is heavily reliant on the microflora and microfauna of the intestines, which can be likened to soil. Tens of trillions of microorganisms from thousands of species inhabit this environment, working continuously to nourish and even heal us. Many experts refer to the gut as a "second brain."

In the Ark, both mineral (excluding radioactive) and organic waste – such as sewage – will be processed by microorganisms into biohumus, which will then be returned to the soil. This process will create a cycle of essential substances for the biosphere's life, such as water, oxygen, carbon dioxide, food for flora and fauna (including humans), as well as management of waste products of all organisms, even in the event of their death.

In the biospheric section of the Ark (Figure 1, zone 1.1), optimal homeostasis must be established across all levels of living communities. This includes regulating abiotic and biotic factors, ensuring optimal trophic chains and maintaining biological rhythms. Without these conditions, achieving stability within the Ark's cenoses over the course of a flight lasting thousands of years would be unrealistic [22].

Before embarking on its journey into deep space, the fully equipped Ark should undergo a quarantine period of one generation (20–25 years). This time will allow for fine-tuning the enclosed biosphere-type ecosystem and the human society within it, facilitating identification and correction of imbalances, especially those that may not become apparent until the lengthy journey begins.

Food Security. The annual organic food requirement (grains, bread, beans, vegetables, gourds, fresh fruits and berries, meat, fish, milk, eggs, etc.) for a crew of 1,000 individuals, including children, is approximately 700 tons, which translates to about 700 kg/person. Modern intensive agricultural technologies enable the cultivation of 10 to 50 kg of agricultural product per 1 m^2 annually in greenhouses, necessitating an average of up to 50 m^2 of cultivated area per person.

To support organic farming in the ECH-Ark, which includes using biohumus (both crumbly and liquid) for plants and microgreens for animal feed produced in vertical farms and chlorella grown in ponds, a more fertile land area will be required – around 100 m^2/person. Considering the food needs of farm animals and aquaculture, this figure rises to about 150 m^2/person. Additionally, another 50 m^2/person will be needed for recreational spaces, walking paths, playgrounds and other communal areas. Consequently, the total area for the residential zone 2.1 (Figure 1) in the Ark should be approximately 200,000 m^2.

All horizontal surfaces within this zone, including the rooftops of dwellings and agricultural farms, should be covered with fertile soil to facilitate biospheric processes. This includes oxygen production, CO_2 absorption and the cultivation of organic food. The tiered soil arrangement in the Ark's vertical farms will provide at least 500 m^2 of productive soil per person. Around 10 % of this area will be allocated for oxygen production (factoring in the use of chlorella), 50 % for growing plant-based foods, and 40 % for animal feed [22].

Resource Security. Within the Ark, a closed cycle of resources (substances) must be established, excluding energy resources, which are irretrievably lost as they convert into heat and are eventually radiated into space. Minimizing losses of both inorganic and organic matter is crucial. For instance, burying the dead in space would result in significant, irretrievable losses of organic matter over thousands of years, potentially amounting to tens of thousands of tons.

The living (biospheric) matter in the Ark primarily consists of fertile soil made from biohumus – insoluble salts of humic acids – along with the necessary macro-, micro- and ultramicroelements. This soil supports a complex symbiosis with thousands of species of agronomically valuable aerobic and anaerobic microorganisms. Without them and earthworms, fertile soil becomes lifeless.

A sufficient quantity of biohumus must be maintained in the Ark, with a minimum of 10 t/person as a baseline. Similar to Earth's biosphere, the amount of humus can increase over time as some inorganic matter in the Ark transitions into organic matter. Beyond ensuring soil fertility, biohumus will also provide additional protection against cosmic radiation and meteorite impacts by covering the Ark's inner surfaces.

Materials and technological (nonliving) substances will primarily exist in the form of water, which will serve as the working mass for generating a braking impulse when approaching an exoplanet. For example, one design variant suggests that the working mass should be total 340,000 tons, with the Ark's initial curb weight being 540,000 tons. After braking in the star system, the mass of the Ark would be reduced to 200,000 tons (Table 1).

Additional reserves of carbon – the primary chemical element in the cells of living organisms – as well as macro-, micro- and ultramicroelements, will be concentrated in thousands of tons of coal. This material contains a balanced mineral composition derived from ancient terrestrial organisms (over 80 chemical elements) that lived hundreds of millions of years ago, along with energy from the ancient Sun, which can be harnessed for onboard energy generation.

Upon arrival at the exoplanet, the Ark's energy and mineral resource needs should be met by harnessing energy from the local star and extracting resources from nearby asteroids and small celestial bodies. Establishing a space mining industry from scratch will be less energy-intensive and more efficient than any planetary mining operation. Given that the gravity well of an Earth-like planet exceeds 6,000 km in depth, extracting resources from such depths and transporting them to the surface (in this case near space) is impractical. Instead, open-pit mining on the surface of local asteroids will be a more feasible approach for the panspermic space industry.

For the space panspermia mission, the primary energy resources will come from nuclear and thermonuclear materials found in our Universe, rather than relying solely on stellar (solar) energy, as many researchers suggest. This perspective is further supported in the section on Energy Security.

Social Security. What should the human society in the Ark look like? Clearly, none of the existing social structures – be it primitive communal, slaveholding, feudal, capitalist, socialist or communist – are suitable for interstellar travel, especially within a confined space with limited resources. This system resembles a social Petri dish.

All known social forms have been centered around various types of consumption. Particularly detrimental to sustainable development is the capitalist model prevalent in today's global civilization. In its relentless pursuit of profit and consumer maximization, capitalism can lead to extremes that undermine foundational societal values, such as family and individuality. The achievement of 8 bln people on Earth should be viewed as a civilizational milestone, not as a tragic error, as suggested by capitalist ultra-globalists who promote the idea of a "golden billion." This warped view of human physiology has given rise to issues such as LGBT, gender reassignment and even cannibalism, rendering such a society unsustainable and, ultimately, doomed in the historical sense.

The space Ark not only needs the genetic diversity of millions of living organisms but also requires a variety of specialists within *Homo sapiens*, those who can efficiently operate and maintain such a complex expedition.

The ECH-Ark serves as a miniature representation of Earth's biosphere, designed to function autonomously for thousands of years while incorporating all the achievements of civilization: energy systems, engines, fuel reserves, engineering communications, repair facilities, housing, agricultural practices, educational institutions and medical services. To ensure its successful operation, the Ark will need highly skilled specialists in at least 100 different fields, not just during launch but throughout the long journey ahead.

A stable society, similar to small tribal nations or ethnic groups that have preserved their customs and cultures over millennia, typically consists of at least 1,000 to 2,000 people. In the Ark, however, modern civilization's full spectrum

should be represented, encompassing science (research labs and design offices), education (from early childhood to higher education), arts, sports, medicine and various forms of production. The society within the Ark should be sustainable and capable of self-improvement, while remaining secular and thoughtfully engineered. An effective organizational model might draw inspiration from Russian communities or Jewish kibbutzim.

This society should have its own charter (constitution and legal framework), which must be adhered to meticulously throughout the thousands of years of travel. Every aspect – physical, social, spiritual and moral – should be optimized with precision. For instance, with an average life expectancy of 100 years and a population of 1,000, around 100,000 individuals will pass away over a span of 10,000 years. To prevent the Ark from becoming a cemetery, there must be established customs, rituals and laws governing funerary practices. Additionally, the longevity and health of each individual are paramount; thus, preference should be given to crew members who are genetically, spiritually and morally predisposed to live long.

Society functions as a unique social organism that requires optimization through social engineering. Rather than simply transferring existing structures from Earth, it should be constructed from the ground up within the Ark, taking the best possible form. Historically, socioeconomic systems on Earth have often been shaped not by rational engineers, but by shamans, priests, politicians, military leaders, officials and businesspeople. Their focus has typically been on consolidating their own power and wealth, rather than genuinely developing society.

Earthly social engineering – such as communication methods (information engineering), the Ten Commandments (social engineering) and the twelve tenets of the Moral Code of the Builder of Communism (ideological engineering) – has largely prioritized the preservation of society rather than its advancement. Even the communist moral code, rooted in religious teachings, contributes to the creation of another self-serving "hive" or "anthill," rather than fostering the growth of socially aware and intelligent inhabitants of the space home named Planet Earth [23, 24].

In the Ark, there is an opportunity to reconnect with our civilizational roots. For instance, the need for modern clothing and footwear may diminish; these items would decay and need replacement multiple times over the thousands of years of space travel. Instead, weaving looms, sewing factories and cobbler workshops may seem unnecessary. In the subtropical environment of the Ark, where optimal climatic conditions are established and safe paths are maintained, it would be feasible to walk barefoot or wear simple garments like hipbands or capes.

It is essential to maintain a balance within the Ark; the development of this closed society should not be counterproductive to its well-being (e.g., preventing crime, terrorism and drug addiction). Concepts of "good" and "bad" for the society have long been articulated in religious commandments – potentially influenced by extraterrestrial civilizations that have visited Earth. The Ten Commandments of Christianity [25], for example, can be distilled into core principles: organizing one's life through faith and participation in community, including family, work, interests and relationships, all guided by these moral commandments. This framework encourages individuals to combat sinful habits and uphold traditional family values [26].

Information Security. After the launch of the first Ark, a second Ark will be dispatched from Earth after a designated period (e.g., one year), with the goal of arriving at its destination simultaneously with the first Ark. This second vessel will travel at a slightly higher speed and will incorporate lessons learned from the operational experience of Ark-1, as revealed through radio communications. Additionally, it will include vital updates and improvements derived from advancements made by humanity over the past year. Eventually, this will lead to a fleet of hundreds, if not thousands, of Arks journeying to the exoplanet. This network of Arks will significantly enhance success of the mission during the extended journey. Continuous radio communication will facilitate the sharing of up-to-date information and mutual support. In case of emergencies, a shuttle equipped on each Ark can be dispatched from the nearest vessel – whether ahead or behind – to physically assist any spacecraft in distress. Such shuttles will also be necessary for landing on the exoplanet.

As a result, all the Arks with their population of more than millions of people will simultaneously get the destination point, while bearing the whole civilization power, which is essential for colonizing the exoplanet. Throughout the journey, the Arks will remain within radio range of each other and their home planet, ensuring they are informed about the technological, moral and spiritual developments of Earth. This caravan of Arks will have access to all pertinent information, thanks to ongoing communication with one another and the civilization on Earth.

Artificial intelligence (AI) will play a crucial role in the space panspermia mission, serving as a tool rather than a controlling force. AI will function as a machine for processing and generating information, akin to the role of the subconscious mind in the human body. Just as our subconscious manages the vast array of systems, organs, tissues and cells – approximately 50 tln in total – our conscious mind cannot handle such a volume of data. Similarly, while the subconscious is governed by consciousness, the AI in the Ark should be directed by the collective intelligence of the crew, representing the diverse personalities aboard the interstellar ship.

Afterword (Philosophical Reflections of an Engineer)

One might argue that some of the author's predictions and engineering calculations are straightforward, grounded in contemporary knowledge. It is reasonable to anticipate that, whether in the near or distant future, we will discover unknown types of energy, advanced means of communication, teleportation of material objects, methods for reversible preservation of humans over extended periods, safe cloning techniques and robots capable of self-replication. The critical moments of change – bifurcation points – are essential in shaping our future. These points and significant breakthroughs in our known trajectory of civilizational development are linked to groundbreaking inventions: the lever, wheel, gunpowder, compass, steam engine, telescope, microscope, electricity, radio, television, automobile, airplane, rocket, antibiotics, vaccines, plastics, computers, robots, mobile communication, the internet, AI, etc.

While this perspective holds true, there is an important nuance to consider. All past and potential future inventions and discoveries do not contradict our current understanding; they emerged because they adhered to fundamental laws governing space, time, matter, gravitation, energy, momentum and other universal properties. These laws are immutable in our Universe. Even the most imaginative futurists and visionaries would not expect them to change over millions or billions of years. A violation of these laws would fundamentally alter our Universe, leading to the disappearance of human civilization along with the very fabric of Matter, Space and Time. The delicate balance of the World would be disrupted, as we exist according to the laws of our reality, not some hypothetical digital Universe where the impossible becomes possible.

Our home, planet Earth, is akin to a vast ark navigating around the center of the galaxy that humanity will inevitably seek to explore. This ark was created by the Creator itself and travels along the galactic orbit at a speed of 230 km/s, adhering to known physical laws rather than relying on wormholes, Morris–Thorne portals, black hole gateways or other speculative shortcuts through space and time. For billions of years, the properties of the Universe – what we call laws – have remained unchanged. No advanced extraterrestrial civilizations (if they exist) or even the Creator have altered or nullified them. So, why should we expect future scientists on Earth to succeed where others have not? Such beliefs may reflect a certain naivety and immaturity within our civilization, still quite young by universal standards.

The author of this study is an engineer who builds upon the engineering knowledge of billions of predecessors who developed the inventions and discoveries mentioned earlier – not a fanciful philosopher envisioning travel to the Moon via cannonball, geese, balloons or sheer thought. Such fantasies bear little practical resemblance to concepts like teleportation, as they contradict our fundamental understanding of physics, a truth that holds even for the distant future.

No unknown forms of energy or properties of matter, time and space will nullify established principles like the law of conservation of momentum. This law dictates that to accelerate any mass in space, a portion of that mass must be expelled in the opposite direction with a certain velocity, requiring a corresponding expenditure of energy. Consequently, the law of conservation of energy is also upheld, leading to another vital principle: internal forces within a system cannot alter its center of mass in space. Thus, the center of mass of any loaded rocket, even one propelled by photons, remains stationary during flight; it does not move off the launch pad because while one part of the rocket (the fuel as combustion products) travels in one direction, the other part (the body) goes in the opposite direction. A similar phenomenon can be observed in everyday life: when a person in a boat moves in one direction, the boat drifts in the opposite direction, keeping the center of mass of the person–boat system in place.

Based on these principles, we can assert that teleportation of material objects in our Universe is impossible. More precisely, it could occur in a modified form: an astronaut could journey in one direction (like "from a cannon to the Moon"), while a clone travels in the opposite direction. In this scenario, their common center of mass, much like that of an interstellar rocket, would remain stationary. However, the question remains: who or what will slow them down upon arrival at their destination? As Elon Musk has noted, "I want to fly to Mars, but I dream of not crashing on its surface during landing." To avoid such a crash, they would

need to carry all necessary supplies with them, including fuel and other working materials, or somehow neutralize each other's momentum through teleportation.

These sobering conclusions are no more author's bold assertions than the Copernicus's negation of the philosophical (but not engineering) idea, universally recognized for thousands of years, concerning a geocentric Universe with stars affixed to a crystal dome in favor of a heliocentric model.

Unintelligent life forms cannot explore neighboring star systems, let alone the galaxy. Similarly, a primitive AI – essentially a high-speed calculator created by an engineer on Earth – lacks the intelligence necessary for such endeavors. For a successful thousand-year journey aimed at civilizational panspermia, AI must carry not only its human creators but also a miniature version of Earth's entire industry (a mini-technosphere), which is a product of human ingenuity, not of the AI itself.

No advanced communication methods, including hypothetical superluminal technologies, can replace the biological carriers of life and civilizational intelligence: flora and fauna, including humanity. True space civilization panspermia can only occur by transporting a portion of the Earth's biosphere to other worlds, rather than utilizing primitive substitutes – such as humans who have been preserved for long stretches of time outside their natural environment. Would flora and fauna also need similar preservation, and what happens if this "canned" life spoils over millennia?

Cloning technology is not a viable solution either. The richness of Earth's Live Nature stems from the diversity of organisms; the biosphere continuously generates new life forms, reflecting evolution rather than merely duplicating existing ones, which would lead to stagnation. Likewise, creating replicating robots will not address the challenges of civilizational panspermia, as this study focuses on the panspermia of human civilization, not on advanced robots, even those labeled as "bio."

Thus, the proposed technology for civilizational panspermia of Earth's engineering civilization is the only rational engineering approach. While the size and shape of the Ark can be adjusted and new types of energy and communication can be employed, the fundamental requirement remains: the Ark must function as a mini-biosphere, led by a human-centered engineering society, capable of self-sustained existence for thousands of years. This mission must carry all necessary resources for its success, including for the eventual exploration of the exoplanet, which will likely also take thousands of years.

What is extraordinary about this approach, compared to concepts like teleportation or wormholes? We are born, live and die within the biosphere of a space ark known as Planet Earth, which travels aimlessly at a speed of 230 km/s around a massive black hole at the center of our galaxy. A journey at the same speed, but with the clear purpose of civilizational panspermia, on a well-equipped mini-planet being safer and more comfortable than the small, fragile ships of Columbus, who sail into the unknown without a clear mission, will represent a worthy endeavor for countless enthusiasts in our multibillion human engineering civilization (with an approximate selection ratio for this mission of 1 in 1,000,000).

Conclusion

Civilizations that advance their engineering technologies – essentially their industries – beyond their home planets in near space and utilize the resources of their star systems, such as deep vacuum, no gravity, etc., are classified as *Ingenium Civilizations*. This term derives from the Latin word *ingenium*, meaning ability, ingenuity or genius, created by the engineering mindset that drives such societies.

These civilizations can be categorized into six distinct levels of development.

Level I: exploration of the home planet. Earth's civilization took approximately 2 mln years to reach this stage, beginning with the use of an open flame. This foundational engineering technology paved the way for all subsequent thermal engineering advancements, including furnaces, boilers, steam engines, internal combustion engines, turbines, jet engines, thermal power plants (in particular potential future atomic and thermonuclear plants), etc.

Level II: exploration of the parent stellar system. From the second half of the 21st century, the Earth's human civilization will require several thousand years to achieve this level.

Level III: exploration of neighboring stellar systems. This phase will take millions of years and is expected to begin with the launch of the first interstellar "Noah's" Ark from the Solar System at the start of the 22nd century.

Level IV: exploration of the mother galaxy. This ambitious endeavor will necessitate several hundred million years.

Level V: exploration of the mother galaxy cluster. Achieving this level will require billions of years.

Level VI: exploration of the Universe. However, this level is unattainable for engineering civilizations, as it would involve altering the fundamental physical laws – an action that could lead to the destruction of both the civilization and the Universe itself due to the disruption of its fine-tuning, including the annihilation of elementary particles and substances made from them. There is no necessity for such an extreme scenario; even if it were to have occurred in the infinite Multiverse trillions of years ago, that space has likely long been occupied by a Level VI civilization. It would have conceived the concepts of singularity and the Big Bang as well as realized the fine-tuning of the Universe. Consequently, everything that has emerged within our Universe, including Earth's life and engineering civilization, was already predetermined. Thus, our engineering civilization will not enter the ranks of Universe creators within the Multiverse – "When in Rome, do as Romans do."

When thermonuclear fusion is harnessed and plasma engines, akin to solar wind but utilizing ionized hydrogen-oxygen particles derived from water and exhausting with a speed up to 1,200 km/s, are developed, the travel time to the nearest star could be reduced to about 1,000 years. This advancement would elevate our civilization to Level II, and subsequently onward to Levels III, IV and V. However, even with such speeds, reaching star systems located 100 light-years away would still require a minimum of 10,000 years.

Several billion years ago, countless atoms – comprising dozens of chemical elements and trillions of bonds – assembled into complex spatial structures, ultimately forming DNA molecules that organized into cells. This is how life began. Tens of billions of neurons interconnected to create the brain, establishing trillions of connections, which gave rise to the mind and intelligence. Over time, billions of individuals united to form a global society, characterized by trillions upon trillions of connections among its members – this is the foundation of engineering civilization. There is no need to artificially diminish the planet's population, as doing so would be similar to justifying a reduction in the number of nerve cells in the human brain – such as lowering them to the level found in a hamster's brain, which is approximately a thousand times fewer.

Thus, civilizational panspermia represents the trajectory of development for extraterrestrial engineering civilizations. Once the Engineering Mind emerges on a planet, it is compelled to spread itself across all accessible lifeless regions of the Universe, infusing them with life. There will be ample space and resources to accommodate an immense number of intelligent beings – trillions upon trillions – yet not machines, including AI. This notion may reflect the philosophy of a Level VI civilization: having created the Universe with its space-time continuum and fine-tuning – specifically, the precise values of fundamental constants – it successfully navigated the singularity and the Big Bang without perishing.

Our fine-tuned Universe can be seen as a manifestation of a Level VI civilization. It resembles an invisible fungus that infiltrates everything, producing visible fruit – life – only on planets with the right natural and climatic conditions. For ordinary fungi, this includes the presence of plants that form symbiotic relationships, as well as suitable soil and humidity. Therefore, the emergence of life and, subsequently, consciousness in our Universe was predetermined, with Earth fortunate enough to be one of the planets where the necessary conditions for life were established.

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Ensuring Public Security During Construction and Operation of General Planetary Vehicle

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This article addresses the critical issues related to public security during both the construction and operation of the General Planetary Vehicle (GPV). Key areas include maintaining public order, preventing warfare and acts of terrorism, ensuring safety during emergencies and providing primary medical care as well as sanitary and epidemiological safety.

The study outlines various strategies for organizing these activities along the GPV overpass. It identifies the main tasks for bodies responsible for public security and order across a transport and infrastructure facility spanning over 40,000 km, estimates the number of personnel required, proposes an appropriate organizational structure, hierarchy and legal framework. Given the increasing number of member countries and the expanding global influence of BRICS, the article concludes that forming an international force for the GPV public security would be a reasonable solution. This international force would be built on the cooperation of the BRICS members. The paper presents its structure and objectives as well as staffing and financing mechanisms.

The significance of this study lies in its examination of factors that could critically impact the feasibility of constructing the GPV, even after an initial decision to build one. Effective management of public security risks, preparedness for various threats as well as rapid response to incidents, emergencies and their consequences are essential components of the GPV construction and operation management that contribute to the overall success of the EcoSpace program.

Keywords:
General Planetary Vehicle (GPV), public order, public security, right-of-way.

Introduction

The construction and operation of the geocosmic transport and infrastructure complex, spanning over 40,000 km and crossing the territory of 11 countries, with its main structural element being a self-supporting flying vehicle weighing tens of millions of tons – the General Planetary Vehicle (GPV) – will undoubtedly be the most ambitious and complex project in the documented history [1].

Never before have representatives of different nationalities, as well as many nations, united to realize such an ambitious project (valued at around 3 tln USD) for the benefit of all humanity. Even in ancient times, people understood that achieving success in great undertakings required not only technical knowledge, materials and tools but also the unification of nations with a firm understanding of common goals, methods and rules. The well-known Old Testament legend of the Tower of Babel tells that an angry God caused people to speak in different languages, and it seems that the resulting conflicts, arguments and misunderstandings halted construction [2]. Thus, it can be assumed that the erection of the Tower of Babel was the first mentioned project that did not succeed due to issues related to organizational and social-behavioral factors.

Throughout history, in any major undertaking, ensuring public order and security has played a crucial role and dramatically influenced the completion time, cost and final outcomes of projects. For example, the construction of the Panama Canal in the 1880s was halted, and the entire project came close to collapse due to the proximity of malaria-infested swamps, unsanitary conditions for workers and the lack of timely medical assistance. All of this led to thousands of casualties. Approximately 25,000 people died from diseases, accidents and disorders [3].

In recent history, even in such a highly organized and centralized state as the Soviet Union, the neglect of public order and security often led not only to delays or the complete halting of projects but also to the loss of lives. The 1928 unrest during the construction of the Turkestan–Siberia Railway or the 1992 mutiny of military builders at Baikonur are little-known events, yet they underscore the importance of planning both engineering and construction work and measures for ensuring public order and security [4].

As previously noted, the construction and operation of the general planetary geocosmic complex have no historical precedents, either from a technical or societal perspective. A defining feature of this project is that the GPV overpass will pass through regions with diverse geographic, climatic, ethnographic and demographic conditions as well as different environments, spanning water bodies (lakes, seas and oceans) and land, including mountainous terrain.

The proposed GPV route crosses areas with difficult mountain landscapes, urban developments, industrial sites as well as maritime and land-based transportation networks. All of this will undoubtedly require the development of tailored approaches to public security, given that this grand civilizational project offers humanity a real opportunity to begin space exploration.

At the same time, even by the most conservative estimates, hundreds of thousands of engineers and workers from different countries, with distinct cultural, religious and everyday practices, will be involved in the construction and operation of the GPV. They will be living and working not only in remote but often hard-to-reach areas. This vast workforce must be reliably protected against threats to public security, especially considering that some sections of the GPV will be located in regions with a high likelihood of natural anomalies and disasters (the Sunda Islands and eastern regions of the South American continent), political instability (southern Somalia, northeastern Democratic Republic of the Congo (DRC) and mountainous areas on the Colombia–Ecuador border) as well as complex sanitary and epidemiological conditions (the Amazon rainforest).

This article cannot comprehensively address all aspects and solutions related to public security. The organizational structure, operational activities of specialized agencies, their deployment, logistics and management are deeply interconnected with political, financial and other factors – subjects that could form the basis of multiple research studies. However, since the project's key technological parameters have already been defined, and the location and dimensions of the GPV right-of-way will remain largely unchanged, it is possible to anticipate the most significant threats and risks likely to emerge during construction and operation. Accordingly, this paper proposes fundamental solutions for ensuring public security in this project.

Concept of Public Security in GPV Deployment Zone

The definition of public security may vary across different sources depending on the country, author or areas of activity to which it is applied. However, there are no significant discrepancies in its interpretation. Both in Russia

and in the West, the concept is understood similarly and essentially carries the same meaning in almost all sources.

In the Russian Federation's Public Safety Concept, approved by the President in 2013, public security is defined as the state of protection of individuals and citizens, the material and spiritual values of society against criminal and other unlawful encroachments, social and interethnic conflicts as well as emergencies of natural and man-made origin [5].

The Western model of public security typically provides a broader definition: "the function of governments which ensures the protection of citizens, persons in their territory, organizations and institutions against threats to their well-being – and to the prosperity of their communities" [6].

Regarding the GPV, it is necessary to adopt a definition that not only aligns with generally accepted approaches but also considers the specifics of the project. It should be kept in mind that this discussion pertains specifically to public security. This is due to the fact that the construction of the GPV effectively creates a community of people comprising various social groups, such as builders and operators, their families and residents of settlements located along the GPV deployment zone, who are situated in an isolated area and united by the goal of advancing the project to transfer the harmful part of Earth's industry into space for the benefit of all humanity.

For this reason, the article proposes defining the terms "public security" and "ensuring public security" in the context of the GPV project as follows. Public security is the state of comprehensive protection of all individuals within the GPV deployment zone against events of any nature that may harm health, safety and material assets as well as hinder the GPV leadership and personnel from fully carrying out their duties. Accordingly, ensuring public security for the GPV project can be understood as a set of measures aimed at responding to and preventing various risks, threats and events in the military, political, social, natural and technological domains to create conditions for the stable operation of the geocosmic transport and infrastructure complex.

Maintaining public order within the territory and waters along the GPV route is a key element in ensuring public security, the normal functioning of people's daily lives and the operation of equipment. It is important to understand that public order in the GPV zone is a framework regulating the behavior of different individuals and the activities of entities associated with the project, in accordance with a system of laws, rules and requirements established in the interests of ensuring public security in this zone.

Division of GPV Right-of-Way into Zones for Ensuring Public Security

To ensure public security along the entire length of the land and maritime sections of the GPV overpass, a dedicated right-of-way must be established. This area, located along the equator, will be designated exclusively for the construction and operation of the geocosmic complex, accommodating personnel, infrastructure and equipment directly related to its construction and operation.

To organize the unobstructed maintenance of the GPV, prevent unauthorized access to the transport and infrastructure complex, safeguard personnel, equipment and assets from vandalism and terrorism, the right-of-way must be divided into a restricted zone and a limited-access zone along its width.

The restricted zone, which is strictly controlled, will house the GPV takeoff and landing overpass along with other essential structures, facilities, equipment and machinery required for the geocosmic complex. This zone must be wide enough to prevent unauthorized approach to the overpass and its critical elements, with strictly controlled access, security barriers and technical surveillance systems in place to mitigate potential threats.

The limited-access zone, which is controlled, will surround the restricted zone and include residential clusters for personnel as well as scientific, industrial and agricultural enterprises (newly established or incorporated into the right-of-way) whose activities directly or indirectly support the GPV operations. These residential, industrial and agricultural areas within the limited-access zone will be interconnected through transport lines and unified into the Equatorial Linear City (ELC) [7], developed as part of the terrestrial infrastructure of the entire GPV geocosmic complex.

The total width of the right-of-way, including the restricted zone, may range from 6 to 10 km (3 to 5 km on either side of the GPV), depending on local terrain conditions and the military-political situation in the region. This will ensure the secure accommodation of workers and their families, the life-support and supply systems of the ELC as well as prevent unauthorized persons from approaching the GPV transport overpass within the range of small arms fire. The boundaries of the right-of-way must be equipped with barriers, security alarm systems and other protective measures (Figure 1).

Access to the GPV right-of-way must be restricted and controlled. Entry into the restricted zone will be permitted only for specialized personnel directly involved in the operation, maintenance and repair of the GPV.

The waters within the right-of-way must also be monitored by public security forces, which, considering the neutral status of these waters, will be responsible for ensuring the safety of personnel and equipment of the geocosmic complex while also maintaining maritime navigation across the equator in accordance with international maritime law.

To ensure the full functionality of the GPV, including the management of public security oversight bodies, the entire corridor of the complex should be divided into continental and oceanic zones which in turn should be subdivided into operational regions and sectors. For the complex as a whole, as well as for each zone, region and sector, it is necessary to define boundaries (areas of responsibility) and determine the locations of control centers.

A total of two continental zones are planned (tentatively named Africa and America) along with four oceanic zones (Atlantic, Oceania, Nusantara, an ancient name for Indonesia [8], and Mahasagar, ocean – महासागर in Hindi). Each zone will include between six and ten operational regions, while each region will be divided into three to five operational sectors. Each operational region and sector will have its own management (command) structure.

Figure 2 presents one possible way to divide the right-of-way into zones for overall management and public security.

Continental zone Africa is located along the equatorial line on the African continent, extending 3,730 km through the territories of Somalia, Kenya, DRC, the Republic of the Congo, Gabon.

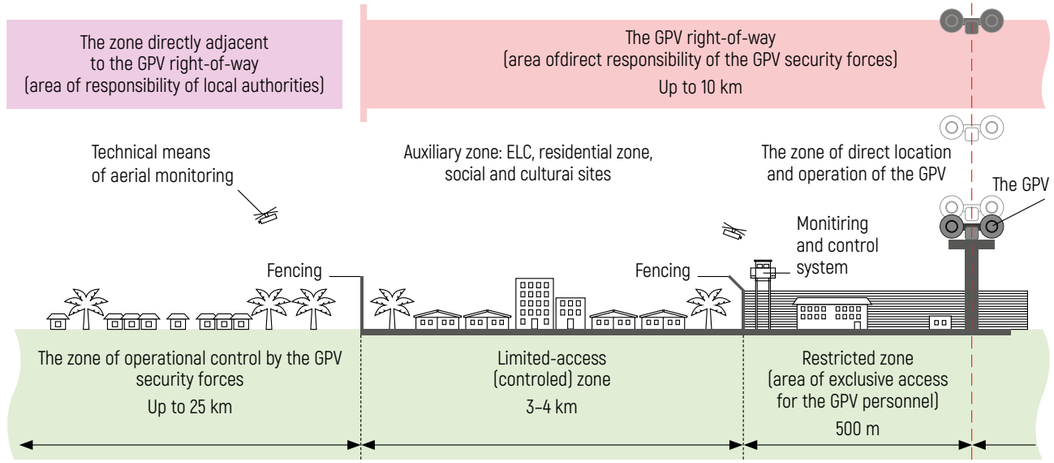

Figure 1 – Division of GPV right-of-way into zones for ensuring public security

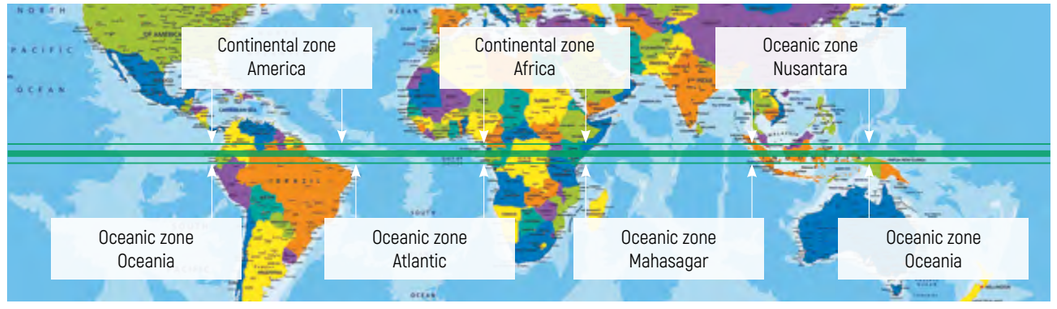

Figure 2 – Division of GPV right-of-way into continental and oceanic zones

Continental zone America is located along the equatorial line on the American continent, stretching 3,426 km across Brazil, Colombia and Ecuador.

Of the more than 40,000 km of the GPV line running along the equator, nearly 33,000 km (about 80 %) pass outside continental zones, either over water or through island archipelagos. The establishment and operation of the maritime component of public security forces in oceanic zones are crucial for successfully constructing and operating the GPV (Figure 3).

As noted above, it is advisable to divide the water area along the GPV route into four oceanic zones located along the equator in the Atlantic, Pacific and Indian Oceans as well as in the Sunda Archipelago (part of Indonesia).

Oceanic zone Nusantara crosses Sumatra and Kalimantan, the two largest islands of the Sunda Archipelago, with the GPV right-of-way extending 460 km and 925 km, respectively. It also traverses numerous medium and small islands within the archipelago, all of which belong to Indonesia. The remaining oceanic zones pass through ocean waters, intersecting small archipelagos and islands: São Tomé and Príncipe in the Atlantic Ocean, the Line Islands in the Pacific Ocean and the Maldives in the Indian Ocean.

In general, maritime public security operations have several common characteristics that must be considered when planning activities in the oceanic sections of the GPV route. First, most of these zones, apart from small areas, do not belong to any single country and are governed by the UN Convention on the Law of the Sea. Second, it is nearly impossible to install physical barriers to prevent unauthorized access by ships and boats to the GPV overpass. Third, compared to land sections, the response time for deploying public security forces and resources will be longer due to increased travel distances.

Composition and Size of GPV Public Security Forces

Given the project's scale and specific requirements, as well as the importance of a unified approach to the GPV construction and operation tasks, the land (for terrestrial sections) and water areas (for oceanic sections) of right-of-way must be under the exclusive management of the GPV central leadership. Accordingly, public security within the right-of-way will be ensured by the GPV public security forces, operating under unified rules and plans and reporting directly to the leadership of the geocosmic complex. This approach will enable effective threat mitigation and rapid response to events that pose risks to people, equipment and infrastructure within the right-of-way.

To determine the number of personnel required for public security in these areas, average regulatory standards for border and perimeter protection, as adopted by various countries and organizations, can be applied.

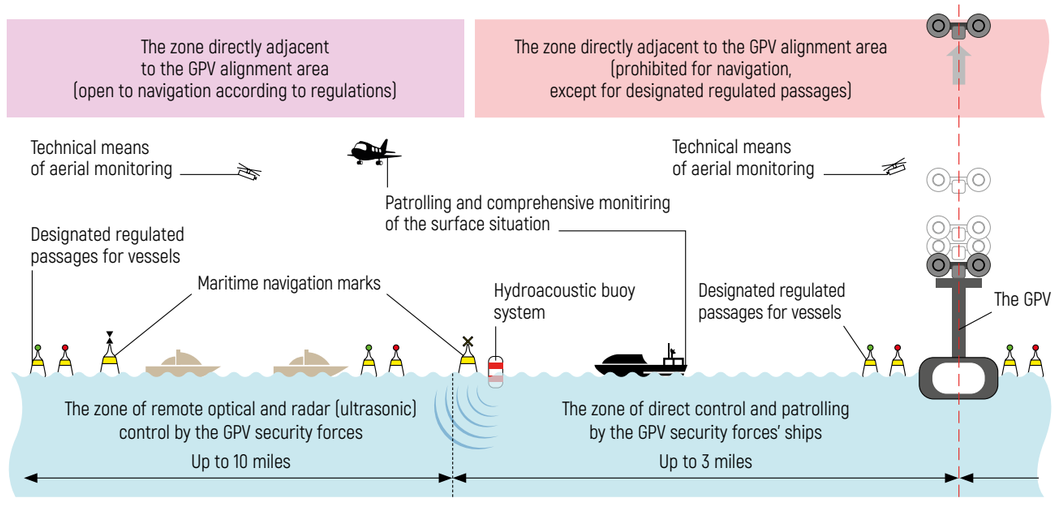

Figure 3 – Division of water sections of the GPV location into zones for ensuring public security

The total length of the GPV right-of-way land borders (southern and northern boundary lines), including Indonesia's islands, is approximately 16,000 km (given that 8,000 km of the right-of-way passes over land). Based on the security density along the Mexico–United States border – 6.3 personnel/km [9], with the use of advanced surveillance technologies and drones – more than 100,000 personnel would be required to secure the land perimeter alone.

When estimating the total number of people present within the GPV right-of-way, it is necessary to consider employees of the geocosmic complex (approximately 200,000 people [10]), their family members (ranging from 200,000 to 400,000 people) and the population permanently residing in this area. According to available data (Table), more than 4 mln people currently live within the future GPV right-of-way, excluding oceanic zones Atlantic, Oceania and Mahasagar, where the resident population is minimal.

Thus, the total number of people who will be permanently located within the GPV right-of-way will be about 5 mln. Based on the number of law enforcement personnel in countries like Russia and China (more than 400 per 100,000 inhabitants [12]), at least 10,000 employees will be needed solely for maintaining public order in the right-of-way (excluding oceanic zones Atlantic, Oceania and Mahasagar).

Considering that the GPV public security forces should also include maritime forces, firefighting and disaster response teams, sanitary and epidemiological control and response units as well as personnel from management, supply and logistics structures, it can be estimated that around 150,000 people will be involved in ensuring the security of the land-based part of the GPV, with approximately 1,500 ships, boats and other watercraft (one vessel for every 20 km of water area) and around 400 aircraft and helicopters of various types (one aircraft, including drones, for every 100 km of overpass length).

Table – Approximate population within GPV right-of-way

Sector boundaries		Country	Population density, people/km² [11]	Average population density per 1 km²	Sector length along the equator, km	Population of the GPV right-of-way, people
West	East					
1	2	3	4	5	6	7
Continental zone America						
80°06′ W	79°38′ W	Ecuador	41–100	70	60	42,000
79°38′ W	78°36′ W	Ecuador	101–500	300	113	339,000
78°36′ W	78°11′ W	Ecuador	41–100	70	45	31,500
78°11′ W	77°47′ W	Ecuador	11–40	25	43	10,750
77°47′ W	75°34′ W	Ecuador	2–10	6	250	15,000
75°34′ W	71°34′ W	Columbia	2–10	6	450	27,000
71°34′ W	70°01′ W	Columbia	≤2	1	170	1,700
70°01′ W	58°53′ W	Brazil	≤2	1	1,250	12,500
58°53′ W	52°59′ W	Brazil	2–10	6	650	39,000
52°59′ W	51°30′ W	Brazil	≤2	1	165	1,650
51°30′ W	50°42′ W	Brazil	11–40	25	80	20,000
50°42′ W	49°22′ W	Brazil	≤2	1	150	1,500
Total					3,426	541,600
Continental zone Africa						
00°00′ E	00°00′ E	Gabon	≤2	1	15	150
00°00′ E	13°56′ E	Gabon	2–10	6	500	30,000
13°56′ E	25°34′ E	DRC	2–10	6	1,275	76,500
25°34′ E	27°01′ E	DRC	11–40	25	160	40,000

End of Table

1	2	3	4	5	6	7
27°01′ E	29°46′ E	DRC	41–100	70	300	210,000
29°46′ E	33°58′ E	Uganda	101–500	300	460	1,380,000
33°58′ E	34°52′ E	Kenya	101–500	300	100	300,000
34°52′ E	35°30′ E	Kenya	≥500	500	100	500,000
35°30′ E	35°55′ E	Kenya	101–500	300	50	150,000
35°55′ E	39°05′ E	Kenya	41–100	70	350	245,000
39°05′ E	40°57′ E	Kenya	11–40	25	200	50,000
40°57′ E	41°29′ E	Somali	2–10	6	60	3,600
41°29′ E	42°56′ E	Somali	11–40	25	160	40,000
Total					3,730	3,025,250
Oceanic zone Nusantara (Indonesia)						
99°35′ E	101°56′ E	Sumatra	101–500	300	155	465,000
101°56′ E	103°47′ E	Sumatra	11–40	25	200	50,000
109°05′ E	109°30′ E	Kalimantan	41–100	70	55	38,500
109°30′ E	112°42′ E	Kalimantan	11–40	25	350	87,500
112°42′ E	117°33′ E	Kalimantan	2–10	6	550	33,000
119°37′ E	120°06′ E	Sulawesi	41–100	70	60	42,000
Total					1,370	716,000
Grand total					8,526	4,282,850

This implies that the GPV public security forces, in terms of size and technical capabilities, will be equivalent to the average size of a fully-equipped armed force of a nation on Earth [13]. Therefore, to ensure their effective use, an optimal organizational structure and management, financing and support systems tailored to the tasks at hand, the objectives set and the specific conditions they will operate in must be established.

Based on the factors, tasks and personnel numbers outlined above, the security forces of the geocosmic complex should include not only central and territorial command structures and support groups for logistics, communications and rear services but also command units and groups for military police and dispatch services, public order maintenance, emergency response, firefighting as well as sanitary and epidemiological control. To address the needs of the maritime service in the oceanic zones, considering its specificity, it is also necessary to create a maritime command responsible for navigation support, vessel management and maritime basing.

Main Tasks of GPV Public Security Forces

The range of tasks assigned to the bodies (units, departments or companies) designated (contracted) to ensure public security, which can be outlined at the current stage of the development of the GPV creation and operation program, is shown in Figure 4 and includes:

• comprehensive monitoring of the ground and air situation (for oceanic zones, surface and underwater monitoring), coordination and dispatch service (for oceanic zones, navigation and dispatch service);

• control of access for people, vehicles and cargo to the GPV right-of-way and restricted zone, organization of transit through the right-of-way (commandant service);

• risk assessment and operational activities to prevent public security threats within the GPV right-of-way and on adjacent territories;

• repelling military and criminal attacks on facilities located within the GPV right-of-way;

• prevention and elimination of natural and technological emergencies within the GPV right-of-way, fire safety, firefighting, monitoring of safe operations and technical oversight;

• ensuring public order and enforcing behavior regulations within the GPV right-of-way, prevention and suppression of offenses, conducting monitoring;

• sanitary and epidemiological control within the GPV right-of-way and adjacent areas, carrying out relevant emergency measures in contamination hotspots.

All tasks facing the public security forces within the GPV right-of-way can be conditionally divided into routine activities and emergency response (Figure 5).

The specifics of the routine operations of the maritime component of the GPV public security forces include organizing the movement of vessels across the transport overpass line (navigation and dispatch service), monitoring underwater situations and meteorological observation.

A distinctive feature of the security forces' operations is that the GPV overpass comprises Unitsky String Transport (uST) transport and infrastructure complexes for both cargo and passengers, including rapid and high-speed versions. As a result, significant forces and resources can be quickly deployed to threatened areas on both land and oceanic sections of the GPV.

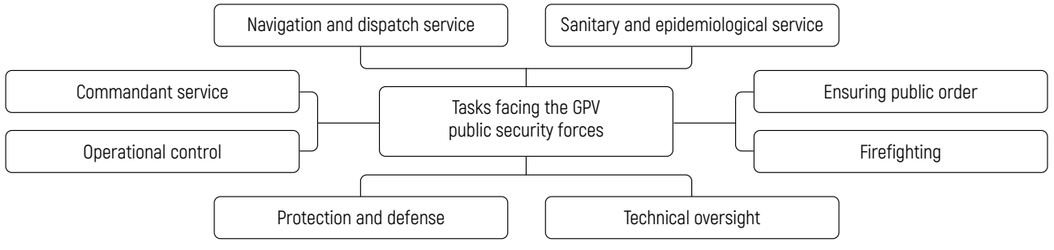

Figure 4 – Tasks of GPV public security forces

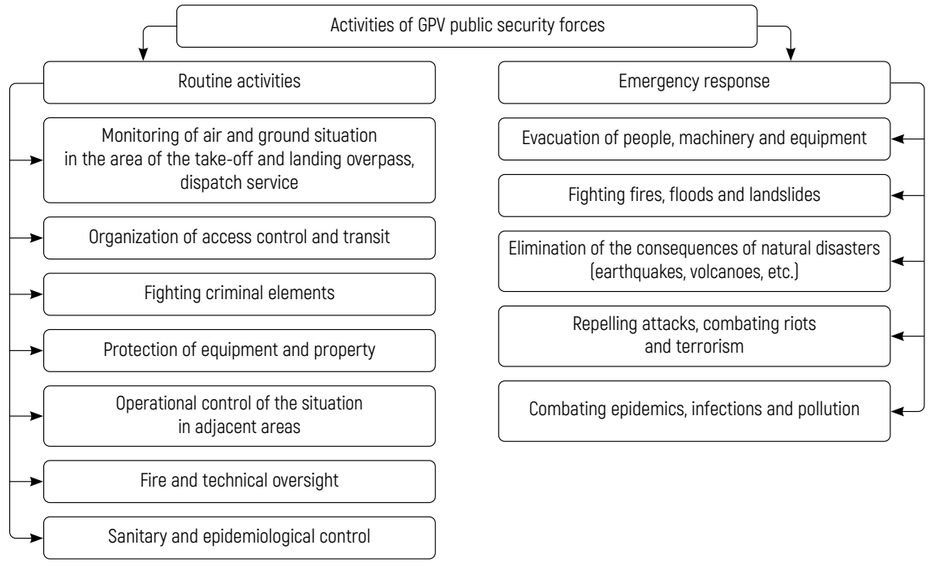

FIgure 5 – Division of tasks facing GPV public security forces by type of activity

For example, emergency transportation of large numbers of people and cargo from the eastern to the western coast of the African continent via the GPV overpass would take only 7–9 h. Therefore, technical and operational capabilities must be provided for the rapid transfer of people, equipment and resources using high-speed (up to 360 km/h) uST rolling stock operating within the GPV overpass – under the runway.

Options for Creation and Staffing of GPV Public Security Forces

Since the GPV public security forces carry out a complex and responsible mission, their management, staffing and comprehensive support must, on the one hand, be centralized and organized according to unified rules, while, on the other hand, it cannot be the prerogative of a single country, even one as influential and powerful as China, the United States or Russia. Therefore, existing political or military unions of several countries can serve as an effective tool for the creation and operation of the public security system for the project. For example, peacekeeping forces are formed as necessary under the United Nations. Decisions on their creation, composition, use and funding are made by the UN Security Council, with strategic leadership implemented by the Military Staff Committee [14]. Additionally, within the framework of peacekeeping and law enforcement activities in conflict zones, UN Police (UNPOL) operates, consisting of 9,000 police officers tasked with ensuring security and public order in countries with unstable situations and internal conflicts [15].

Thus, under the auspices of the United Nations, it is possible to form public security forces based on existing UN peacekeeping and police forces or by establishing a separate UN unit or committee. However, it should be noted that UN forces (both peacekeeping and police) have never been particularly effective in their operations. Without delving into the reasons for this, it is worth mentioning that the UN, as a political organization, has recently been losing the trust of its member states and its authority on the international stage [16]. It is widely acknowledged that despite having virtually unlimited resources, the UN has failed to achieve many of its declared programs and initiatives.

An alternative solution to the issue of ensuring public security for the GPV is delegating the corresponding powers to an existing or newly created private military-police company under the auspices of participating countries. Private military companies (PMC), which currently exist in many countries around the world, are commercial entities staffed with highly skilled specialists offering military-related services.

History knows many examples where private organizations successfully solved strategic tasks, ranging from the famous West and East India Companies (Netherlands, Great Britain), which maintained their own army and navy, to modern Academi and Blackwater (USA), Wagner (Russia) and G4S (UK). It should be noted that the British company G4S has about 800,000 employees [17], while the Russian Wagner group, consisted of more than 50,000 people in 2023, was capable of independently conducting operational-level combat actions, armed with artillery, tanks and aircraft. Nearly all large PMC have practical experience in guarding critical state and industrial facilities, ensuring personnel safety, fire protection, aerial surveillance and reconnaissance, protecting sea routes and vessels from pirates and other illegal activities – tasks that are very similar to those GPV public security forces will face.

At the same time, it is important to understand that the involvement of a private organization in carrying out one of the most important missions of a global civilizational project carries certain risks that must be considered when making such a decision. Firstly, there is still no internationally recognized definition of the legal status of PMC, and consequently, the regulation of their activities and responsibilities remains unclear [18]. Secondly, the cost of employing a PMC for large-scale tasks over vast territories may be very high compared to other solutions, potentially having a critical negative impact on the project funding. Lastly, there is always the risk that an isolated PMC, although formally subordinated to the main management of the geocosmic complex, may handle all staffing, organizational and financial matters internally and in its own interests, which could lead to problems if its commercial ambitions are placed above the priorities of the GPV project. Here are some examples that confirm this:

- the British East India Company, founded in the 17th century by the British government to ensure the state's trade expansion, by the 18th century was acting more for its own purposes, which led to government intervention in the company's affairs and ultimately its decline and closure [19];
- the mutiny of PMC Wagner, which effectively defied the state, nearly resulting in a catastrophe for Russian state power, only further proves the dangers of involving armed entrepreneurs to carry out important public and state tasks in the long term.

In the author's opinion, the most acceptable option for organizing the public security of the GPV is the creation of international forces based on an alliance of states that have a direct interest in the success of the project and the ability to implement it. Currently, the BRICS grouping is gaining increasing political influence, consisting of nine states (Brazil, Russia, India, China, South Africa, UAE, Iran, Egypt and Ethiopia). Furthermore, 20 countries have officially applied for membership in the organization, and another 40 have expressed interest in joining. BRICS is characterized by its member states' consolidation around the principles of noninterference, equality and mutual benefit [20]. Managing the GPV project as a whole, and specifically the formation of international public security forces for the GPV, could become a significant step toward increasing BRICS' international influence, enhancing its authority and fostering relationships among the peoples of our planet.

Conclusion

The global scale, vast area covered and the number of people involved in or affected by the GPV project in any way are unprecedented in world history. They require extraordinary actions as well as the joint efforts of all humanity, unprecedented cooperation among countries, peoples, communities and social strata.

The construction and routine operation of the GPV depend not only on resolving technical, commercial and operational issues but also on ensuring public security. This is due to the presence of threats and risks related to both natural and human factors along the entire length of the GPV overpass and at all stages of the geocosmic complex implementation, from design and construction to regular employment.

The analysis of the GPV location shows that the main risks to the public security of the facility are potential natural disasters (seismic and volcanic activity, floods, landslides, fires) as well as terrorist and other hostile activities, civil unrest and various crimes and offenses (including those of an environmental nature) within the boundaries of the GPV right-of-way and nearby. In addition, significant threats to public security could include mass diseases, epidemics and issues related to sanitary and hygienic conditions.

The key to success in emergency actions is the prompt use of the GPV transport overpass to relocate forces and resources to the threatened area and the accumulation of necessary personnel to counter the threat or mitigate its consequences as quickly as possible.

It is advisable to form and organize the GPV public security forces based on an international alliance of states, such as BRICS. The members of the organization have positive experience in international projects and are capable of allocating the necessary number of personnel, equipment and resources to maintain public security for the GPV.

Thus, with the proper approach to ensuring public security for the GPV and by implementing timely measures aimed at risk assessment and addressing public security threats, the project can be successfully implemented and achieve the objectives of global civilizational scale set by its organizers. At the same time, ignoring these issues will have a negative impact and affect both the construction timeline and the possibility of normal operation of the GPV.

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EcoSpace Program as Basis and Horizon for Transformation of Dominant Socioeconomic Model

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The article reveals the goal-setting of the EcoSpace program using the concept of noosphere. The approaches to defining the content of this term in the literature are considered. An assessment of the possibilities of transitioning to the state of the noosphere through the implementation of this global project, proposed by the Belarusian engineer, inventor and visionary A. Unitsky, is presented. The generalizations of the Russian scientist F. Yanshina regarding the conditions for the noosphere formation are analyzed in detail in terms of their compliance during the implementation of the large-scale program.

The importance of preventing inequality and wars in the context of realizing of the plans proclaimed by the Unitsky school is emphasized. The inability of the capitalist system to eliminate intracivilizational conflicts as a fundamental component of social life is demonstrated. The contours of the socioeconomic system built on the implementation of the EcoSpace program elements are outlined – a unique path distinct from both capitalist and communist approaches.

Keywords:
labor, linear cities, noosphere, property, society, state.

Introduction

The EcoSpace program, conceived by Belarusian engineer, inventor and visionary A. Unitsky, aims to fundamentally reshape our socioeconomic reality through the adoption and expansion of nature-oriented technological solutions. This project does not imply redistribution of the property, changes of the world map and so on. The issue is fully different in comparison with tradition European way. The changes are planned to begin not from the top, but from the basic layer – through the integration of innovative transport systems, new forms of human settlement, renewable energy and sustainable agriculture, collectively referred to as biosphere technologies [1].

Proponents of the Unitsky school assert that their proposed solutions could have a transformative impact on society, akin to how the invention of the plow shifted humanity from nomadic to settled lifestyles, or how mechanized production catalyzed the transition from feudalism to capitalism.

In the transport sector, the EcoSpace program focuses on developing elevated high-speed transport systems based on Unitsky String Technologies (uST). This initiative promises to reduce travel costs, enhance safety and achieve speeds of up to 360 km/h, all while expanding transport accessibility and preserving natural landscapes and biogeocenoses. By elevating the transport infrastructure above ground level, the project aims to return soil to its rightful owner – the planet's biosphere.

The program envisions the development of linear cities along high-speed routes, designed as cluster-type settlements stretching hundreds to thousands of kilometers. These pedestrian-friendly clusters, which serve various purposes – residential, industrial, educational, recreational – are seamlessly connected by transport and logistics networks. Each settlement is designed for maximum autonomy, allowing households to grow their own food and process waste on-site into nutrient-rich biohumus. Thermal power plants utilizing brown coal, oil shale, peat or other organic fuel will provide excess heat for residential heating, as well as carbon dioxide for greenhouse cultivation, while the by-products of coal combustion (ash, slag, sludge, etc.) will be repurposed to enrich the soil.

A hallmark of the EcoSpace program is its integrated approach, which is one of its primary strengths. Notably, all proposed solutions build on existing technologies, with the exception of the geocosmic aircraft – the General Planetary Vehicle (GPV) – which is yet to be realized.

The program positions the GPV as a crucial tool for large-scale expansion into space. Its development is expected to unite a significant portion of the global population, unlocking vast opportunities for industrial growth within our technocratic civilization. By relocating harmful industrial activities to orbit, the project aims to address ecological challenges and harness the raw materials, energy and technological resources available in near and distant space.

However, achieving these ambitious goals necessitates clear international objectives. This paper aims to analyze the potential of various aspects of the EcoSpace program, exploring how they could contribute to fostering socioeconomic cohesion in the context of global projects like the GPV.

Implementation of EcoSpace Program: Pathway from Anthroposphere and Technosphere to Noosphere

The EcoSpace program represents a transformative shift for civilization, moving it toward a qualitatively new state. This transition is fundamentally linked to making near space accessible on a large scale. Currently, overcoming gravity and achieving cosmic velocities demands immense resources and comes at a high cost – cargo delivery to orbit can exceed 10 mln USD/t. However, with the potential for large-scale, peaceful expansion beyond Earth, reducing geocosmic logistics costs to around 10,000 USD/t would enable humanity to view the entire planet – not just isolated communities on its surface – as a unified space for action. This shift would contribute to the emergence of a new planetary sphere, often referred to by researchers as the noosphere [2].

The noosphere is seen as the culmination of the development of the lithosphere, hydrosphere, atmosphere, biosphere, anthroposphere and technosphere. In this context, the creation of the GPV and the implementation of other components of the EcoSpace program are crucial for facilitating this transition, built upon a specific set of technological solutions envisioned by A. Unitsky. This perspective aligns with the principles of noosphere theory, which highlights the significance of innovative technologies in the context of planetary advancement.

The famous natural scientist V. Vernadsky asserted that two key conditions must be met for the anthroposphere to evolve into the noosphere: humanity's mastery over nature and the supremacy of rational thought over their lower instincts [3]. Scientific and technological progress serves as the primary means to achieve these objectives. Vernadsky remarked, that the evolution of scientific thought unfolds before us as a natural progression in the history of the biosphere.

This historical process, which reflects the broader narrative of human history, reveals itself primarily as a natural phenomenon of significant geological importance [4].

For the noosphere to take shape, the unification of humanity is essential. Vernadsky believed that by the mid-twentieth century, the groundwork for this unity had already been laid. He stated, that for the first time in history, we find ourselves in a unified historical process encompassing the entire biosphere of the planet [4]. He was also among the first to recognize that failing to transition to a new mode of existence could lead to humanity's downfall. Humans must realize they are inhabitants of the planet and must think and act in a planetary context, beyond individual, familial or national considerations [4].

The EcoSpace program offers a practical framework for realizing the ideals of planetary unity and responsible stewardship of Earth, setting the stage for the transitioning from the anthroposphere to the noosphere.

Twelve Conditions for Transitioning from Anthroposphere to Noosphere Within EcoSpace Program

The noosphere represents a thoughtfully organized and functioning living layer of our planet, and its establishment hinges on overcoming irrationality. Simplifying V. Vernadsky's statement, we can identify two fundamental aspects of this process: spatial and behavioral. First, intelligent life must evenly and effectively develop the entire Earth, ensuring transport accessibility even to the most remote areas. This will enable comprehensive monitoring and management of conditions across the globe. The more challenging task lies in structuring society to eliminate the root causes of irrational behavior among individuals and their local and global communities.

Such behaviors often stem from inequality in its various forms – be it physical, spiritual or cultural. The uneven distribution of limited resources, underdeveloped connections, lack of education and the disempowerment of certain individuals against a backdrop of privilege for others create societal tensions. Addressing these tensions often consumes immense resources that could otherwise be directed toward fostering a more rational and harmonious existence for humanity as a whole.

The awareness of inequalities, particularly when perceived as injustices, breeds frustration and can lead to destructive actions at all levels of society. This is why social transformation projects have historically aimed to combat inequality, often rallying around mottos like "Liberty, Equality, Fraternity." However, the inherent impossibility of absolute equality has led to the emergence of two primary models for a just society:

- limited equality: this model seeks to ensure equality in specific areas of social life, such as human rights or legal protections;
- intrasocietal equality: this approach implies equal rights and opportunities within particular groups that exist in hierarchical relations to others.

The challenges in implementing both models arise from their focus on behavioral aspects while neglecting the importance of correlation between people's freedoms and opportunities with their spatial distribution. Essentially, new social norms have been proposed within existing environments. For example, in postrevolutionary France, while rights were proclaimed equal, the stark differences in starting positions for children from various social classes were obvious. Similarly, despite societal divisions into castes or estates, individuals from different backgrounds often interacted, highlighting both their disparities and shared needs. This leads to a clear perception: some possess everything, while others have nothing.

Historically, conflicts stemming from inequality have been minimized when people lived in small isolated groups where wealth and opportunities were relatively equal. In such settings, it becomes feasible to reduce inequality, making this approach a viable strategy for addressing the root causes of irrational social behavior.

While people differ in height, strength, skin color, talents, interests and culture, complete equality is unattainable. However, it is possible to form groups of equals who can live and work together toward common goals without awareness of disparities – thus avoiding conflict, environmental degradation, revolutions and crimes against one another. Achieving this in today's hyperurbanized society poses challenges, but the EcoSpace program offers a revised approach to spatial organization that facilitates such a vision. Through the development of cluster-type linear cities, together with the common blessings of the civilization, the people will be provided with the following:

- even population distribution across the Earth's landmass;
- creation of comfortable living environments in small, self-sufficient communities (ranging from 1,000 to 5,000 residents) that address food, water, energy, transport and infrastructure needs;
- localization of farming practices within these communities, effectively eliminating social inequality and fostering a more equitable way of life for each resident of any community.

The EcoSpace program offers a comprehensive framework for addressing the causes of social irrationality through innovative engineering and technical solutions, facilitating the establishment of the noosphere as a rational living layer of our planet. According to Russian scientist F. Yanshina, there are 12 key conditions for the formation of the noosphere [5]:

1) human settlement of the entire planet;

2) sharp transformation in means of communication and exchange between different countries;

3) strengthened ties, including political connections, among the nations of Earth;

4) predominance of humanity's geological impact over other geological processes occurring in the biosphere;

5) expansion of the biosphere's boundaries and access to outer space;

6) discovery of new energy sources;

7) equality for people of all races and religions;

8) increasing role for the masses in shaping foreign and domestic policy;

9) freedom of scientific thought and inquiry from the pressures of religious, philosophical and political constructs, along with the establishment of conditions conducive to independent scientific exploration within social and governmental systems;

10) enhancement of the well-being of working people, creating genuine opportunities to prevent malnutrition, hunger, poverty and to alleviate the effects of disease;

11) rational transformation of the Earth's natural environment to fulfill the material, aesthetic and spiritual needs of a growing population;

12) elimination of war from societal life.

While some of these conditions have been partially met, the EcoSpace program provides the necessary tools for further progress toward achieving them. For the conditions that remain unfulfilled, the program offers a consistent and effective pathway to reach the desired outcomes. Let us explore each point in detail.

1. The goal of fully settling the planet is far from realized. Most of the population is concentrated in large cities and regions with favorable climates, leaving areas like the Arctic, Antarctica and deserts largely uninhabited. Humans don't live on most of the planet covered by water.

The development of linear cities, where the houses will provide the residents with all the necessary for nutrition and protection against external influences, will fundamentally change human settlement patterns. Constructing an Equatorial Linear City as part of creation of the GPV takeoff and landing overpass and a geospatial logistics network will initiate the colonization of ocean surfaces. Herewith, the technologies associated with linear cities could transform previously uninhabitable areas into spaces offering high living standards.

This more equitable distribution of human settlement will necessitate a shift in environmental protection approaches. The core of the ecology science will be changed as the human environment expands and restructures, the rationale for locating polluting industries in remote areas will diminish, alleviating the anthropogenic burden on densely populated regions. Consequently, new opportunities will arise for the sustainable use of spatial resources on a global scale.

2. The evolution of various communication types (transportation and logistics, energy and power supply lines, communication and the Internet) and the efficient exchange of goods and services between countries are also conditions that remain only partially fulfilled. While advancements in rail, road, air transport, telecommunications and energy generation have dramatically improved over the last 150–200 years, progress has stagnated. Although information and money can be transferred almost instantaneously, the average speed of transportation is declining due to urban overcrowding, increased motorization and various environmental challenges, including global ones affecting the whole biosphere of the planet. Meanwhile, the majority of cargo continues to be transported by sea and rail, modes of transport that have seen little change in the past two centuries.

The introduction of uST promises to balance the disparity between data transmission speeds and transportation rates. Its technical and economic viability will make it more accessible than air travel, which currently serves a limited portion of the global population. This innovation is poised to enhance overall mobility, stimulate economic growth in both developed and developing nations and optimize global logistics chains, leading to a more rational system for the exchange and distribution of goods within human civilization.

3. The strengthening of various ties, including political ones, among nations remains a challenging goal that is far from being fully achieved. Instead of fostering cooperation, interactions among countries often lead to weakening relationships or unilateral destruction. This trend has been especially pronounced since the early 2020s.

One of the primary sources of tension in today's world is the competition for influence and resources, driven by the capitalist dynamics of production and trade. This struggle often devolves into a fierce battle for markets. The EcoSpace program offers a fundamental solution by proposing the creation of new, large-capacity markets across various sectors, including energy, transport, construction, industrial and residential infrastructure, automation and agriculture. The industrialization of space opens up remarkable opportunities, allowing states to shift from confrontational competition over limited resources to collaborative efforts aimed at developing new resources both on Earth and beyond.

4. While humans' geological role currently exerts other geological processes in the biosphere, this dominance lacks a stable foundation without the successful implementation of the other conditions discussed. The visible impact of *Homo sapiens* on the planet often has destructive consequences, leading to circumstances that could undermine our position in a few generations. The decline of human dominance may arise not only from ecological degradation making Earth uninhabitable but also from potential threats like a deadly virus or nuclear conflicts.

Historically, human dominance over geological processes has increased as civilization has become more independent from natural systems through the technosphere created by the people inside the biosphere. However, this trend reaches a critical limit when the technosphere negatively impacts the surrounding biosphere. A fundamental change in this dynamic can only occur by relocating a significant portion of industrial production off the planet, thereby eliminating its detrimental effects on the living environment. The EcoSpace program envisions this transition, facilitating the emergence of a true noosphere.

5. The expansion of the biosphere's boundaries and access to space has only been minimally realized. A significant milestone will be the establishment of a global geocosmic transport system powered by clean electric energy, capable of transporting tens of millions of tons of cargo to and from orbit each year. Such a development would mark a genuine entry of civilization into space. As demonstrated in the works of the Unitsky engineering school, achieving these parameters is feasible only through the construction of the GPV, which serves as a cornerstone of the EcoSpace program.

6. The discovery of new energy sources will be contingent upon the large-scale expansion into space, particularly concerning solar energy, which is abundantly available in orbit. In comparison, ongoing efforts to harness energy through tokamaks and thermonuclear fusion, pursued for decades, appear less effective and somewhat unnecessary. Why invest in artificial thermonuclear reactors when we have access to the Sun, a natural fusion reactor that outperforms man-made machines on all fronts and guarantees uninterrupted energy supply for at least 5 bln years?

7. Achieving equality among people of all races and religions requires a more equitable distribution of the global population, along with substantial increases in wealth and education. Access to the benefits of civilization must also be equalized. This equality is one of the core objectives of the EcoSpace program, which prioritizes the interests of all individuals over those of specific races, religions, states or corporations. Unlike many populist initiatives that espouse humanism, A. Unitsky's global program provides concrete technological solutions to realize these goals.

8. The EcoSpace program will naturally enhance the role of the masses in shaping both foreign and domestic policy. As people settle in linear cities, living in smaller communities, their capacity for self-governance will significantly increase.

9. The freedom of scientific thought and inquiry from the influences of religious, philosophical and political pressures and creation of conditions for the freedom scientific thought in public and governmental environment will improve as states and corporations interfere less with scientific endeavors. The linear cities proposed by the EcoSpace program will promote this freedom.

Each cluster of linear cities, equipped with essential resources like food and energy and other resources, will be much more autonomous than modern urban neighborhoods in megacities. This autonomy fosters diversity in lifestyles, cultural practices and other characteristics. Such variations, inherent in the settlement and organization of daily life, will be challenging to control centrally. Consequently, it will be more difficult to impose restrictions on scientific inquiry and cognition than in the late 20th century, when large cities became melting pots of industry, culture and education. In those environments, the most powerful industries often prioritized profit and the corruption of power manifested in dominance and violence over societal advancement and the development of the noosphere.

10. Raising the welfare of workers and creating real opportunities to prevent malnutrition, hunger and poverty, while also reducing the impact of disease, are all attainable goals within the EcoSpace program. This can be achieved more organically and swiftly than through any other proposed framework today. The fundamental prerequisites for eradicating the poverty and hunger that have plagued humanity for centuries are the technologies that enable linear cities to supply people with all the essential resources they need in adequate quantities. The program incorporates spatial, environmental and food security as goals to be pursued through concrete actions and engineering solutions that are practical and thoroughly tested in real-world conditions.

11. The reasonable transformation of Earth's natural environment to meet the material, aesthetic and spiritual needs of a growing population is an achievable condition with the introduction of new transport and energy systems. Transitioning to biosphere-based agricultural methods and more ecologically sound forms of settlement can make this transformation a reality. If the steps outlined in the EcoSpace program are implemented, the planet could sustainably support around 100 bln people [6], allowing them to thrive in comfort without causing irreparable harm to the biosphere. The prospects for peaceful expansion into space would broaden significantly, extending the potential for human habitation nearly infinitely like the Universe itself.

12. The elimination of war from human life requires a fundamental shift in the prevailing socioeconomic model of capitalism. This transformation entails redefining the foundational conditions of the economic system and property relations. The technologies and principles underlying the EcoSpace program promote the emergence of a new type of human – an engineer and creator, a core of the economic relations in the technocratic civilization created by him – who is designed to meet a wide array of needs, including security, social connection, housing and food. This new human-creator concept can reshape the future of the global socioeconomic system and redefine the role of states within it. By aligning individual, state, corporate and global interests with the objectives of the EcoSpace program, the chances of conflict and warfare can be significantly reduced, fostering a more peaceful world for all.

Need to Reevaluate Role of State in Society

The execution of projects like the GPV, part of the EcoSpace program, demands collaborative efforts from people and governments around the globe. To achieve this, we must eliminate the irrational forms of social behavior such as wars, terrorism, man-made pandemics, etc. Since states often initiate these conflicts, it's crucial to reassess their roles and functions within society as well as their involvement in the social system.

Among all human activities, economic endeavors are the most significant driving force behind historical progress. While scientific discovery, technological advancement and various pursuits enrich our lives, the processes of extracting, owning, producing and trading valuable goods form the foundation of social relations and are key motivators for change. The exploration of the planet, settlement, development of crafts, trade, artistic achievements, major geographical discoveries, territorial colonization, revolutions and wars – all of these historical events are deeply rooted in economic causes. When viewed through this lens, we often observe the struggles between individuals, along with the resulting disunity and injustice.

As articulated in the opening lines of Manifesto of the Communist Party, which for the first time so radically conceptualized the injustice of society as its inherent characteristic, "The history of all hitherto existing society is the history of class struggles.

Freeman and slave, patrician and plebeian, lord and serf, guild-master and journeyman, in a word, oppressor and oppressed, stood in constant opposition to one another, carried on an uninterrupted, now hidden, now open fight, a fight that each time ended, either in a revolutionary reconstitution of society at large, or in the common ruin of the contending classes" [7].

However, injustice does not stem from human productivity itself; rather, it arises from the exchange of goods produced by that activity. The temptation to seize through force or deceit is an ancient aspect of human nature. To mitigate this, the state is established as a guarantor of the rules agreed upon by the majority, embodying the essence of the social contract theory. Yet, by claiming the authority to use violence to uphold justice, the state can inadvertently become a source of injustice – both towards its own citizens, who are burdened by taxes, and towards neighboring nations. As the state emerges, it becomes a significant player in economic life, often more powerful than any individual.

The pursuit of economic interests by the state leads to widespread human suffering – hunger, poverty, epidemics and wars. The world becomes a battleground for competing nations, shaping a geopolitics that resists the possibility of universal harmony and rational order. Instead, geopolitics posits that international relations are governed by fundamental dualism law. Pioneers of this thought, like A. Mahan and H. Mackinder, suggest that this dualism inherently fosters hostility, which, when combined with political and military ambitions, breeds irreconcilable enmity between two different

cultural and historical civilizations (of democracy and ideocracy) [8]. It is no coincidence that, in the postwar Soviet Union, geopolitics – often leading to the justification of conquests and warfare – was deemed a pseudoscience. The 1951 Concise Dictionary of Philosophy, edited by M. Rosenthal and P. Yudin, defines geopolitics as a "fascist pseudoscience" that seeks to rationalize imperialistic expansion based on geographical factors. It argues that geography cannot dictate the necessity for a country's territorial expansion at the expense of others. The philosophical foundation of geopolitics rests on the fundamentally flawed thesis regarding the determining influence of the geographical environment on societal development. The geographical environment, as argued, cannot be considered the primary or determining factor in social evolution. The foreign policy of a state, as history demonstrates, is profoundly influenced by changes in the socioeconomic system rather than geographical conditions. Ultimately, geopolitics is a product of imperialism [9].

The source of enmity between countries and their coalitions lies not in their differences in political systems, geographical features or other aspects, but in the fact that states are armed actors in economic relations. As long as this situation persists, the transition of humanity to a noospheric state of existence will remain unattainable, making the implementation of the EcoSpace program extremely challenging, if not impossible.

It is important to note that the reduction of state participation in economic activity has been a central theme in social systems since the Enlightenment and the early bourgeois revolutions. The Scottish scientist A. Smith illustrated the potential for organizing economic life without government interference through the metaphor of an "invisible hand," which facilitates the achievement of collectively significant results and establishes a system for the production, distribution and exchange of values by balancing the interests of individual participants. This principle underpins market economies and capitalism. The alternative is total state control within the planned economic model and socialism. However, even within these frameworks, the role of government should be gradually diminished.

In the leftist intellectual tradition, the state is viewed as a necessary institution only during the transitional phase of socialism, not in a fully realized communist society. The German philosopher K. Marx argued that "in a higher phase of communist society, after the enslaving subordination of the individual to the division of labor, and therewith also the antithesis between mental and physical labor, has vanished; after labor has become not only a means of life but life's prime want; after the productive forces have also increased with the all-around development of the individual, and all the springs of co-operative wealth flow more abundantly – only then can the narrow horizon of bourgeois right be crossed in its entirety and society inscribe on its banners: From each according to his ability, to each according to his needs!" [10].

The prominent statesman V. Lenin noted, "The state will be able to wither away completely when society adopts the rule: "From each according to his ability, to each according to his needs", i.e., when people have become so accustomed to observing the fundamental rules of social intercourse and when their labor has become so productive that they will voluntarily work according to their ability. "The narrow horizon of bourgeois law", which compels one to calculate with the heartlessness of a Shylock whether one has not worked half an hour more than anybody else – this narrow horizon will then be left behind. There will then be no need for society, in distributing the products, to regulate the quantity to be received by each; each will take freely "according to his needs".

From the bourgeois point of view, it is easy to declare that such a social order is "sheer utopia" and to sneer at the socialists for promising everyone the right to receive from society, without any control over the labor of the individual citizen, any quantity of truffles, cars, pianos, etc. Even to this day, most bourgeois "savants" confine themselves to sneering in this way, thereby betraying both their ignorance and their selfish defence of capitalism.

Ignorance – for it has never entered the head of any socialist to "promise" that the higher phase of the development of communism will arrive; as for the greatest socialists' forecast that it will arrive, it presupposes not the present ordinary run of people, who, like the seminary students in Pomyalovsky's stories, are capable of damaging the stocks of public wealth "just for fun", and of demanding the impossible" [11].

Suppose that both capitalism, with its free market ideology, and communism aim to diminish the state's role in economic activities. However, in practice, capitalism can lead to the rise of international corporations that replace the state, while communism may devolve into totalitarianism and dictatorship. Thus, the issue of power concentration, along with raw materials and production resources being controlled by specific organizations, remains unresolved, as does the inevitability of conflicts between these entities striving to grow and strengthen.

Simply limiting state participation in economic activity will not eliminate injustices and irrationalities such as wars, genocide, pandemics and environmental terrorism. If the authorities fail to intervene, transnational corporations will fill the void. The consequences could be even more severe, as these corporations do not operate under the same regulatory frameworks aimed at public welfare, protection of individuals and other mechanisms that states claim to uphold. Models of capitalism without state involvement, like K. Schwab's concept of inclusive capitalism, present truly alarming prospects, as such societies prioritize profit maximization above all else, despite claims to the contrary.

An analysis of Schwab's proposal for a "new" model of capitalism ultimately reveals a call to abandon the principle of profit maximization. He suggests that businesses must recognize the end of the era of capital gains, arguing that average profits in many industries are approaching zero [12]. To preserve the capitalist model, Schwab outlines several key points. First, profit should cease to be the primary goal and measure of business success. Second, companies must address consumer needs by lowering prices and gradually eliminating poverty and misery. Third, the conventional belief that corporations belong solely to shareholders must be abandoned [12].

K. Schwab further posits that the purpose of a company is to involve all stakeholders in a collaborative and sustainable value creation process. This means that companies should embrace inclusivity, positioning themselves as the builders of inclusive capitalism, rather than the state. According to his vision, the state should not simply wither away, as suggested in classical Marxism, but instead be included or privatized by the largest corporations [12]. This shift implies a gradual transfer of power from the state to corporations, which would operate without constraints or limitations. The logic suggests that these corporations could eventually establish their own armies, dictate tariffs for essential services, influence healthcare and education and shape cultural narratives.

It is illogical to assume that corporations will fundamentally change their nature. They will continue to pursue the expansion of wealth and power, seeking to minimize costs related to raw materials, energy and labor – essentially treating people as mere resources. This tendency prevents corporations from achieving a balanced system of relations, as their development inherently relies on competition, which leads to indiscriminate means of struggle. Consequently, conflicts, resource depletion, environmental pollution and rising inequality will not only persist but will likely intensify, heading towards an all-encompassing catastrophe.

Wars are an intrinsic aspect of capitalism. As the Russian figure L. Trotsky noted in his work The War and the International, war serves as the method by which capitalism seeks to resolve the insoluble contradictions arising between rival states competing for markets and spheres of influence. He stated, "The future development of world economy on the capitalistic basis means a ceaseless struggle for new and ever new fields of capitalist exploitation, which must be obtained from one and the same source, the earth. The economic rivalry under the banner of militarism is accompanied by robbery and destruction which violate the elementary principles of human economy" [13]. The French socialist J. Jaurès expressed this sentiment even more emphatically: "Capitalism carries war within it, just like clouds carry rain" [14].

The theorists proposing transformations to capitalism aim to preserve the essence of this model, along with the primary cause of all social contradictions: property and the relationships surrounding it. The fundamental difference between capitalist and communist models lies in property rights. Capitalism seeks to maintain the institutions of private property at all costs, as the world's wealth is built upon them. However, poverty – along with all forms of injustice and irrationality – also stems from these institutions.

On the other hand, public ownership of the means of production, resources and other assets is often seen as inferior to private ownership in terms of motivating labor, stimulating development and adapting production, distribution and exchange systems. The communist experiment conducted in the USSR ultimately ended in failure. Meanwhile, capitalism is undergoing a prolonged and escalating crisis, acknowledged even by staunch supporters of the system, such as K. Schwab. Is there any viable alternative to the current system of property rights? Can a framework be realistically established that would allow for the gradual removal of the state from economic activities while preventing the concentration of resources in the hands of corporations?

New Productive Opportunities as a Tool for Combating Inequality and Foundation for a New Property Right

The property right encompasses the ability to possess, use and dispose of something. On the one hand, this pertains to individuals, their labor and the products of that labor. On the other hand, it relates to resources and means of production. These elements form the basis of economic relations, which involve alienated and appropriated objects

for distribution, exchange and consumption. However, the initial conditions are never equal; some individuals have only their labor, while others possess land, factories and ships. The very existence of property creates the potential for conflict on both local and global scales. Once someone claims ownership of something, another is likely to challenge that claim. This dynamic highlights the necessity of the state and law as mechanisms for protecting property, as outlined by social contract theory. Consequently, one of the state's primary objectives is to establish and maintain a system of property relations, effectively by appropriating resources and redistributing them.

Historically, the transformation of the state's role in the economy, along with changes in the structure of property, has coincided with the emergence of new economic management systems and new spheres of value creation. Peasants gain property rights to a portion of their labor's products only after they become the primary wealth-producing force in society, replacing enslaved individuals who possess no rights. Workers only gain the freedom to move and apply their labor as they wish once industrial production flourishes and dominates the economy. The issue of their social protection arises only with the development of the service sector, as companies providing these services become significant objects of property and sources of profit. This also reflects the emergence of the information economy, where information itself becomes a crucial object of property. Throughout these transformations, the state's role and involvement expand and evolve.

In addition to regulating relations in emerging industries, the state seeks to broaden its economic influence and participation. This expansion often leads to confrontations – first with its own citizens and then with other countries that become competitors. As a result, we witness wars over land, industrial resources, service markets and, ultimately, information. Nevertheless, the progress of civilization, driven by advancements in science and technology, corresponds with an increase in individual freedom and the expansion of opportunities to own and utilize both natural and created resources. The primary driver of this change appears to be the overall increase in social wealth. As more goods become available, the share for each individual grows. Theoretically, there may come a time when there is such an abundance of resources that everyone can access them in unlimited quantities. For this to manifest in practice, civilization must be encouraged to rethink the current state of affairs and to envision alternative model of relationships within the framework of human–property–state.

In economics, something exists only as long as there is demand for it. If a particular product, resource or service is no longer needed, it tends to disappear. This principle also applies to the state as an entity engaged in economic activity. In Antiquity and the Middle Ages, power structures were essential for protecting the lives of their subjects, even though individuals could provide for their basic needs through their own labor. With the rise of industrialization, the growing division of labor and mass migration to cities created a need for system to deliver essential services like food, sanitation, heating, transportation, etc. A person could not simultaneously work in a factory and farm the land, as both activities require substantial energy and focus. While technology has advanced significantly, the existing system often operates on inertia, failing to recognize or adapt to new opportunities that have emerged.

In the mid-twentieth century, European nations frequently faced food crises and famines. For instance, Ireland experienced a mass famine from 1924 to 1925, and Spain endured a similar crisis from 1939 to 1952 [15]. Even Germany, one of the most economically developed countries, faced significant agricultural deficits before World War I, with a protein deficiency of 28 % and a calorie deficiency of about 20 %. Food supply crises continued into the 1930s, contributing to the conditions that led to World War II.

The 1950s and 1960s brought the Green Revolution to Europe [16], characterized by the development of more productive plant varieties, expanded irrigation and the use of fertilizers, pesticides and modern machinery. Consequently, just 4–5 % of German farmers became capable of meeting over 70 % of the country's food needs. However, the issue of hunger was resolved only for so-called civilized nations, not for the globe as a whole.

According to the UN, "more than one in five people in 59 countries faced acute food insecurity in 2023" [17]. This translates to an estimated 281.6 mln individuals affected by hunger, or about one in every 30 people on the planet. Throughout much of history, resources were extracted and distributed relatively evenly across populated areas. Today, however, economic inequality continues to grow. In 1820, the income ratio between the richest 20 % and the poorest 20 % was 3 : 1 [18]. By 1991, it had skyrocketed to 86 : 1. A report from the United Nations University World Institute for Development Economics Research in 2000 revealed that the richest 1 % owned 40 % of the world's assets [19]. The situation has only worsened since then. The World Inequality Report 2022, published by the Paris School of Economics after four years of research, indicates that "contemporary global inequalities are close to early 20th century levels, at the peak of Western imperialism" [20].

Currently, 50 % of the world's population holds only 2 % of global wealth, while 10 % of people own 76 % of all known assets [20]. This growing economic inequality is primarily a result of the existing system of property rights. Despite significant increases in the productive capacity of civilization and the overall quantity of resources, these developments have not led to widespread prosperity. Instead, they have exacerbated economic disparities between individuals and states, fueling tensions and deepening global crises.

States and large corporations, by appropriating the fruits of others' labor and concentrating a vast majority of wealth, operate without principled boundaries in their quest for expanded influence and profit sources, which are the meaning of their existence. While aiming for the same goals, these major players are often in competition with one another, they support and justify each other's actions, collectively striving to uphold the historically established system of property rights – one that has long been inadequate to meet the needs of humanity. Consequently, this status quo becomes resistant to internal change and can only be transformed through external factors, such as global crises, revolutions or the emergence of more efficient economic systems. In the latter case, the old systems may gradually be replaced by new, more effective solutions, as is often the case in economics.

In feudal times, a person needed a minimum of 5 ha of land to sustain themselves. This figure represents an average that does not account for regional variations in land quality. Cultivating such a large area, especially with the low level of labor automation, consumed all of a peasant's time. The remainder of their labor was devoted to household maintenance and working the lands owned by the feudal lord. As a result, opportunities for capital accumulation were severely limited, as peasants had no surplus resources – be it labor, raw materials, money or time – that could be invested elsewhere. While the feudal system, where wealth was tied to land and the labor invested in it, may seem just, it had inherent sources of injustice, including:

- the disparity in land fertility across regions;
- the inability of individuals to balance farming with other pursuits, such as military service, politics, arts, crafts, etc.

Imagine a scenario where land is uniformly fertile and requires only about an hour of labor each day to provide sufficient food. In such a reality, there would be ample opportunity for self-organization and self-management within peasant communities. If individuals could dedicate only a fraction of their time to caring for the land and livestock, they could spend the rest of the day engaging in activities aligned with their interests. Communities could establish their own political structures, form well-trained military units and pursue crafts, painting and music. This would not necessitate the concentration of capital in the hands of large landowners, thereby reducing the need for a state structure.

So far, the conditions for this scenario have been limited by technology, but today, the possibilities are within reach. Furthermore, in the postindustrial era, land is no longer the primary source of wealth. Instead, industrial production means, intellectual labor, information and services are becoming more valuable. If every household can satisfy its needs through agricultural production, the value of land will diminish even further, signaling the end of industrial food production. However, global food security is likely to increase rather than decrease.

People will no longer rely on timely deliveries, the reliability of supply chains or large agricultural enterprises. They will sustain themselves through their own land, which, thanks to advanced technologies, can be drastically reduced in size per consumer. This could involve including the residential plots in the house area and combining them into a highly automated smart system that offer protection from natural elements, provide nutrition and create an environment conducive to creativity. While the broader economic landscape will remain outside the home, it will inevitably undergo significant transformation as well.

With the right technical organization of housing, transport, energy and industrial infrastructure, modern individuals can fully sustain themselves with healthy food while also engaging in production, services, creativity and any other pursuits they desire. To achieve this, we must return to a natural form of human settlement but at a new technological level. Small communities of 1,000 to 5,000 people, spaced comfortably apart (about 1 km), should be arranged in linear clusters. These residential areas would be connected by highly efficient transport corridors based on uST, allowing speeds of up to 360 km/h for even the most remote locations. These clusters will be equipped with autonomous sources of energy and agricultural products through a set of proven solutions. The roofs of homes will feature greenhouses, where organic fertilizers produced from household waste, along with heat and nutrients from relict solar bioelectric power plants, will sustain plant growth. Basements can be utilized for livestock breeding.

In addition to residential clusters, production hubs will be strategically located near raw material extraction sites, leveraging the efficient transportation system that allows to cover a substantial distance in a half-hour convenient for any individual. This proximity will reduce costs and facilitate the seamless integration of extraction, processing and production.

As individuals become economically independent, their desires will naturally grow. They will seek more living space, advanced technology, clothing, travel, entertainment and various other needs, driving the pursuit of wealth. Historically, there have been three primary avenues for wealth acquisition:

- labor;
- speculation;
- theft or robbery.

Let us set aside the last option, as it tends to flourish in direct correlation with societal injustice and imperfection. Instead, we can explore how labor and speculation might evolve in a new order where basic human needs for subsistence are already met.

In this scenario, a person's labor motivated solely by creative aspirations and the desire for nonutilitarian goods would be valued more highly than the labor of someone who, lacking means of subsistence, is compelled to accept any employer's terms under the threat of starvation. While exploitation in the Marxist sense would still exist, it would be voluntary, transforming into a service which seems fundamentally different. The labor market will continue to dictate prices, but once individuals have the choice to work or not, wages will need to rise significantly to incentivize labor. Eventually, capitalists (owners of production means) will be compelled to offer workers a fair share of the value added by the products they create. This shift will impact capital profitability and lead to a restructuring of capitalist production, fostering a fairer system of profit distribution among participants.

As people experience greater happiness in their daily lives, they will become less willing to work for capitalists. This sense of happiness is influenced less by consumption levels and more by the chosen value system and an individual's acceptance of their societal role. In simple terms, we feel fulfilled when we possess what we desire, whether material or nonmaterial. Our desires are shaped by our surroundings. If expensive cars, designer boutiques, gourmet restaurants and people who consume all of the above while constantly traveling from one end of the planet to the other on private jets and enjoying its most beautiful corners, dominate our environment, we are likely to yearn for those things. If we cannot attain them, feelings of dissatisfaction may arise. Conversely, if such nonessential items are absent, they lose their significance. Indigenous peoples and our ancestors living in small villages did not require these luxuries to define happiness, nor do those who choose to relocate to rural areas today. The necessity for surplus goods will diminish when organizing communities within linear cities. This is primarily because what impacts us most profoundly is our immediate environment – our neighbors and community.

The value system is shaped not only by the cultural environment in which it develops but, more significantly, by specific human needs. Luxury goods exemplify this principle; under certain lifestyles and goals, they can transform into perceived necessities. In a large city, an individual's life is often considered decent and comfortable only if they possess a home or apartment in a prestigious area (ideally with a concierge, staff and security), a personal vehicle, a spacious office in a business district, access to high-end shopping and opportunities to dine at fine restaurants and attend cultural events. For city dwellers, these elements are not mere indulgences; they are essential for creating a sense of security and comfort in a potentially hostile and uncomfortable environment. Conversely, a villager does not require such luxuries. They would not milk cows in evening attire or drive a sports car through rough terrain. Instead, practical tools like tractors, trucks and sawmills – items a city resident may not even recognize – hold significant value for them. The question of who is happier in these scenarios does not yield a straightforward answer, nor can we easily determine who is more cultured without further context. However, it seems clear that a farmer with a stable income, fertile land and a loving family is likely closer to happiness than a successful stock speculator surrounded by the trappings of wealth. This difference arises because the farmer's desires are more tangible and manageable compared to those of the speculator, because happiness is the alignment of what we desire and what we truly want with what we possess. So, the speculator constantly seeks more wealth while living in fear of losing what they have.

While human desires are fundamentally vast, there are circumstances where the material aspects of those desires may feel limited, especially when assessed through a functional lens. For instance, one does not need 10 shovels, 20 chainsaws or 50 harvesters for a plot of land that can be managed with just one. However, in a social context that demands status, having a dozen expensive watches or several cars may feel necessary. Would such desires exist without an awareness of these social pressures? Likely not. If my work and social environment promote a balanced and healthy lifestyle, and if I begin to evaluate objects primarily based on their functionality, my material desires will narrow. I won't need to toil endlessly for a capitalist to acquire what I want. Once I have my needs met, it will be challenging to motivate me to engage in wage labor at all. I would work for myself, which would suffice. If I am satisfied with what I possess, I would have no reason to resort to theft. Moreover, if the majority of those around me also have their needs met, speculation – while it may not disappear entirely – would likely diminish in scale and scope.

Thus, personalized labor can become the primary source of wealth. By establishing conditions conducive to a new socioeconomic system, we can take further steps to minimize irrational social behaviors. Over the long term, this shift would facilitate a transition from a society of scarcity to one of abundance, characterized by an excess of resources that remain unclaimed due to the dismantling of large capitalist structures through the elimination of forced labor and the emergence of new property right relationships.

Maximal automation within residential and industrial clusters will reduce the physical and administrative resources required for their maintenance. Highly efficient mobility will serve as a catalyst for the development of remote areas, thereby mitigating the artificially created disparities in land value. With an abundance of essential resources within their communities, individuals will achieve greater autonomy, leading to a diminished role for the state and corporations. People will no longer be compelled to work, a traditional foundation of property right, since any ownership is fundamentally rooted in labor or derives its value from it.

A plot of land, a forest or an oil field has worth only when it is tended by a farmer, logger or driller. The establishment of property right essentially involves appropriating the results of labor – whether that labor is one's own or someone else's. When it is one's own, it feels like a natural entitlement; when it belongs to another, it seems unnatural and a source of injustice. Therefore, if the state aims to create a just property system, it must establish clear and strict connection to labor, its nature, quality and quantity.

The proposed fundamental tenets of a new system of property rights are as follows:

- property rights should apply only to those material objects that a person directly uses, regardless of the purposes they choose for themselves;
- direct use of property entails physical or intellectual participation in applying its properties to obtain specific products or services for personal consumption or resale. Profit derived from the valuation, marketing or leasing of any products or services should be classified as indirect use, rather than direct;
- material objects not actively used by a person but assigned to them must be transferred to another individual or group through sale, auction or other customary methods;
- objects acquired for sale or collection can only become property for the mentioned purposes. Profits from such production should not be appropriated by the owner if they do not actively engage in the process; rather, they should be distributed among the participants;
- property can be inherited, provided that the inheritor or their guardians make direct use of the inherited objects;
- money and securities can be owned, held and exchanged for goods or services, as their primary purpose is to be stored or exchanged.

Establishing a system of property rights based on these principles will prevent the emergence of large capital entities, such as states and corporations. This shift will help eliminate the primary causes of social inequality and the resulting conflicts, which are often irrational in nature. By narrowing the scope of economic subjectivity, states will be compelled to focus less on ensuring their sovereignty and economic power and more on implementing projects of universal significance on a global scale, such as the GPV.

How to Build Linear Cities and Attract Residents

Any significant social transformation begins with the establishment of new living models. Within the EcoSpace program, clusters of linear cities serve as pivotal centers for the proposed socioeconomic system. The logic guiding civilization's transition to this form of community organization will not differ fundamentally from the patterns that have historically shaped human settlement. This transition is influenced by several factors, the most critical being the efficiency of system production process and the transport accessibility of various regions.

Over the past few centuries, urbanization has been viewed as a steady trend. People have migrated en masse from rural areas to cities, where the primary productive forces and job opportunities are concentrated. This movement was accompanied by advancements in transport, particularly

motorization, which expanded transport accessibility and allowed cities to grow significantly, enabling comfortable travel over distances of tens of kilometers. While these changes improved living standards for many, urbanization has its limits. Eventually, cities can become overcrowded, polluted and uncomfortable for their residents. As a result, a shift towards deurbanization is increasingly seen as promising. However, this should not be a mere reversal but rather a progressive movement that creates new productive forces and settlement patterns aligned with them.

Linear cities advocate for spatial and sectoral decentralization of industries. In this framework, the agricultural and energy sectors should be managed by local communities, laying the groundwork for reorganizing services, heavy and light industry. The only economic branch that should continue to develop and remain centrally managed is transport, as it requires coordination over extensive areas. With appropriate regulatory and legal adjustments, all other sectors can effectively function within clustered territorial units. By developing a network of high-speed transportation (up to 360 km/h), efficient chains for services, raw material supplies and product sales can extend across hundreds of kilometers. There, clusters of various specializations – such as raw materials, industrial, cultural, educational and others – will be strategically located in ideal areas. Individuals will have the option to choose their residence close to their workplaces. If, for exceptional reasons, this proximity is unfeasible, the distance for comfortable transport accessibility will still span hundreds of kilometers rather than the dozens typical of modern megacities.

Life within these clusters will fundamentally differ from urban living, resembling a village lifestyle. With fewer inhabitants, pedestrian-friendly spaces, homegrown healthy food and untouched nature within walking distance, individuals will thrive in a natural environment tailored to their needs. At the same time, thanks to affordable, safe and eco-friendly high-speed transport, they will have access to all the benefits of modern civilization: education, culture, recreation, entertainment, etc. This vision aligns with the growing desire for such living conditions, making mass deurbanization not only possible but also technologically feasible within the framework of the EcoSpace program.

The transition to new forms of spatial-regulatory organization in society can occur in two ways: through state programs or via individual development projects funded by future residents of the newly created clusters. In the second option, the main incentive for purchasing this new type of real estate and relocating will be the guarantee of a year-round supply of healthy agricultural products, along with the potential for passive income through the sale of surplus produce. According to estimates from the Analytical Department of Unitsky String Technologies Inc. (Minsk, Belarus), with housing costs comparable to the average market price (approximately 1,000 USD/m^2), passive income for each household in such a cluster could exceed 10,000 USD/year. This means that a homebuyer could fully recoup the purchase cost over a ten-year period and subsequently transform their home into a source of income.

From the perspective of cluster management in a linear city, the most effective model is one where governance is carried out locally by the residents. A centralized system would be inefficient; if the clusters are small and spread apart, it would require excessive resources. Through self-governance, we achieve a social structure resembling a community, which in some socio-philosophical doctrines serves as a state-legal ideal. For instance, Slavophiles view the community as a traditional institution that ensures continuity across generations and integrates individuals into a cohesive social system. It balances private and public interests, regulates social relations and addresses conflicts between labor and capital, large landowners, small landholders and rural workers. It is a form of collective social labor, a means of providing for community members in need of social assistance, a body of public self-government [21].

Communities can take various forms, but their essence remains unchanged: they represent the most ancient and natural way for people to live together. Slavophiles noted that even in the early days of Russian statehood, urban and rural communities (miry, vervi) addressed issues related to governance, taxation, property management, military organization, judicial matters and the distribution of agricultural land among members. They facilitated communal use of land, forests, pastures and water resources while managing community and state duties and taxes, enforcing laws, maintaining public order, searching for criminals, etc. [21].

Russian publicist Yu. Samarin argued that all forms of community are manifestations of a gradual expansion of a communal spirit, reflecting a fundamental need for harmonious living, which each member recognizes as a supreme law binding on all [21]. Similarly, ideologists of Slavophilism, such as A. Khomyakov, stressed the importance of preserving space for private initiatives within communities. He asserted that personal activity and enterprise should have their own rights and spheres of action; they will always find a foothold in the rural world, through which they will put up with public interests without leading to egotistical disunity [22].

Achieving a harmonious balance between collective and private interests is one of the primary objectives of social construction. Within the framework of the EcoSpace program, this balance is addressed at both the spatial-territorial and behavioral levels, thereby eliminating the conditions that lead to irrational social actions and fostering the noosphere as a realm of reason.

Conclusion

The implementation of the EcoSpace program's initiatives, which focus on developing new forms of settlement and enhancing transport, energy and agricultural technologies, establishes a foundation for creating market niches with high potential. Additionally, the living conditions proposed within EcoSpace could lead to the emergence of a qualitatively new labor market subject, whose basic needs for food, housing and social life will be inherently satisfied.

The autonomy of housing in linear cities and the resulting reduction in forced labor are expected to strengthen the role of self-governance while diminishing the influence of states and large private capital in socioeconomic life. This shift will create a public demand for a reevaluation of property rights system to prevent the further concentration of large amount of resources and capital (the super wealth) in the hands of any single business entity and to mitigate inequality, a primary driver of social irrational behavior on a global scale. In this way, the necessary conditions will be established for a constructive socioeconomic model of a new type, characterized by a significant reduction in inequality, which will, in turn, decrease tensions and reduce the incidence of conflicts and wars. This transformation will accelerate the execution of key objectives of the EcoSpace program, including the large-scale, peaceful expansion of humanity into space, the relocation of environmentally harmful industrial production to orbit and the opening of access to inexhaustible space resources, energy and fundamentally new resources (weightlessness, deep vacuum, technological purity, etc.).

The implementation of certain aspects of the EcoSpace program will inevitably lead to the realization of others. The adoption of technologies proposed by Unitsky engineering school will act as a catalyst for political changes, which will, in turn, enhance efforts toward a common goal: transforming Earth civilization into a space civilization. Thus, EcoSpace can be viewed as both the foundation and the vision for transforming the prevailing socioeconomic model worldwide toward greater humanization and rationalization.

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Influence of Space on Humans: Psychological Aspects of Life in New Environment

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This study examines the impact of factors associated with prolonged habitation in near-Earth space on the psycho-emotional state of individuals. It investigates the patterns of psychological effects on cosmonauts both in model experiments and in real space flights. The analysis includes the peculiarities of behavior and interactions of crew members. Drawing from the experience of international human spaceflight programs, a comprehensive set of tools utilized by ground flight control teams to mitigate negative influence arising from extended stays in artificial living environments is outlined. Practical recommendations for psychological support are provided to facilitate the adaptation of residents in the EcoCosmoHouse to conditions that differ from those on Earth.

The formulated conclusions and proposals aim to enhance individuals' psychological well-being, ensure their comfortable existence, and maintain their performance during the implementation of the uSpace program.

Keywords:
EcoCosmoHouse (ECH), outer space, psyche, psychological state, psychological support, space industrialization, space psychology.

Introduction

In the latter half of the 20th century, humanity embarked on a transformative journey into outer space. Today, the active exploration of the Universe and the quest to understand life beyond the confines of Earth have become increasingly significant areas of study. This trend is global in scope. K. Tsiolkovsky envisioned a future where humans would not only alter the Earth's surface, oceans and flora but also reshape themselves. He predicted that humanity would gain control over the climate and manage resources both within the Solar System and on Earth which will remain our home for the foreseeable future [1].

The organization of activities on a cosmic scale represents a natural progression in the development of planetary civilization, impacting numerous domains, such as technology, finance and society, including psychology. The emotional well-being of individuals in space and the psychological effects of prolonged missions have become critical areas of investigation within neurophysiology, psychology, space medicine, cosmology and even philosophy [2]. Increasingly, researchers are focusing on adaptation mechanisms that can mitigate the negative impacts of various factors to ensure the success of future extraterrestrial missions.

The study of human activity in the context of Universe has been explored by pioneers such as K. Tsiolkovsky, who laid the groundwork for modern cosmonautics; A. Chizhevsky, a key figure in space biology and heliobiology; L. Orbeli, a founder of evolutionary physiology; O. Gazenko and V. Yadzovsky, who were instrumental in developing space medicine. Notable contributions also come from A. Gurdzhian, a specialist in aviation physiology, among others [2].

This article presents the findings from analyses on how factors associated with long-term habitation in near-Earth space affect the psycho-emotional state of humans. It also offers practical recommendations aimed at helping residents of the EcoCosmoHouse (ECH) adapt to their new environment.

Psychological Studies of Cosmonauts' Functional States

Concerns regarding humans' ability to endure the conditions of space began to surface even before Yu. Gagarin's historic flight. There were uncertainties about whether a person could adapt to the extreme changes in environmental conditions. However, pioneering journey into orbit not only demonstrated that humans could survive but also that they could perform effectively in near-Earth space. This groundbreaking achievement underscored the need to investigate the intricacies of mental activity in this new environment.

For the first time, space psychology emerged as a field dedicated to studying the mental states of cosmonauts, both through long-term modeling experiments and actual space missions. Yu. Gagarin significantly advanced this field by prioritizing psychological over physiological challenges before his landmark flight. He raised critical questions: Would a person's mental functions be disrupted during a space mission? Could they live and work effectively beyond Earth?

Yu. Gagarin actively contributed to the development of a psychogram for professional cosmonauts, aimed at answering essential questions about their roles during missions. This psychogram outlined the psychological qualities and character traits necessary for success in space. It revealed that cosmonauts must be adept at controlling the spacecraft during various maneuvers, managing numerous systems aboard the ship and orbital station, performing repairs both inside and outside the craft or station, conducting scientific research across multiple disciplines and testing new spacecraft and technical systems. Moreover, Yu. Gagarin emphasized, that a cosmonaut should possess strong purely human qualities and a profound desire to explore space. The formulation of this psychogram ultimately enhanced the psychological selection process for candidates [3].

Following Yu. Gagarin's tragic death, his colleagues continued to advance the field of space psychology. A. Leonov, the first person to conduct a spacewalk and a participant in the Apollo–Soyuz program, published multiple articles and four monographs on the subject, often collaborating with cosmonaut psychologist Ye. Khrunov [4]. G. Beregovoy, head of the Yuri Gagarin Cosmonaut Training Center, also contributed by defending a thesis focused on space psychology. V. Sevastyanov, P. Popovich, Yu. Artyukhin, B. Volynov and Yu. Glazkov published articles addressing similar issues in this evolving field [5].

By 1970, under the guidance of F. Gorbov, who was responsible for the psychological readiness of the first group of cosmonauts, teams were established to address both practical issues at the Yuri Gagarin Cosmonaut Training Center and scientific challenges at the Institute of Biomedical Problems [6]. The foundational theories and practical approaches of space psychology drew heavily on applied studies with military pilots and insights from military medicine, particularly from the Central Military Aviation Research Hospital of the USSR.

Through a combination of model experiments and real missions, experts identified a direct correlation between

the mental well-being of cosmonauts and their performance effectiveness during specific operations as well as the overall success of near-Earth space exploration program.

During missions aboard the Salyut, Mir long-term orbital stations and the International Space Station, crews did not exhibit significant negative changes in psychological well-being. Instances of abnormal situations attributed to the "human factor" accounted for less than 18 % of total occurrences [7]. Reports of psychological issues were infrequent, and in some cases, entirely absent. However, it is important to acknowledge that the actual number of abnormal situations might have been underestimated, as cosmonauts were often reluctant to discuss their experiences. Despite these findings, the potential for the development of negative psychological states among flight participants cannot be dismissed. Ground experiments consistently indicated that the most significant challenges during extended missions were psychological in nature.

Numerous scientific studies have concluded that long-duration space flights can have a wide array of adverse effects on the psycho-emotional health of crew members. N. Yerakhovets examined social and psychological issues arising from experiments conducted in enclosed ecosystems on Earth, such as BIOS-3 and Biosphere 2. In these environments, participants faced environmental stressors, such as a lack of oxygen, insufficient food and demanding daily tasks, that negatively impacted their health and mood. Additionally, interpersonal dynamics often led to divisions among the participants, resulting in conflicts that further exacerbated their physical and emotional well-being [8].

The detrimental effects of extended space missions on mental health were also evident in the Mars 500 experiment, during which participants were isolated in a confined setting for 520 days. Researchers closely studied the phenomenon of "detachment from Earth," finding compelling evidence that as distance from the planet increased, crew members experienced a decline in motivation and overall activity. This detachment often resulted in a disregard for flight control instructions and an overestimation of their own capabilities, accompanied by a growing sense of isolation and longing for family and friends back on Earth.

In 1967, the Institute of Space Biology and Medicine initiated a similar project titled "A Year in an Earth Starship." Three volunteers spent a year in a spacecraft mock-up measuring just 12 m^2. The experiment highlighted the negative impact of confined spaces on interpersonal relationships, as communication among participants frequently led to conflicts and heightened susceptibility to depression.

The reference [9] stated that periods of animosity sometimes escalated to "blind hatred" and "physical disgust," making it particularly challenging for individuals to maintain close contact without the option of physical isolation. Over time, the participants ceased meaningful communication, exchanging only brief remarks necessary for work.

Impact of Living in Near-Earth Space on Human Psyche

The Table outlines various groups of risks related to the mental health of individuals during extended stays in near-Earth space. It also identifies the factors that contribute to these risks and significantly affect the psychological well-being of cosmonauts.

It is important to highlight that the dynamics within an international team can be complicated by language and cultural barriers. Misunderstandings regarding traditions and the unique perceptions of individuals from diverse backgrounds, psychological incompatibility among crew members as well as limited opportunities for open communication may result in tension, social isolation, a lack of emotional connection, egocentrism and the emergence of new sources of conflict.

The impact of these factors can significantly diminish cosmonauts' efficiency, difficulties with sleep, mood fluctuations, anxiety, nervousness, despondency and apathy.

An analysis of real flight experiences and long-term modeling experiments underscores the increasing relevance of enhancing psychological well-being. Ensuring a comfortable living environment and maintaining operational capacity in artificial physical settings is more critical than ever.

As we advance toward the next phase of near-Earth space exploration with the uSpace geocosmic program – a venture that envisions long-term human habitation in the ECH – thorough research into modern diagnostic methods for assessing psycho-emotional states is essential. This includes providing psychological support to facilitate successful adaptation to new environments, correcting processes when necessary, reducing stress levels and fostering harmonious relationships within the society.

It is essential to address the aforementioned challenges through a comprehensive psychological support system for cosmonauts. This system should be guided by previous experiences to avoid redundancy and ensure efficient use of resources when developing new ideas and solutions.

Below are existing measures of psychological support that could also be applied to residents in the ECH.

Table – Risks associated with prolonged human presence in space and their contributing factors

Risk groups	Triggering factors
Risk of mental disorders due to radiation exposure. Risk of erroneous decision-making caused by sleep deprivation, fatigue, desynchronosis and excessive workload. Risk of adverse behavioral and psychiatric conditions caused by the complex interplay of flight-related factors. Risk of negative situations caused by insufficient level of group cooperation, inadequate selection / team staffing, inadequacy of cosmonaut training and low psychological adaptation [7]	Weightlessness leads to a reduced load on the cardiovascular system, which in turn depresses the feedback afferentation and consequently – mental activity. Sensory deprivation. A significant decrease in environmental stimuli within a monotonous setting can lead to sensory hunger. This condition results in decreased activity in the brain's hemispheres, causing loss of interest, apathy, emotional instability and heightened irritability. Confined space conditions and the lack of social distance can trigger negative reactions such as aggression and tension. Over time, this may reduce the need for communication among crew members, potentially leading to complete breakdowns in interaction. Social isolation can result in a loss of vital mental connections to familiar social circles, including family, friends, colleagues, etc. Feeling of detachment from Earth. The feeling of being cut off from familiar natural elements, such as the expansive sky and distant horizons, can provoke confusion and a sense of foreboding. Inability to diversify the circle of communication for a certain period of time contributes to increased tension in the team and, accordingly, may adversely affect the success of the mission. Loneliness. Communication among crew members is infrequent, often due to shift work, where one cosmonaut is on duty while another sleeps. Meals are typically eaten separately. That leads to feelings of spiritual isolation and decreased efficiency. The presence of a constant real threat to life, such as meteorite impacts and radiation exposure, create a state of anxiety that can trigger various phobias. First-time cosmonauts may experience fear of the unknown, leading to chaotic stress responses as "fight or flight" that disrupt bodily functions. Operational autonomy. The necessity for independent decision-making in emergency situations, coupled with a lack of real-time communication with ground control, can heighten stress levels. The repetitive nature of tasks and lack of new information can lead to a scarcity of stimulating experiences, resulting in information hunger. Cosmonauts may struggle to comprehend their situation after leaving Earth orbit, particularly regarding the impossibility of emergency landings. They must quickly adapt to new environments while continuing to perform essential tasks for the mission. Extended stays in outer space often evoke feelings of nostalgia

Psychological Support: Preventing Adverse Effects of Prolonged Residence in Earth Orbit

Psychological support consists of a range of strategies employed by ground-based flight control teams to mitigate the negative impacts associated with long-term stays in artificial habitats. Its aim is to preserve the psychological health, socialization, well-being and emotional balance of cosmonauts, while also fostering a positive psychological climate aboard the spacecraft.

To explore effective methods of psychological support for the ECH residents, insights from international piloted space missions were analyzed. It should be noted that such support measures have been developed through both the practical experience of medical and psychological assistance during extended space flights and the analysis of data from ground experiments that simulated adverse flight conditions.

Support factors can be categorized as material and nonmaterial. Material factors include the design of spacecraft and space stations, the arrangement of interiors, the availability of personal space as well as facilities for work, recreation and physical activities. Nonmaterial factors encompass positive interactions among crew members and opportunities for communication with Earth.

For residents of the ECH to thrive, their living environment must incorporate specific components (Figure).

A human habitat can be made comfortable by closely mimicking the Earth's biosphere, which includes a diverse range of flora and fauna – elements that are often lacking in modern space stations. The creation of a General Planetary Vehicle would facilitate the construction of more advanced structures.

By harmoniously designing the ECH space, we can develop an enclosed ecosystem that, combined with contemporary technological advancements, closely resembles Earth conditions and is suitable for long-term human habitation. Addressing issues such as cramped quarters, limited social interaction, the absence of gravity and the unavailability of familiar earthly food can be managed at the design stage of the ECH. The proposed planning approach will incorporate various biological and anthropogenic ecosystems, thereby creating a more favorable environment for humans.

One of the primary goals in close living environments, such as space missions, is to cultivate harmonious relationships among crew members. To achieve this, it is crucial to form teams that exhibit a high degree of psychological and operational compatibility – often referred to as small-group compatibility. This necessitates a careful psychological selection process for candidates.

Socionics can serve as an effective tool in this context. Broadly defined, socionics is the study of psychoinformation systems – encompassing individuals, groups, cultures and states – and their interactions. It focuses on the types of information metabolism.

Drawing on information models of the psyche, socionics has developed a theory of intertype relations. This theory allows for the prediction of psychological and working compatibility between individuals. By applying socionics, stable teams with high productivity and a positive sociopsychological climate can be formed, which is especially vital for enclosed groups such as cosmonauts, sailors, geologists and polar explorers. This consideration becomes even more critical in extreme environments where human factor is paramount.

The theoretical aspects of intertype relations have been validated through model experiments. In these studies, distinct groups were assembled, and their relationships, information exchange, communication patterns and behavioral dynamics were analyzed. Researchers identified groups with similar cognitive styles, work motivations and relaxation dynamics, as well as those where certain members hindered communication and cooperation.

Based on the theory of intertype relations, real teams have been successfully formed. For instance, since 1992, specialists from the International Institute of Socionics have been creating and reorganizing production and management units in the Far North, comprising over 150 small groups. These efforts were grounded in principles of psychoemotional and operational compatibility, with ongoing monitoring conducted over 5 to 7 years. Findings indicate that socionics and its practical applications effectively address these challenges, revealing the information structure of the psyche and predicting the nature of psychoemotional interactions – from mutual understanding to conflict – along with insights into the dynamics and development markers of specific work and interpersonal relationships [10].

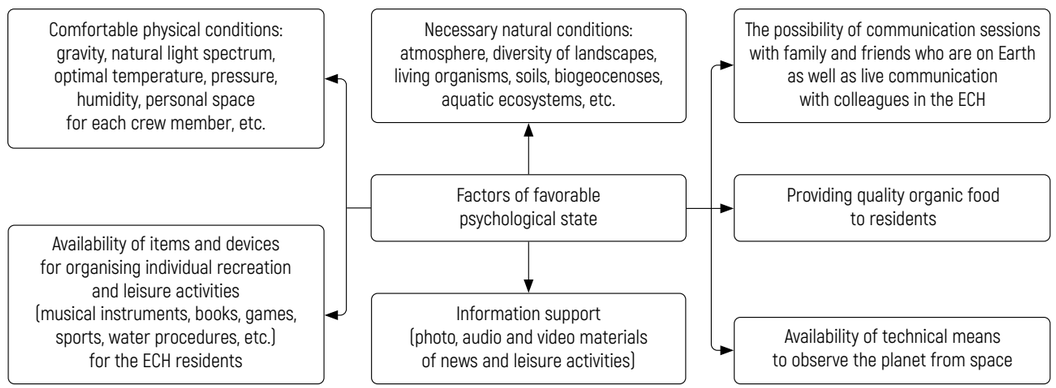

Figure – Factors of favorable psychological state of ECH residents

The establishment of groups in the ECH grounded in the theory of intertype relations serves as a crucial foundation for creating cohesive teams. Individuals living harmoniously in organized space will naturally enhance the quality of their relationships. Small groups with shared interests will help fulfill their social needs.

Monitoring and assessing the psycho-emotional states of individuals is particularly vital in the ECH environment. Private consultations between psychologists and each crew member can serve as an effective diagnostic tool. In western psychiatric practice, such initiatives, introduced by NASA, have become integral components of psychological support system.

During these consultations, topics may include the psychological challenges of their current phase in orbit, sleep quality and experiences during spaceflight. These private sessions facilitate a more effective approach to addressing the psychological issues faced by individuals under stress, helping to overcome communication barriers and enhance psychological resilience and motivation.

Furthermore, it is essential to consider incorporating certified clinical psychologists with the relevant means and equipment, psychoneurologists and specialists in work and rest regimes into the ECH crew. Their roles would involve conducting psychoneurological assessments, monitoring the well-being of the ECH residents, maintaining their work capacity and managing conflict situations.

This practice has proven effective at the Mission Control Center, where a dedicated team of psychologists and psychoneurologists is always on duty. They listen to radio communications between cosmonauts and Earth and periodically conduct individual consultations. By analyzing the speech patterns and communication styles of crew members, specialists can gain valuable insights into their mental health, stress levels and interpersonal dynamics within the team.

Conclusion

The analysis presented highlights the significant relevance of psychological adaptation for individuals during extended stays in near-Earth space. The psychological challenges that arise during long-duration flights are varied and influenced by multiple factors, necessitating further attention from educational institutions and the scientific community. It is essential to thoughtfully consider the psychological support available to the ECH residents. Ongoing research into adaptation mechanisms is vital to mitigating the negative impacts of prolonged near-Earth habitation on mental well-being.

This article reviews over 50 years of psychological support measures for cosmonauts and offers the following evidence-based recommendations for fostering a healthy psychological environment within an enclosed artificial biosphere:

- quality living conditions: the ECH residents should have access to high-quality organic food, comfortable physical and natural environments and resources for individual recreation and leisure;
- candidate selection: one of the most crucial factors in ensuring a favorable climate in the ECH is the selection of candidates based on psychological and operational compatibility; forming small groups should adhere to the principles of intertype relations as proposed by socionics;
- psychological consultations: private consultations between psychologists and each ECH resident can serve as a valuable diagnostic tool for understanding their psychoemotional states;
- inclusion of medical professionals: it is advisable to include full-time doctors certified in clinical psychology with the relevant means and equipment, psychoneurologists and specialists in work and rest regimes within the ECH crew; these professionals will conduct psychoneurological monitoring.

The insights gained from providing psychological support to the ECH residents can be applied on Earth to individuals working in environments similar to those of extended space missions, such as polar explorers, submariners, and other similar professions sector-specific in terms of psychology. These principles can also be relevant during pandemics when people experience prolonged social isolation, as well as in medical contexts where patients undergo long-term rehabilitation away from social interaction.

Given the importance of these ideas and the need for their ongoing refinement and testing, this topic will continue to be explored in future scientific research.

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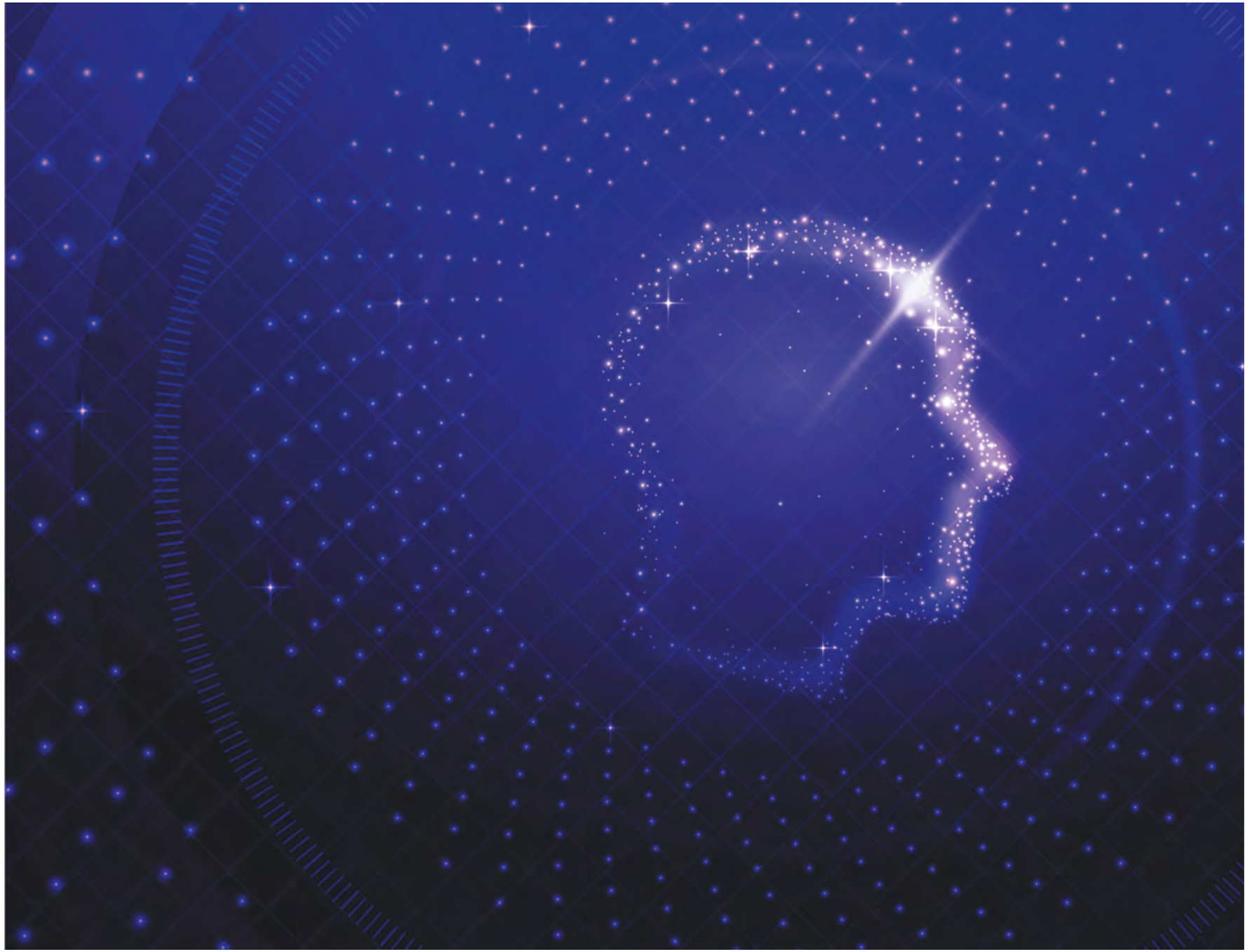

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Personnel Training for Biospheric Civilization: Sociocultural and Cybernetic Approach

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The need for a new education doctrine in the Union State of Russia and Belarus aimed at training personnel for a biospheric civilization is substantiated. The current shortage of engineers in space and other material production sectors is examined. The focus is on the importance of preparing specialists for future-demand professions in the field of relict solar bioenergy, biospheric agriculture, construction of linear cities and string rail transport. Drawing on the developments of engineer and inventor A. Unitsky, a scientifically grounded approach to the creation of the doctrine is proposed. It aligns with the requirements for training specialists in biospheric engineering technologies which have the potential to become key industries for the Union State, propelling it into global leadership in both moral and technological progress. The interconnection of fundamental knowledge, practical skills, creativity, moral education, culture and science is emphasized, along with the critical role of sociocultural atmosphere in education. Additionally, the need for cybernetic planning to implement a competent educational policy is outlined.

It is proposed that the doctrine be based on the concept of education for a sovereign Russia, developed by scientists from the public organization "Education – Our Future," led by Doctor of Philosophical Sciences and Ph.D. in Pedagogical Sciences I. Dzherelievskaya. To align state education policy with the personnel needs of various industries, the doctrine incorporates the practice of cybernetic planning – a dynamic model of interbranch-intersectoral balance developed by Professor at M.V. Lomonosov Moscow State University, Doctor of Economic Sciences E. Veduta.

The implementation of this new education strategy within the Union State will not only lead to the continuous improvement of its socioeconomic indicators but also foster the development of a moral human creator essential for building a biospheric future for our planet.

Keywords:
biospheric civilization, Cyberplan, dynamic model of interbranch-intersectoral balance, education doctrine, personnel training, staff shortage.

Introduction

Global economic and cultural transformations, along with the pervasive influence of information technologies, pose significant challenges for the state in cultivating individuals who meet contemporary societal demands.

To achieve a biosphere-oriented civilization supported by a new economic model, society requires well-educated, morally grounded and skillful individuals. These individuals should be capable of making responsible decisions, forecasting the consequences of their actions, working collaboratively and being prepared to defend their homeland.

Addressing these challenges necessitates the implementation of innovative biosphere-oriented technologies and the acquisition of new knowledge. Central to this development is the creation of an innovation-driven economy, with the education system as a crucial institution [1]. It is important to recognize that advancements in science and technology alone will not suffice. Equally vital is acknowledging the deep human need for self-realization and creativity, which calls for a strong connection between material civilization, culture and spirituality [2].

To cultivate individuals with these qualities, a new education doctrine in the Union State of Russia and Belarus is essential. It should articulate the purpose and values of education, outlining a systematic approach to developing a new educational framework and its expected outcomes for citizens both within the Union State and globally.

The overemphasis on pedagogical techniques and methodologies at the expense of the fundamental purpose of education, the disconnect between educational strategies and the broader development goals of the state, along with attempts to align education with the ever-changing demands of the market economy, as well as lack of well-organized and fast direct communication between educational institutions and business entities have created a personnel crisis. This crisis is characterized by a widespread shortage of highly qualified specialists and highlights the lack of manual workers, as reported by many employers in Russia and Belarus.

The objective of disciplines such as pedagogy, philosophy and cybernetics is to develop an educational system that facilitates a significant improvement in personnel training. This enhancement will, in turn, contribute to the civilizational progress of both the Union State and the world at large.

Staff Shortage in Key Economic Sectors: Challenges and Causes

Staff shortage has emerged as a pressing issue in both Russia and Belarus between 2022 and 2024. Sociological surveys and labor experts state a significant deficit of qualified specialists in the leading industries of both nations.

As of 2023, Russia faced a personnel shortfall of 4.8 mln people [3]. Figure 1 shows the analysis of the employee provision for Russian enterprises in 2023–2024 [4]. Media reports indicate that certain sectors, such as the automotive industry, electrical equipment manufacturing and petroleum production, are experiencing particularly acute shortages of skilled workers [5].

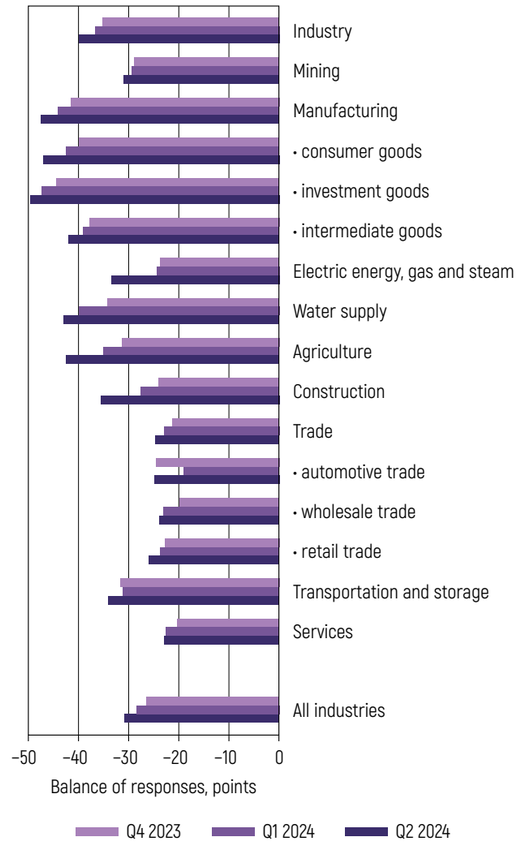

Figure 1 – Analysis of employee provision for Russian enterprises in 2023–2024

In Belarus, state organizations in construction, agriculture and education are feeling the impact of this personnel crisis [6]. Industrial enterprises are also understaffed; for instance, OJSC MAZ lacks 13 % of its workforce, while OJSC Minsk Motor Plant is facing high turnover rates among fitters, turners, electricians and other skilled roles [7]. Currently, Belarus requires over 133,000 specialists [8], which constitutes approximately 2.7 % of its labor force [9].

Top officials in both countries have acknowledged the gravity of the labor shortage. In August 2023, Russian Prime Minister M. Mishustin referred to it as a significant challenge for the national economy [10]. In May 2023, the President of the Russian Federation V. Putin signed Decree No. 342, urging regional public authorities to implement additional measures to create attractive financial and social incentives aimed at retaining the population and preserving human capital [11]. In August 2023, he emphasized the need for "personnel sovereignty" by training specialists in scarce professions [12]. In early 2024, at a meeting in Tula with activists from the All-Russian People's Front, V. Putin reiterated the importance of making the country self-sufficient, which he identified as a key aspect of sovereignty [13]. Meanwhile, in April 2024, the President of the Republic of Belarus A. Lukashenko highlighted the urgent need for more workers, particularly in manual labor sectors [14].

Both countries are addressing these challenges at a strategic level. In February 2024, during his Address to the Federal Assembly, the Head of the Russian Federation announced the launch of a new national project titled "Personnel," which comprises four key initiatives: employment for graduates; retraining of current employees; workplace injury reduction; encouraging youth participation in entrepreneurship [15, 16].

In the Republic of Belarus, the Concept of State Personnel Policy was approved to establish a comprehensive system for the effective formation and utilization of labor resources, thereby enhancing the human resource potential across various economic sectors and areas of activity [17].

Since the space industry is strategically significant for the Union State [18], it is crucial to address the shortage of specialists within its enterprises. It is important to recognize that collaboration between Russia and Belarus in the space sector began during the Soviet era. Scientific organizations and industrial enterprises of the Belarusian SSR were integral to the scientific and production cooperation of the USSR in the development of space rocket technology [19]. The Treaty on the Creation of the Union State, signed on December 8, 1999, emphasized the creation and operation of a common scientific, technological and information space between Russia and Belarus, with space facilities and technologies as key components [20].

For several decades, research on near space exploration and the launch industry into near-Earth orbit has been hold in Belarus by scientist, engineer and entrepreneur A. Unitsky. He has also proposed a project aimed at ecological improvement of our planet, enhancing the habitat and quality of life for people. This project includes the further innovative engineering technologies:

- relict solar bioenergy;
- biospheric agriculture;
- construction technologies for linear city (uCity) development;
- transport and infrastructural complexes of the "second level" – Unitsky String Transport (uST) [21].

All fields related to space, transport, agriculture and construction technologies require qualified, young personnel with a broad perspective, fundamental knowledge and substantial experience. Breakthrough innovations in both space and terrestrial applications are unattainable without engineers who have mastered their disciplines and possess interdisciplinary expertise.

The most promising profession in this context is that of an engineer in a rocket and space industry (RSI). This role is vital due to the many revolutionary discoveries in science and technology associated with space exploration in the 20th and 21st centuries. The professional domains for engineers in this field are diverse, encompassing various specialties such as physics, chemistry, biology, agronomy, design and information technology.

However, the space industry in both Russia and Belarus has been grappling with a significant shortage of employees for several years. In the first four months of 2023, the demand for spacecraft specialists surged fivefold compared to the same period in 2022. During this time, approximately 400 job vacancies for engineers, programmers and skilled workers were announced in Russia [22]. By the end of 2023, it became clear that the development of competencies within Roscosmos is resource-intensive, and there will soon be a substantial personnel shortage in the industry, hindering growth in the space sector [23].

Regarding the references [24–32], the authors of this article identify several reasons for the staff shortage in the RSI, categorizing them into socioeconomic, philosophical and psychological factors (Figure 2).

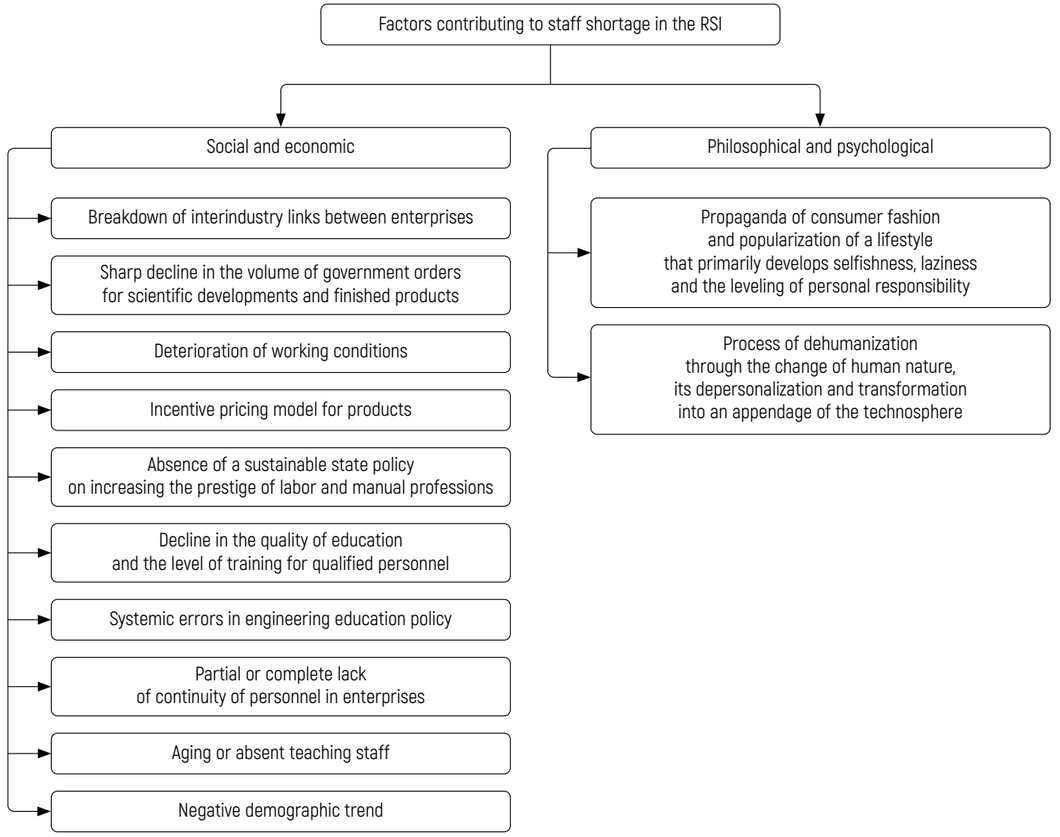

Figure 2 – Factors contributing to staff shortage in the RSI of Russia and Belarus

Another contributing factor to the current personnel crisis in the RSI, as well as in other strategically important industries in Russia, is the lack of alignment between foundational documents outlining future educational development and the country's overall development strategy. For instance, the national project "Education" aims to create conditions for fostering a harmoniously developed and socially responsible individual grounded in the spiritual and moral values of the Russian Federation's peoples and their historical and cultural traditions [33]. This aligns with Presidential Decree No. 809, issued on November 9, 2022, which endorses the principles of state policy for preserving and strengthening traditional Russian spiritual and moral values [34]. However, the document, including its subordinate federal projects, fails to provide concrete, comprehensive measures to achieve these goals.

In Belarus, the Resolution of the Council of Ministers dated November 30, 2021 (No. 683), titled "On the Concept for the Development of the Education System of the Republic of Belarus Until 2030," emphasizes that modern global economic and social changes present new challenges for the country. Among them are enhancing national competitiveness and ensuring the state's resilience amid economic and social transformations [1].

The document's content is directly and indirectly linked to the strategic goal of sustainable development in Belarus, which aims to ensure a high standard of living for its citizens and create conditions for the harmonious development of individuals, all while transitioning to a highly efficient economy, based on knowledge and innovations, upon favorable environment for future generations [35].

On the Need to Establish an Education Doctrine for Biospheric Civilization in the Union State

Addressing the personnel challenge is more complex than the goals and objectives outlined in existing documents, necessitating a multifaceted and cybernetic approach that incorporates feedback mechanisms.

Given the economic and cultural unity of Russia and Belarus, there is a pressing need to create a doctrine aimed at training specialists for the biosphere's sustainable development. This way is essential for facilitating the Union State's transition to a new economic model that prioritizes the enhancement of both material and spiritual well-being for its citizens. The development of this doctrine should be grounded in cybernetic principles, ensuring direct feedback from all stakeholders involved in the educational process. Additionally, it should focus on cultivating a unique sociocultural environment that supports this vision.

Cybernetic Approach to Education Doctrine in the Union State

The primary tool for cybernetic management within the education, upbringing and training system aimed at enhancing people's welfare is cybernetic planning, coupled with scientific forecasting based on mathematical modeling. This approach accounts for the simultaneous demand for skills and intelligence within the Union State.

Cybernetic planning in the education and training system is viewed as a component of a dynamic model of interbranch-intersectoral balance, known as Cyberplan. It serves as a management tool for the economy, designed to benefit the populace [36]. The theory behind this planning is being developed by the "Artificial Intelligence in Economics" section of the Scientific Council Under the Presidium of the Russian Academy of Sciences, led by Professor E. Veduta, alongside members of the public organization "Education – Our Future," which includes teachers, scientists and parents. Thus, cybernetic planning within the education system is an integral part of the Cyberplan, currently in a stage of scientific advancement.

The foundation of this planning involves balancing the needs of economic entities for specialists with the state's capacity to train such personnel, assuming that education is treated as a public good. The analysis considers current needs alongside a rolling planning horizon of 5, 10 or even 30 years.

The sequence of cybernetic planning is outlined in Figure 3, demonstrating how it generates the indicators necessary for implementing the state's educational and personnel policies.

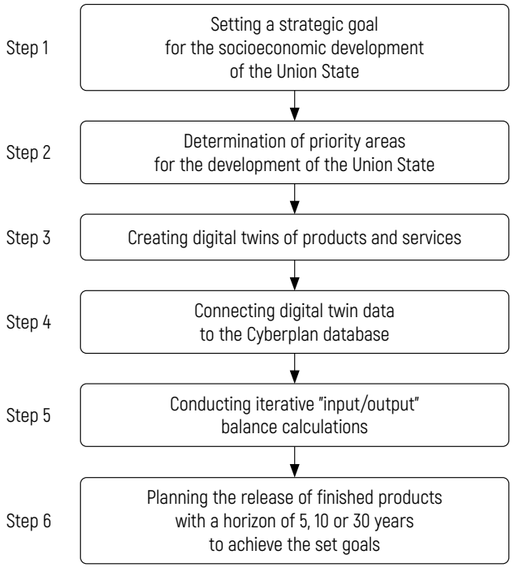

Figure 3 – Steps of cybernetic planning for implementation of the Union State policy in the field of education

The first step in cybernetic planning is to establish a strategic goal for the country's socioeconomic development. In our case, it is the continuous improvement of people's welfare, which entails providing the population with essential material and spiritual benefits [37]. A specific manifestation of this goal for the Union State could be the creation of a biospheric civilization, as proposed by A. Unitsky. The model encompasses the enhancement of all means vital for human reproduction:

- nature as the primary habitat for sustaining vital forces;
- workplaces as main environment for acquiring knowledge and skills through professional mastery;
- housing and public spaces as essential settings for fulfilling social functions.

The second step involves identifying the priority areas for the Union State's development. Drawing from A. Unitsky's concept of biospheric civilization, this includes the uSpace geocosmic program, which aims for the non-rocket exploration of near space as a site for industrial enterprises. It also encompasses the construction of uCities, which consist of pedestrian-friendly cluster-type settlements, alongside initiatives in relict solar bioenergy and biospheric agriculture [21].

The third step focuses on creating digital twins of products and services. These digital representations are established during the raw material extraction stage and continue throughout the entire production and supply chain to the final consumer. Data for these digital twins is collected in real time through a system that includes product labeling, invoices, staff schedules and various other enterprise reports, ensuring that all necessary information for accurate calculations is readily available.

The fourth step involves integrating the information from these digital twins into the Cyberplan database.

The fifth step requires conducting iterative "input/output" balance calculations using algorithms based on a dynamic model of interbranch-intersectoral balance. This helps determine the needs of economic entities for final products and services, as well as the current production capacity – including labor resources – to meet those demands. The needs database within Cyberplan updates in real time, reflecting current consumer demand, income levels and purchasing power. Prices for goods and services are established as equilibrium prices rather than fixed planning values. At this stage, the quantity and quality of required personnel by sector are calculated, along with the capacity of educational institutions to train them. The Cyberplan assumes full employment, ensuring sufficient job availability for the entire working population, virtually eliminating long-term unemployment, and matching job opportunities with individuals' professional skills, education and experience.

The results of these calculations inform adjustments to the state's current education and training policies. This may involve accelerating the training of specific specialists, enhancing retraining and continuing education programs, and increasing access to higher education and scientific resources for a broader audience, particularly in light of automation and the digitalization of routine processes.

The sixth step consists of planning the output of finished products with a horizon of 5, 10 or 30 years to realize the established goals and priorities for the state's development. At this stage, modeling socioeconomic development takes precedence over mere forecasting and foresight projects. Here, the education strategy for the next 5, 10 or 30 years is formulated, future professions are defined, and the educational framework for training new personnel is established. This may lead to the emergence of new educational fields, such as specialists in systems engineering [38], solar bioenergy, biospheric agronomy, eco-settlement construction, string space transport engineering and many other essential professions.

The Cyberplan undergoes continuous adjustments and recalculations. This proactive approach to socioeconomic development ensures that the education system aligns with contemporary needs. It emphasizes deep fundamental knowledge and promotes an interdisciplinary framework, equipping children from an early age with practical skills essential for their psycho-physiological growth. Additionally, it provides adults with opportunities for professional advancement, enabling them to master new specialties and acquire advanced scientific knowledge.

Sociocultural Approach to Education Doctrine in the Union State

The doctrine cannot be confined solely to cybernetic management of the education system. To develop a comprehensive strategy, it is essential to incorporate a philosophical and ideological framework. Education and upbringing, which focus on human reproduction, should aim for deepening the personality and improving it. This involves not only fostering creative abilities but also advancing society as a whole, ensuring that these capabilities are harmoniously utilized to achieve the goals of both society and the state [39]. This process unfolds within a sociocultural environment, which the doctrine must clearly define.

A significant factor contributing to the personnel crisis is the misguided motivations of individuals, such as an emphasis on individualism, success, efficiency and overconsumption, that fosters the process of dehumanization. To address this issue, we must reintegrate high meanings, genuine values and life principles into our social fabric. This involves cultivating a creative and highly moral sociocultural environment, where national culture plays a pivotal role.

The cultural environment is a multilayered construct of values and meanings, encompassing the personal level, which influences individual behavior in daily life; the social level, which shapes communal values; and the transcendental level, which pertains to eternal, absolute values being the realm of meaning-making [40]. It is crucial to establish a sociocultural environment where people are educated

and inspired by ideals that are deeply rooted in our traditions, history and culture. In this context, national culture celebrates the laborer and the creator, encouraging individuals to build a Great Country based on the best domestic and international practices. The information space of the Union State ought to promote collective creative labor, share best practices and support national norms and traditions. The sociocultural atmosphere should foster unity among people, unveil their potential, strengthen trust in authorities and encourage a responsible, communal spirit.

The education system must aim to cultivate spiritually and morally grounded, highly intelligent individuals who are committed to self-education, hard work and service to their homeland. It should focus on nurturing the inner world of each person, emphasizing the understanding of life's meaning and the significance of their work. Such individuals, characterized by a strong moral compass and a sense of responsibility, will become creators, patriots and architects of the world. In terms of teaching methodologies, the primary goal is to foster a new worldview among students, shaped by a holistic understanding of the world that bridges science focused on concepts, philosophy, religion and art, which explore meanings.

The selection of methods, techniques, approaches and educational programs should align with the values, significance and objectives of education. If the Union State aspires to achieve a scientific and technological breakthrough while preserving sovereignty and traditional spiritual and moral values, improving citizens' welfare, enhancing their living conditions and exploring outer space – while maintaining humanity – then these objectives will guide the methods used to transmit knowledge, skills, values and meanings from one individual to another.

Expected Results of Developing and Implementing Education Doctrine in the Union State

As A. Unitsky aptly notes in his book "Ingenium. The World as an Engineering Project," "education is something everyone is involved in. Through education, a socially oriented person is formed. At any moment of time. And that is why all reforms here and now should start with education." Therefore, all reforms must begin with education. He emphasizes that "the task of the educational system is to familiarize the forming consciousness with the basic ideas and principles of moral and ethical doctrines" [41].

The conceptual foundation of the new doctrine centers on aligning education and upbringing with the higher meanings of existence while relying on fundamental scientific knowledge. The anticipated outcome of this educational process is the cultivation of human creator who possess:

- ability to set ambitious goals, devise strategies to achieve them and follow through;
- empathy, moral self-regulation and a humanity-centered perspective toward the world;
- proficiency in various types of thinking, ranging from figurative to dialectical [32].

Implementing this doctrine offers several advantages:

- a significant enhancement in national security through the stability of the social system, fostered by the development of well-rounded individuals;
- positive improvements in socioeconomic indicators;
- a surge in collective creativity, scientific innovation and public enthusiasm.

For the doctrine to be effectively implemented, it must be a mass endeavor, necessitating adjustments in the human environment and sociocultural atmosphere. This environment should promote the harmonization of scientific and technological progress with social relationships and societal norms.

The expected outcome from developing and applying the doctrine is the establishment of a planetary worldview [42] and a substantial improvement in people's quality of life, which serves as both a goal and a condition for progress. Unlike living standards, which fluctuate over time, the parameters of quality of life remain constant. These foundational aspects are affirmed by world religions, which emphasize universal commandments such as "do not kill," "do not steal," "do not commit adultery," "do not despair" and "be fruitful and multiply." To assess the quality of life, the following statistical indicators reflecting fundamental human values are utilized [43]:

1) physical health:

- birth rate of the population;
- mortality rate;
- active life expectancy;
- number of citizens with chronic, serious noncommunicable diseases;
- number of individuals leading a healthy lifestyle;

2) social health:

- share of long-lasting marriages (indicative of family stability);
- number of marriages among those under 30 (reflecting social optimism);
- proportion of citizens with higher education (indicating intellectual development);
- employment rates (showing professional demand);
- number of social orphans (reflecting societal care);
- number of adoptions (indicative of moral maturity);
- number of complaints regarding constitutional rights violations (showing respect for freedom and human rights);
- income disparity between affluent and impoverished families (indicating social polarization);

3) spiritual health:

- suicide rates (reflecting the meaning and value of life);
- incidence of offenses against human life and health (indicating levels of humanity);
- crimes against property (showing the fairness of wealth distribution);
- number of discoveries and inventions (demonstrating scientific progress and educational quality);
- number of new artistic works (reflecting cultural development).

This approach to the doctrine aims to create a society characterized by creative and fulfilling lives. As A. Unitsky succinctly states, "the highest individual goal is individual happiness. The highest common goal is common happiness. Such a goal can only be impersonal, and therefore, it is achievable only on the path of engineering without any priests, in this case, power "elites," claiming special laurels and percentages of profit" [41].

Conclusion

A. Unitsky views the historical process as a form of social development driven by creative work. It is difficult to disagree with his assertion in "Ingenium. The World as an Engineering Project" that "every significant change (of the public relations. – *The author's note*) is provided by some technology created by engineers" [41]. Today, engineers have laid the groundwork for a breakthrough towards effective and ethical social relations, leading to an unprecedented advancement of productive forces. The challenge now lies in transforming society by consciously moving away from a culture of selfish consumption and private property towards a culture of creative collaboration and shared planetary goals. This transformation can be achieved through education and the sociocultural environment, using a cybernetic approach to managing complex systems, including socioeconomic development. Given that the current anthropological crisis is not a result of rapid technological advancement but rather the stagnation of sociocultural progress, the future of civilization hinges on our ability to overcome this gap. Addressing the crisis will necessitate revolutionary changes in social and cultural spheres as well as in economic management approaches.

The proposed doctrinal framework fosters the alignment of collective intelligence and enhances humanity's capacity to impact the natural environment, driven by accelerated scientific and technological progress. By shifting the mindset of the present generation in the Union State, we can guide the global population toward harmonious development, aspiring to Vernadsky's noosphere – a new organizational form that emerges from the interplay of nature and society, transforming the world through human creativity, grounded in scientific thought and intellect.

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Impact of Near Space Industrialization on Socioeconomic Development of Equatorial South American Countries

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The necessity for developing fundamentally new approaches to the exploration of near-Earth space has been established, driven by rapid advancements in space technology, the increasing importance of environmental protection and the growing global challenges facing humanity.

The relevance of implementing the uSpace program for the world community is discussed. An analysis of the current economic conditions in equatorial South American countries (Brazil, Colombia, Ecuador), where it is planned to locate a takeoff and landing, transport and infrastructure complex for a geocosmic spacecraft – a General Planetary Vehicle, is presented. Global and local effects of the near space industrialization program on human civilization as a whole and on the specified nations in particular are identified and classified. The potential for socioeconomic benefits from its realization is noted.

Keywords:
General Planetary Vehicle (GPV), global effect, local effect, near space industrialization, space industry.

Introduction

The exploration of near-Earth space is one of the priorities of humankind, which largely determines the future of our civilization. Investments in space technologies and research bring great profits, finding practical application in real sectors of the economy.

For the first time, the international community's interest in this issue was reflected in the resolution of the UN General Assembly in 1958, titled Question of the Peaceful Use of Outer Space [1]. The impetus for this increased attention was the launch of the first artificial satellite of the Earth by the Soviet Union in 1957. Since then, UN has been coordinating the political, legal, scientific and technical aspects of space exploration, emphasizing the importance of its development for the benefit of humanity.

Today, the priorities of space activities are gradually shifting from general scientific research to the practical application and commercialization of the results of near-Earth space exploration. This process is impossible without an innovative approach, modernization of basic industries of the economy, development of fundamental and applied sciences and education. The space industry opens up new opportunities for energy, meteorology, telecommunications, transport, aviation, navigation and other sectors of the economy.

The American analytical company BryceTech stated that the value of the global space economy is currently estimated at about 400 bln USD [2]. According to preliminary forecasts, by 2026 it will amount to more than 500 bln USD, and by 2030 it will reach 1 tln USD and continue to grow (Figure 1).

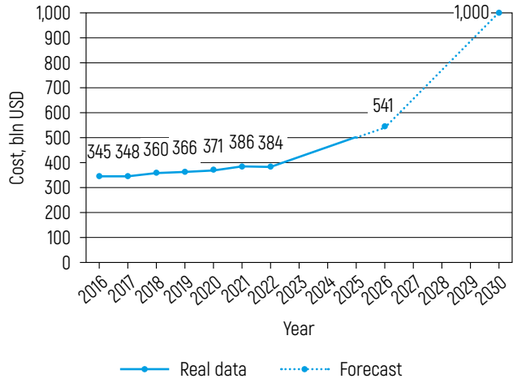

Figure 1 – Dynamics and forecast of global space economy in 2016–2030

The development of the space industry and the results achieved in this area also contribute to space expansion, opening up prospects for the exploration of new resources: spatial, energy, technological (weightlessness, deep vacuum, etc.) and raw materials. Research in this area expands scientific knowledge, helps to establish international contacts and strengthen the positions of states on the world stage.

One of the directions of global space expansion is the industrialization of near-Earth space, which makes it possible to create a new economy. However, the established traditional form of space exploration causes enormous harm to the planet and makes it impossible to use the available resources rationally. Due to its high cost and the traditionalism of government departments, the industry in question and the promising areas of its development could not become widely available, are ineffective and poorly integrated into the global industry and economic environment [3].

In this regard, there is a growing need to form innovative programs capable of bringing practical cosmonautics to a fundamentally different level. One of the rational concepts for the creation of the space industry is the uSpace program, developed by researcher A. Unitsky, which proposes to bring the environmentally hazardous part of the Earth's industry into near-Earth space in order to ensure the sustainable development of humankind and preserve the natural biosphere balance on the planet [4].

Analysis of Equatorial South American Countries of as Participants of uSpace Geocosmic Program

The objective of the first project stage is the construction of the General Planetary Vehicle (GPV) takeoff and landing overpass with a total length of more than 40,000 km, located along or parallel to the Earth's equator (at a distance of up to 100 km) and passing through the territory of 13 countries of Africa, South America and Asia. The creation of the GPV will require attracting global investments of approximately 2 tln USD as well as a certain political will and the use of significant labor, natural materials and energy resources from the states where the overpass will be located [5].

With sufficient technological, economic and resource potential (Table), the equatorial countries of South America – Brazil, Colombia and Ecuador – can become a launching pad for the development and strengthening of international relations within the framework of the project.

Brazil, Colombia and Ecuador are actively developing the space industry, using science and technology for sustainable socioeconomic growth and national security.

Table – The main statistical and economic indicators of the equatorial countries of South America [6]

Indicator	Value by country		
	Brazil	Colombia	Ecuador
Population, mln people (2024)	217	52.2	18.3
GDP per capita, USD (2022)	8,918	6,624	6,391
GDP, bln USD (2022)	1,920.1	343.6	115
Ease of doing business index	124	67	129

Brazil participates in space programs and missions, launches satellites, develops technologies, etc. Among its organizations are the Brazilian Space Agency (AEB), the National Institute for Space Research (INPE), the Alcântara Space Center and others. Colombia has the Colombian Space Agency (AEC), the Colombian Institute of Aeronautics and Space, the astronomical observatory based at Sergio Arboleda University and others. Ecuador is just beginning its journey in this field, but is already taking steps to participate in space programs and research, demonstrating interest and commitment to becoming involved in this industry.

Since the GPV launch is associated with high energy costs (the initial energy reserve required to raise the GPV is 4.2×10^{11} kW·h), the project is needed not only its own power plants but also the ability to obtain energy from the network of the countries of the planet's equatorial belt [7]. Brazil has a huge energy potential and is one of the largest electricity producers in the world (in 2023 it generated 7.1×10^{11} kW·h) [8]. Colombia's energy industry is showing significant growth: its capacity has doubled over the past 20 years. The Government of Ecuador is taking measures to stabilize the situation in the energy sector by replacing oil power plants with hydroelectric ones.

The equatorial countries of South America, although they differ in their level of socioeconomic development, are jointly able to make a huge contribution to the implementation of the uSpace project, having the necessary potential for the production of capital- and knowledge-intensive products in the oil and gas, mining, telecommunications, metallurgy and aerospace industries.

Directions for Obtaining Socioeconomic Benefits from uSpace Geocosmic Program Implementation

Since the implementation of the uSpace program is a long-term process that involves several stages and affects both the global community and individual countries, its impact can be broadly divided into global and local effects (Figure 2).

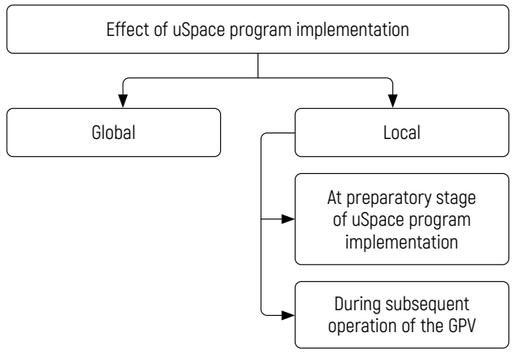

Figure 2 – Types of effects from implementation of uSpace geocosmic program

Global Effect

A positive result for all humankind is expected to be achieved at the stage of practical industrialization of space. At the same time, the countries where the launch overpass will be located (including the equatorial countries of South America) will benefit both during the preparatory phase of the project and during the subsequent operation of the GPV.

The global effect of the uSpace geocosmic program implementation is based on the creation of fundamentally new areas of economic activity.

1. Operation of the GPV, a highly efficient and environmentally friendly vehicle for geocosmic transportation of passengers and cargo (up to 10 mln tons of cargo and 10 mln passengers per flight). The main effect of using the GPV is a significant reduction in transportation costs compared to traditional launch vehicles. The savings on the delivery of a ton of cargo to equatorial orbits will be approximately 10 mln USD.

2. Creation and development of businesses in the near-Earth orbit for basic industries such as energy, mechanical engineering, metalworking, chemical production, pharmaceuticals, etc. The economic efficiency and qualitative competitive advantages of the space industry are due to the easily accessible and inexhaustible nature of space resources and the physical features of its technological environment.

3. Mining of space minerals. The significant concentration of valuable resources in asteroids (iron, nickel, magnesium, cobalt, titanium, precious and rare earth metals, etc.) gives the world community access to the resources of the main asteroid belt in the amount of 700 quintillion USD (in the depths of an average asteroid with a diameter of 1.5 km there are metals worth about 40 tln USD – according to the inflation index) [9]. The economic efficiency of obtaining asteroid minerals is due to the reduction of costs associated with the extraction, transportation and processing of ore raw materials. In addition, the expenses of cleaning and disposal of harmful emissions, the return of waste rock to the quarry and its reclamation will be eliminated, which, considering environmental requirements, must be carried out on planet Earth but is not necessary in space conditions.

4. Using the GPV as a giant linear kinetic power plant. The high economic efficiency of solar electricity generated in near-Earth space is determined by the large specific capacity of the solar flux available around the clock in space and the absence of fuel costs reaching 50–70 % of the cost of electricity produced by traditional terrestrial power plants.

5. Construction and operation of the international network of transport, energy and information communications uNet and its land transport and infrastructure complex with a length of about 25 mln km to ensure intercontinental (including across seas and oceans), continental, regional and urban cargo and passenger transportation by unpiloted electric rail vehicles on steel wheels (uPods) [10]. Savings on the construction of such routes in comparison with other types of overpass roads will amount to more than 100 tln USD.

6. Construction of the Equatorial Linear City (ELC), i.e., cluster-type settlements characterized by high efficiency of urban management, decent standard of living and comfortable working conditions, along the GPV overpass. The ELC represents the development of residential, administrative and industrial clusters using eco-oriented technologies: the supply of green electricity and heat, natural food as well as the formation of high transport and communication accessibility. The new urban concept is capable of providing housing for more than 100 mln people [10].

The global impact of the near-Earth space industrialization program will be shared among all countries of the world community, including the equatorial states of South America, depending on their contribution to the development of space infrastructure and participation in the project within the framework of international cooperation.

Local Effect

Positive local effect is connected with the direct territorial involvement of the equatorial South American countries in the preparatory stage of the organizational plan for the implementation of the uSpace program as well as with the process of subsequent operation of the GPV and the performance of geocosmic flights.

Local effect at the preparatory stage of the program implementation includes the following:

1) creation of large research centers, nonprofit organizations and interdepartmental institutions based on existing space agencies in South America and the Caribbean;

2) loading and expanding the existing capacities of the industries of equatorial South America involved in the manufacturing of the GPV and the construction of the take-off and landing overpass, such as metalworking, machine building, construction, radio electronics, energy, aerospace, etc. The erection of more than 3,000 km of the GPV overpass in Brazil, Colombia and Ecuador alone will expand the production capacities of leading industries worth over 50 bln USD (about 8 mln tons of metal structures and 1 mln m^3 of reinforced concrete);

3) construction of fundamentally new industrial facilities that will become part of the space industry (clusters for the assembly, maintenance and repair of the GPV nodes);

4) establishment of transport and logistics centers and a high-performance transport network for operations related to the movement, storage and distribution of space industry products across North and South America;

5) creation of a fuel and energy complex with an emphasis on innovative energy sources, such as relict solar bioenergy, capable of providing energy to all components of the geocosmic complex as well as the processes of takeoff and landing;

6) construction of the ELC with high urban efficiency indicators, a decent standard of living and comfortable working conditions for at least 50 mln people;

7) reducing unemployment by the creation of millions of new jobs in the industrial sector, training and retraining, eliminating factors that reduce professional and geographical mobility of the workforce via the formation of a developed housing market;

8) improving people's quality of life through effective engagement (maximizing the involvement of the working-age population in the economy, making optimal use of labor potential), sustainable income growth and improving the social environment;

9) investment development of the economy by attracting additional funds to projects aimed at creating innovative and high-tech industries, scientific institutes, educational entities and social, environmental and institutional infrastructure facilities;

10) strengthening and growth of human capital through investments in education, healthcare and science;

11) increasing the revenue side of the budgets of Brazil, Colombia and Ecuador, expanding the circle of taxpayers (innovative and high-tech industries, educational and scientific institutions, science and technology parks, etc.);

12) stimulating industrial cooperation, contributing to increased labor efficiency, technological modernization and the creation of capital-intensive products; the development of the equatorial countries of South America as international platforms for the implementation of high-tech, innovative projects with huge export potential.

The local effect of the GPV operation at the stage of basic and large-scale industrialization of near-Earth space is associated with the need to ensure the stable functioning of the geocosmic industry which needs continuous technological development in the production and infrastructural spheres.

The constant complication of technological processes, the intensification of information flows and the organization of new sectors of the economy in the process of near space industrialization require an increase in the educational level and cultural development of human, society and business. The operation of the GPV and maintenance of space transportation will lead to the creation of a large number of high-paying jobs for qualified personnel, which will become the foundation for the formation of growing prosperity, social integration and cohesion.

Conclusion

The implementation of the uSpace program in the equatorial South American countries (Brazil, Colombia and Ecuador) will ensure global and local effects and give impetus to international economic and social cooperation. At all stages of its implementation, the project will contribute to the sustainable development and economic security of countries, increasing the prosperity and quality of life of the population through synergy and scaling as well as strengthening the competitiveness of national economies and their positions in the global economic system.

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Global Problems of Humanity: Current State and Solutions

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The path of Earth's civilization from antiquity to modern society, with its vast array of discoveries and inventions, has not only fostered the development of science, technology and engineering but has also posed a real threat to the survival of all living things on our planet.
The overall increase in human material needs, driven by the chosen trajectory of our society, has led to an ecological crisis, the depletion of essential natural resources, food shortages and a range of other interrelated issues.

This article examines the global problems facing our civilization, the dynamics of their escalation and the methods proposed by the international community for their resolution. It underscores the importance of reevaluating humanity's developmental path to transition to a new qualitative level of existence. Alternative approaches to overcoming ecological threats are reviewed.

Keywords:
ecological problems, environment, global issues, growth limits, hunger, poverty.

Introduction

Throughout history, humanity has made remarkable progress, from the production of stone tools to the invention of robots, airplanes and artificial satellites. Along this journey, people have consistently sought to improve their standard of living and accelerate technological and scientific advancements. However, as civilization has grown more complex, it has increasingly faced deep crises that threaten its very existence.

Despite significant achievements in science and technology, as well as the widespread availability of knowledge, the number of global challenges facing humanity continues to rise. On the one hand, irrational human activities, growing consumption and economic processes have enhanced the quality of life; on the other hand, they often inflict severe damage on the environment. The escalation of ecological issues, in turn, exacerbates social problems and constrains further development.

At different times, many renowned scientists – such as D.H. Meadows, D.L. Meadows, M. Strong, R. Lenoir, E. Pestel, M. Rener, V. Sukachev, V. Vernadsky, M. Budyko, K. Hoffman and others – have expressed interest about these processes.

At the global level, numerous programs, including those actively supported by the United Nations, aim to address economic, social and environmental challenges. Nevertheless, despite growing interest in these issues, the study of them cannot be considered complete. The measures implemented by international, national and local nongovernmental organizations have not yet halted the processes of degradation.

The alternative to the existing solutions is a cohesive concept proposed by the engineer, designer and inventor A. Unitsky: the EcoSpace program. This initiative aims not only to enable humanity to live comfortably on Earth but also to address and repair the damage already inflicted on our planet's biosphere – a shared home for billions of species with a rich evolutionary history spanning billions of years.

The purpose of this paper is to examine and systematize the destructive changes occurring globally due to human activities. It will analyze historical attempts to resolve global environmental concerns and assess their current status. Additionally, the article seeks to demonstrate the effectiveness of the EcoSpace program, which presents economically viable and rational engineering solutions aimed at mitigating harmful anthropogenic impact on the Earth's biosphere from the technosphere.

History of Environmental Studies in the Global Community. The UN Sustainable Development Goals

As far back as the 6th to 4th centuries B.C., ancient thinkers contemplated the human impact on the surrounding environment. However, this issue began to receive serious academic attention only in the second half of the 20th century. The reason was driven by both the accumulation of knowledge about the surrounding world and the growing awareness of the damage caused by the Industrial Revolution, including the improper disposal of industrial waste and the uncontrolled exploitation of natural resources. During this period, new branches of ecological science and research began to emerge.

In 1972, a team of experts from the Massachusetts Institute of Technology led by D.L. Meadows – a specialist in system dynamics – prepared the first report "The Limits to Growth" for the Club of Rome[1]. The authors based the document on a computer model that examined five key trends in global development: population growth, industry, food production, the irrational use of nonrenewable resources and environmental pollution.

The report indicated that all these components were increasing annually according to what mathematicians refer to as the law of exponential growth. The authors concluded that existing models of economic growth, production and consumption were undermining the harmonious development of natural ecosystems, thereby hastening an ecological catastrophe. The very survival of humanity was deemed to be at serious risk [1].

"The Limits to Growth" significantly shaped public perception of ecological crises, elevating environmental protection issues onto the global political agenda. The findings of the report were discussed by the international community alongside the organization of the 1972 UN Conference on the Human Environment (the Stockholm Conference). This event marked the first major international meeting focused on environmental issues, resulting in the adoption of a series of documents, including the Declaration on the Human Environment, which can be regarded as a cornerstone of international environmental law. Furthermore, the United Nations Environment Programme (UNEP) was established during this conference to promote interstate cooperation in the field of nature protection [2]. However, despite the relevance and importance of the issues raised at the conference,

[1] The Club of Rome is an international nongovernmental public organization established to study the global problems of modernity.

the global socio-ecological situation did not improve during the first half of the 1980s.

In 1980, the World Climate Research Programme was established with the aim of developing fundamental scientific knowledge about the physical climate system and its processes, as well as studying climate change and the extent of human impact on it.

In 1982, the UN General Assembly adopted the World Charter for Nature, which called for the preservation of key natural processes at relatively unchanged levels and ensured that all forms of life would have the opportunity to thrive.

The final report, "Our Common Future," presented to the UN General Assembly in 1987, was optimistic in its outlook. It emphasized that society could overcome challenges such as poverty, resource depletion, environmental pollution and more, if economic growth were directed toward rational activities, efficient resource use and the enhancement of human potential.

The strategy for the positive functioning of civilization is closely linked to the implementation of the concept of its sustainable development [3]. The materials of the report and the results of its international discussions laid the groundwork for the decisions made at the UN Conference on Environment and Development (the Earth Summit, Rio de Janeiro, 1992), which reflected on the outcomes of the "ecological twentieth anniversary" (1972–1992). Through the collaborative efforts of forum participants, three fundamental documents were prepared and adopted:

- Rio Declaration on Environment and Development: comprising 27 principles derived from the Stockholm Declaration;
- Agenda 21: an action program aimed at implementing the concept of global sustainable development;
- Statement of Principles for the Global Consensus on the Management, Conservation and Sustainable Development of All Types of Forests.

Additionally, the UN Framework Convention on Climate Change and the Convention on Biological Diversity were opened for signature [4].

The Rio-92 documents, or the Earth Summit, acknowledged the increasing degradation of the global ecosystem, despite extensive efforts in the field of environmental protection.

This conference coincided with the 20th anniversary of "The Limits to Growth." After analyzing statistics from this period, D.L. Meadows' team concluded that, despite minor numerical fluctuations, the negative trajectory of civilization as a whole persisted [5].

The World Summit on Sustainable Development, known as Rio+10, took place in Johannesburg, South Africa, from August 26 to September 4, 2002. During this summit, commitments were made to ensure access to water resources and sanitation, promote energy development, increase agricultural production, regulate the use of toxic chemicals and conserve biodiversity [6]. The results of the "sustainable decade": despite the actions taken by the world community to stabilize the socio-ecological situation, at the global level it was not possible to significantly improve the quality of human life and the state of the natural environment.

As the 30th anniversary of the first report to the Club of Rome was approaching, studies continued to confirm that society was moving steadily toward a "nonequilibrium state," indicating a deterioration in the global socio-ecological situation. From 1950 to 2000, annual consumption of fossil energy resources increased nearly tenfold (with oil consumption rising 7 times and natural gas by 14 times), while the world population grew 2.5 times during the same period. In the book "The Limits to Growth: The 30-Year Update," D.L. Meadows concluded that without a "profound correction" in the use of natural resources, the collapse of humanity in one form or another would be inevitable, stating, "it will occur within the lifetimes of many who are alive today" [7].

In June 2012, the next UN Conference on Sustainable Development Rio+20 was held in Rio de Janeiro. The main topics of discussion included how to create a green economy to achieve sustainable development and lift people out of poverty, as well as how to enhance international coordination for sustainable development [8].

Later, at the UN Summit on Sustainable Development, the document "Transforming Our World: The 2030 Agenda for Sustainable Development" formulated 17 global Sustainable Development Goals (Figure 1) focused on the period leading up to 2030 [9].

Despite the numerous bills, interstate agreements and forums that have been adopted and approved, the reality is that, according to UN statistics, the situation is not improving but worsening. The dynamics of individual socio-ecological indicators reflecting humanity's evolution are presented in the Table.

On a global scale, the principles of sustainable development often remain merely aspirational goals proclaimed from podiums. The global environmental crisis continues to escalate, and current management systems are failing to alleviate the increasing pressure that society exerts on the natural environment and its resources.

Figure 1 – Sustainable Development Goals for humankind

Table – Dynamics of selected indicators of human development*

Indicator	1990	2005	2018	2023	Growth rate 2023 to 1990, %
Earth's population, bln people	5.28	6.51	7.59	8.02	+51.89
Share of people living in cities with a population of more than 1 mln, % of total population	18	21	24	25	+38.89
Electricity consumption, kW·h**	1×10^{13}	1.5×10^{13}	2.2×10^{13}	2.4×10^{13}	+140
Cropland area, ha/person	0.23	0.21	0.18	0.18	–21.74
Forest area, mln km^2	42.03	41.2	40.6	40.45	–3.76
CO_2 emissions, bln tons	21.3	28.4	35.6	37.4	+75,59

* Based on the data [10].
** Based on the data [11].

The year 2022 marks exactly half a century of the publication of "The Limits to Growth" report. Professor D.L. Meadows, the head of the scientific team, remarked on this occasion that whatever he recommended in 1972 is not relevant now. In 1972, humanity's environmental impact was likely below the planet's self-sustaining level, and our aim was to slow things down before we reached the limit. Now it's clear that the scale of human activity is well above that limit. The goal now is to bring the system back to previous – acceptable – levels. We need to reduce our needs to a level that the planet can sustain. These are very different tasks from those we set out to accomplish in 1972. These tasks will require a very different model than the one we built, and someone will have to write new books [12].

Major Global Challenges of Our Time

The global challenges we face today encompass a range of issues that are planetary in nature and affect the interests of all humanity.

The global problems considered in this article are illustrated in Figure 2.

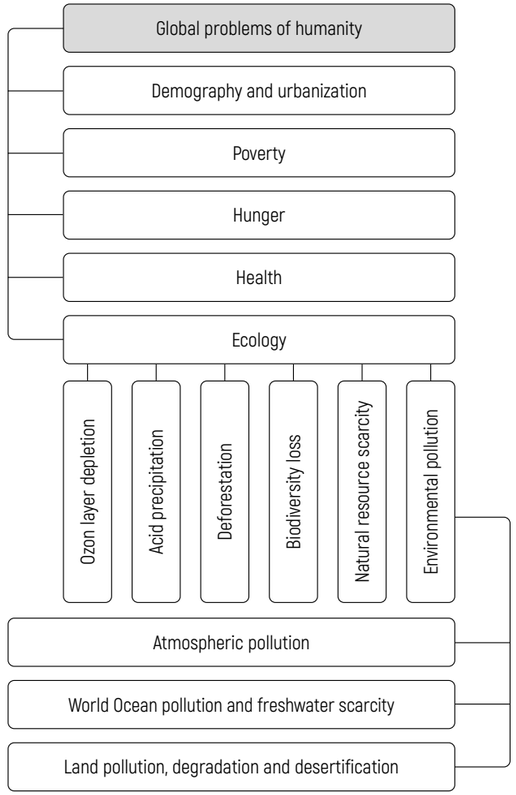

Figure 2 – Global problems of humanity

Demography and Urbanization

In 2022, the Earth's population exceeded 8 bln, having increased by 1 bln since 2010. Although the growth rate is gradually slowing, the UN predicts that the population will reach approximately 9.7 bln by 2050 and 10.4 bln by 2100 [13] (Figure 3).

This increase in the global population inevitably intensifies humanity's impact on the environment, leading to the irrational use and depletion of natural resources. It also contributes to rising poverty levels, food shortages and challenges related to migrants and refugees, along with rapid urbanization, which causes ecosystems to lose resilience and degrade.

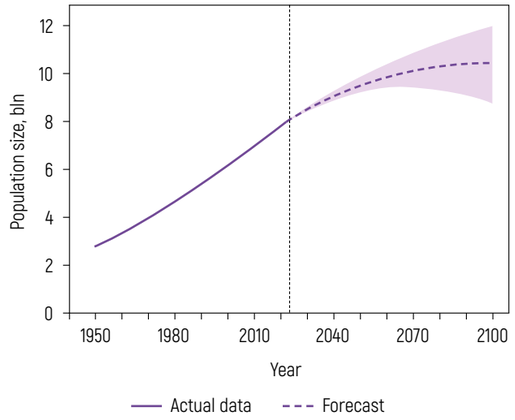

Figure 3 – World population 1950–2100

The impact of population growth is not solely a matter of numbers; it also reflects increased consumption per person and the non-environmentally friendly technologies employed to support this consumption.

Currently, about 55 % of the world's population resides in urban areas. The UN forecasts that by 2050, this figure will rise to 70 %, with most growth occurring in Asia and Africa. Modern urbanization is often accompanied by environmental degradation, particularly in developing countries, where it poses significant threats to public health. Chaotic urban development, inadequate planning and insufficient legislative regulation characterize many of these regions. The close proximity of densely populated residential areas to industrial facilities that utilize outdated technology and lack proper waste treatment exacerbates the situation [14].

Poverty

Today, poverty is increasingly recognized as a global phenomenon that reflects a threshold below which people's basic needs for food, clothing and shelter cannot be met.

According to the UN's 2023 report, in 110 countries, 1.1 bln of the world's 6.1 bln people – just over 18 % – live in severe multidimensional poverty [15]. The report reveals that:

- more than 50 % of those living in poverty have neither electricity nor clean cooking fuel;
- over 30 % lack adequate food, shelter, sanitation and safe cooking fuel simultaneously;
- nearly 40 % lack access to drinking water and proper sanitation.

A joint study by UNICEF and the World Bank provides alarming statistics: more than 333 mln children worldwide – one in every six – live in extreme poverty [16]. Experts warn that, at the current rate of growth in the number of impoverished individuals, the sustainable development goal of eradicating child poverty by 2030 will not be achievable.

Hunger

In August 2023, the UN Security Council meeting focused on the prevention of hunger revealed that the number of hungry people worldwide reached 250 mln in 2022, the highest figure in recent times [17].

The State of Food Security and Nutrition in the World 2023 report indicates that an average of 735 mln people faced hunger in 2022. This marks an increase of 122 mln (approximately 19.9 %) compared to 2019. Additionally, acute hunger affected 281.6 mln people in 2023, and millions of children under the age of five continue to suffer from malnutrition [18].

Health

The World Health Organization (WHO) reported the World Health Statistics 2023 and highlighted a lack of recent progress on key health indicators when compared to trends observed between 2000 and 2015. The report also warned of the growing threat posed by noncommunicable diseases, which now account for nearly 3/4 of all annual deaths [19].

Exposure to adverse social, economic, geopolitical and environmental factors, including poverty, violence and inequality, has also increased the risk of mental disorders. According to the WHO, these disorders rank among the top five causes of disability globally. In 2019, one in eight people, totaling approximately 970 mln, experienced such conditions [20]. By 2020, the prevalence of anxiety and major depressive disorders rose by 26 and 28 %, respectively [21].

Another significant issue is cancer. By 2050, more than 35 mln new cases are expected, representing a 77 % increase from 2022. Key risk factors for this rise include tobacco use, alcohol consumption and air pollution [22].

Ecology

Changes in the environment resulting from human impact or disasters that disrupt the functioning of natural systems are referred to as environmental problems.

Some of these issues were identified as early as 1972 at the UN Conference on the Human Environment. At that time, scientists and experts advocated for the rational use of the Earth's natural resources, the reduction of greenhouse gas emissions and the prevention of marine pollution. More than 50 years have passed since then, yet these challenges remain unresolved, and the situation continues to deteriorate, with the list of environmental problems growing longer.

What are the global environmental issues we face today?

Ozone Layer Depletion. The ozone layer serves as a unique protective shield for Earth, absorbing most of the cosmic radiation, including ultraviolet rays, that are harmful to all life on our planet.

Until the 1970s and 1980s, ozone concentrations in the atmosphere remained relatively stable. However, then scientists began to observe a depletion of the ozone layer, which was linked to the release of depleting substances into the atmosphere.

These substances can enter the atmosphere through two primary means:

- human activity (this includes the use of chlorine-releasing compounds found in solvents, aerosols, air conditioners and refrigerators);
- natural processes (such as volcanic eruptions, sunspots and stratospheric winds).

Currently, experts believe that the main contributors to the thinning of the ozone layer are supersonic jet aviation and the launch of heavy space rockets.

In 1985, a region approximately 1,000 km in size was discovered over the South Pole, where ozone concentrations had decreased by about 50 %. This area became known as the ozone hole. In 1995, a record ozone drop of more than 40 % was registered over Eastern Siberia, and in October and November of 1996, the largest and deepest ozone hole was detected over Antarctica. Scientists warn that similar ozone holes may soon appear over Scandinavia, Russia and Canada [23].

According to the UN study, the concentration of ozone-depleting substances in the stratosphere is slowly declining, likely due to the implementation of the Montreal Protocol, which was established to protect the ozone layer. This agreement, adopted in 1987, outlined a series of measures aimed at reducing substances that harm the ozone layer, and these measures have been regularly enforced since then.

Acid Precipitation. Rainfall with a substantial amount of nitric and sulfuric acid, commonly known as acid rain, occurs in areas with a high concentration of industrial plants, highways and significant population density. This type

of precipitation is destructive to soil, plant and animal life. Acid rain not only harms the environment but also damages buildings and monuments. Furthermore, people who are forced to drink contaminated water suffer as a result.

The primary solution to the problem of acid precipitation is to reduce emissions of sulfur and nitrogen oxides, particularly sulfur dioxide.

Deforestation. Currently, forests grow on all continents except Antarctica, covering about 31 % of the land and occupy more than 4,000 mln ha.

Their environmental impact is significant; forests regulate climatic processes and the global water cycle, play a crucial role in preserving biodiversity and are essential for sustaining life on our planet. They produce a substantial amount of biospheric oxygen, absorb CO_2 and help purify the air by filtering out dust and soot, and prevent their further spread.

According to the Food and Agriculture Organization of the United Nations (FAO), the global area of forests decreases by approximately 10 mln ha/year [24]. For context, the total area of the Republic of Belarus is 20.8 mln ha.

Forests face serious threats of degradation and destruction due to increasing human pressures. A report from the British conservation organization Botanic Gardens Conservation International indicates that between one-third and one-half of all tree species are at risk of extinction, which could lead to the loss of thousands of plant and animal species that depend on them.

The FAO estimates from 62 countries – representing 78 % of the world's tropical forest area – reveal that between 1980 and 1990, forests were being destroyed at a rate of 16.8 mln ha/year. The remaining 800 mln ha of tropical forests are being cleared so rapidly that projections suggest only 200 to 370 mln ha will remain by 2030.

In 2021, more than 100 world leaders convened at the UN Climate Change Conference to sign a pledge aimed at halting and reversing deforestation by 2030. However, despite these commitments, forested areas continue to shrink.

If forests disappear, the planet will lose its natural protective barrier, leading to increased fires and floods, while once fertile soils may transform into deserts.

Biodiversity Loss. The totality of all species of living organisms constitutes the planet's biodiversity.

According to the International Union for Conservation of Nature, 94 species of birds and 63 species of mammals have gone extinct since 1600. The FAO notes that many rare species of animals, plants and other organisms have disappeared in recent decades. The primary drivers of this decline include climate change, habitat loss, overexploitation of natural resources, poaching and illegal trade [25].

A recent report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services indicates that approximately 1 mln species of flora and fauna are on the brink of extinction. Many of these plants and animals could be irretrievably lost in the coming decades. Furthermore, over 90 % of marine fish stocks are either overfished or rapidly declining [26].

By losing the Earth's biodiversity, humanity jeopardizes its own future. Red Books serve as a vital tool in the protection of rare and endangered species. In support of this cause, the Convention on Biological Diversity was signed in June 1992 at the UN Conference on Environment and Development in Rio de Janeiro.

Natural Resource Scarcity. One consequence of the Earth's growing population is the gradual depletion of its nonrenewable resources. Increased consumption, along with economic and industrial development, has led to a rising demand for oil, gas, minerals, timber and freshwater. The UN estimates that the extraction of the planet's natural resources has tripled over the past five decades. According to a report published in March 2024 by the International Resource Panel of the UNEP, mineral extraction is projected to increase by 60 % by 2060. This surge could undermine efforts to achieve global goals related to climate change, biodiversity conservation and pollution control [27]. The report emphasizes the need for radical policy changes and suggests reducing the growth of resource use by one-third to mitigate environmental impacts.

At current rates of mineral consumption, and considering ongoing growth in demand, the known reserves of hydrocarbon fuels will only suffice for humanity for a few more decades – essentially one or two additional generations. Meanwhile, renewable natural resources, particularly bioresources, are also at risk of depletion.

Environmental Pollution. Environmental pollution is a global concern that affects all countries, particularly in the developing world. The entire world economy contributes to pollution and waste generated during the production of final products, which eventually become waste themselves.

Let us explore the types of environmental pollution.

Atmospheric Pollution. The primary sources of atmospheric pollution include thermal power plants, metallurgical, chemical and petrochemical industries, as well as the pulp and paper sector, construction industry and road transportation. Harmful substances from these sources can infiltrate water, soil and plants, eventually entering the human body. Developed countries account for a significant portion of these emissions.

According to the WHO data, nearly the entire global population (99 %) breathes air that exceeds recommended limits and contains high levels of harmful substances. The cumulative impact of ambient air pollution, both outdoors and indoors, contributes to the premature deaths of approximately 6.7 mln people each year [28].

To address this issue, it is essential to implement measures that reduce the impact of major air pollution sources. These measures should promote the development of environmentally friendly transport, enhance energy efficiency in buildings and industrial processes and improve municipal waste management systems.

World Ocean Pollution and Freshwater Scarcity. Oceans cover more than 70 % of the Earth's surface, and the health of ecosystems and the planet's climate relies on water quality.

Every year, thousands of highly toxic chemicals – including heavy metals, pesticides, nitrates, phosphates, surfactants and pharmaceuticals – pollute these waters. Additionally, radioactive waste from nuclear power plants contaminates marine environments. Up to 12 mln tons of oil enter the seas and oceans annually, causing significant damage to the biosphere and posing a growing global threat. The discharge of untreated wastewater leads to microbiological pollution, with total anthropogenic discharges into the sea estimated at around 100 mln t/year.

According to the WHO, 80 % of diseases worldwide are linked to poor water quality and unsanitary conditions. Approximately 90 % of rural residents rely on contaminated water for drinking and bathing.

The World Meteorological Organization's report "The State of Global Water Resources 2022" indicates that 3.6 bln people experience insufficient access to water for at least one month each year. This figure is projected to rise to over 5 bln by 2050 [29]. Scientists anticipate a gradual decline in terrestrial water supplies.

To protect the World Ocean from increasing anthropogenic pressure, special measures are necessary. These should include prohibiting water pollution, regulating resource use, creating protected marine areas, conducting monitoring and other.

Land Pollution, Degradation and Desertification. Land degradation is the reduction or loss of productivity of arable land or pasture as a result of land use.

Once fertile soils are now suffering from erosion caused by human activities and a warming climate. Each year, at least 100 mln ha of healthy land are lost. Recent information from the UN indicates that land is degrading faster than we can restore it [30].

Today, one-third of soil worldwide has been degraded by erosion. The FAO predicts that by 2050, 90 % of the world's soil will be destroyed as a result of this phenomenon [31]. If degradation continues at this rate, the fertile cover of the Earth may be entirely depleted within 100 years.

The causes of land degradation involve overgrazing by livestock, increased land cultivation, deforestation and agricultural practices such as plowing and the use of chemical fertilizers and pesticides. Other factors include overexploitation from construction, mining and urbanization as well as extreme climatic events like droughts and salinization of coastal lands. Industrial pollution, as well as emissions from transport, also contributes significantly.

Land degradation contributes to climate change and the destruction of natural ecosystems worldwide, affecting the biosphere as a whole. Currently, approximately 280 mln people are impacted to varying degrees by desertification, which leads to poverty and hunger. In 1982, the World Soil Charter was adopted, urging all governments to recognize soil cover as a global heritage.

Alternative Option for Humanity's Development

Unfortunately, the concept of sustainable development has proven inadequate in addressing many contemporary issues.

To achieve sustainable progress, recent events have shown that this approach often suggests restraining economic growth and technological advancement, as well as incurring additional costs for developing "environmentally friendly" and "resource-saving" technologies. However, this can lead to increased living costs and highlights the ineffectiveness of various popular ideas regarding long-term environmental sustainability and resource conservation, as evidenced by electric cars, green energy, carbon footprints, etc. Furthermore, strict restrictions are often perceived as infringements on personal freedom.

According to the UN projections, if current trends persist, the global goals of eradicating poverty, hunger, food insecurity and malnutrition will not be met by 2030. The number of undernourished people remains significantly higher than pre-pandemic levels, with nearly 600 mln expected to face

hunger by 2030. Millions of children under five continue to suffer from stunting (148 mln), wasting (45 mln) and overweight (37 mln). No region is on track to meet the 2030 target for reducing the proportion of low-birth-weight infants, which is closely linked to the nutritional status of women before and during pregnancy [32].

To date, critical global environmental issues, such as the biodiversity crisis, declining water quality, destruction of forest ecosystems, urban and industrial pollution and increasing domestic and industrial waste, remain unresolved. Artificially restraining economic growth and technological development, along with reducing consumption, currently fails to address environmental pollution and resource scarcity.

The planet requires a reset of the engineering approach to civilization's evolution toward a fundamentally new paradigm [33]. We need a program that will gradually transform the existing socio-ecological landscape, ensuring food, energy, technological, infrastructural and environmental security.

An alternative development option is proposed by engineer, designer and inventor A. Unitsky through the large-scale EcoSpace program [34]. This initiative encompasses a range of measures aimed at addressing the global environmental crisis, from rethinking the design of modern cities and transport and infrastructure solutions to safely relocating harmful terrestrial industries into near space. The main elements of the program and their interconnections are illustrated in Figure 4.

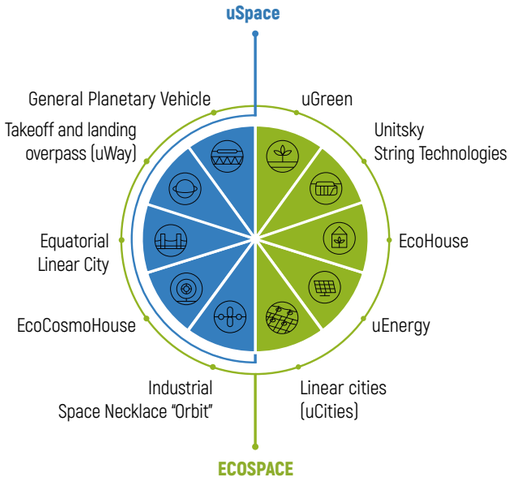

Figure 4 – Elements of EcoSpace program

The program envisages the following main aspects:

• restoration of the terrestrial biosphere, including natural and cultural (organic farming) ecosystems on the planet's land; oceanic, marine and atmospheric ecosystems with the environmentally friendly control of weather and climate from outside; flora and fauna with their biodiversity preserved; terrestrial humanity, each individual of which is healthy and happy;

• formation of the Earth's industry (i.e., located inside the biosphere of the planet) on the basis of new ecologically clean technological branches consisting only of biosphere-friendly (biospheric) engineering technologies necessary for human civilization;

• creation of a geocosmic self-supporting (relying only on itself) aircraft – the General Planetary Vehicle (GPV) [35], providing environmentally friendly for the biosphere transportation and logistics connection between terrestrial and space components of the industrial TechnoSpace. The launch of the GPV with its high carrying capacity (up to 10 mln tons of cargo and up to 10 mln passengers per flight) will allow to build the Industrial Space Necklace "Orbit," including industrial facilities (solar power plants, orbital factories, workshops, laboratories, etc.) and EcoCosmoHouses, which will give humans (service personnel) the opportunity to lead a full life away from their earthly home;

• formation of the space industry consisting of energy-consuming, resource-intensive, ecologically harmful and other industries that have been moved outside the Earth's biosphere.

The technological platforms developed by Belarusian designer A. Unitsky and his engineering team are intended to maintain ecological balance within the Earth's biosphere.

The uGreen technological platform is organic, eco-oriented farming that entirely avoids oppressive anthropogenic impacts on the biosphere. The use of agro-biotechnologies, such as biohumus and organic uTerra fertilizers, is expected to accelerate crop growth and increase yields by 35–50 %. Additionally, these practices will enhance the nutritional content of food, normalize soil acidity and reduce the presence of nitrates, radionuclides and heavy metals in food.

The uEnergy technological platform focuses on generating green electric and thermal energy on Earth through various innovative methods:

• specially equipped thermal power plants: these facilities will enable environmentally friendly combustion of brown coal, shale, peat and other organic materials, transforming combustion waste into living fertile humus;

• renewable energy sources: this includes harnessing solar energy both on Earth and in space as well as utilizing wind and sea currents;

• hydrogen–oxygen pair: this will serve as a fuel accumulator to optimize the planet's energy sector and support long-distance space flights, including for resource extraction from the asteroid belt.

Solar bioenergy technology is entirely environmentally friendly and waste-free. The by-product of bio-thermal power plants, biohumus, can adequately offset the production of electric and thermal energy. For instance, a plant with a capacity of 1 mln kW can generate enough biohumus annually to transform a 2,500-hectare desert into fertile chernozem.

The EcoHouse technological platform focuses on eco-oriented construction of residential and industrial buildings on Earth. The primary goal is to achieve zero impact on the environment and human health. By utilizing efficient heating and cooling systems, this approach aims to reduce energy consumption, decrease reliance on fossil fuels, improve air quality and enhance food and energy security.

The Unitsky String Technologies (uST) technological platform involves the construction of a new type of transport, infrastructure, energy and information networks.

Several types of uST elevated electric unmanned rail transport will provide transport accessibility. These transport modes are: urban (up to 150 km/h), high-speed (up to 360 km/h), ultrahigh-speed (up to 600 km/h) and hypervelocity (over 600 km/h) for cluster, regional, continental and intercontinental distances, including those across seas and oceans.

This transport is environmentally friendly, with a high capacity – one line can accommodate up to 1 mln passengers and 500,000 tons of cargo per day [35]. It requires minimal resources for construction, and it is energy-efficient and cost-effective. The uST transport is easy to operate and manage, is characterized by high safety, reliability and durability, all while minimizing land use (pointwise for supports, which is about 100 times less than for a highway).

The alternative to megacities will be uCities, which will harmoniously fit into the environment of any natural and climatic zone of the planet. They will feature gardens on rooftops, creating additional fertile land. These cities will be self-sufficient in clean energy, organic food and fresh water [36]. The implementation of this project will make it possible to produce millions of tons of living fertile humus annually, to eliminate negative impact on environment and optimize energy resources usage, to ensure food security for residents of the linear city, to increase soil fertility, to build a unique barrier-free setting.

All of the technologies mentioned are cost-effective, attractive for investment and mutually supportive. The economic stability guaranteed by the inexhaustible resources available in near and far space will enable the creation of a society that thrives in harmony with nature.

Humanity possesses the necessary tools to implement the EcoSpace program, and we are able to transform Earth into a flourishing planet with ample space and resources for current and future generations, even if their numbers reach 10, 20 or 30 bln.

Conclusion

If the current rate of growth and development of the technosphere, created by our engineering civilization on Earth, continues unabated, predictions indicate that within two generations, pollution and destruction of the biosphere, along with the depletion of certain resources, could render our planet uninhabitable.

Despite these pessimistic forecasts, there are eco-oriented technologies that can address many environmental challenges and restore the Earth's biosphere. This concept includes the implementation of environmentally safe second level transport, the establishment of self-sufficient linear cities of a cluster type, a transition to fully organic agriculture and the development of green bioenergy. Additionally, it envisions transforming deserts into highly fertile chernozem.

The realization of the GPV project will unlock vast opportunities in geocosmic logistics as well as in information and energy communications. It will provide effective access to the unlimited resources of space – energy, mineral, spatial and technological (such as weightlessness and deep vacuum) – while enabling the relocation of manufacturing sector and industrial energy beyond the biosphere.

This article presents, systematizes and structures the global environmental problems facing humanity. It concludes that the doctrine of the engineer A. Unitsky offers the most viable solutions for addressing these challenges within our shared home named Planet Earth, following the logic of "Earth – for Life. Space – for Industry."

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Resolution of the VII Global Conference on Near Space Industrialization

On September 13–14, 2024, the VII Global Conference on Near Space Industrialization was held in Maryina Gorka, Belarus.

The event program included a plenary session, a poster session, section meetings, discussions as well as an exhibition and demonstrations of innovative space, infrastructure, transport and logistics, energy, biospheric, socioeconomic and agrobiotechnological solutions. A total of 37 presentations were delivered to the participants.

For the first time, the scientific forum was held under the title "Global Conference on Near Space Industrialization" and became a landmark international event in the field of large-scale industrial development of near-Earth space. The aim of the conference was to summarize the results of scientific and applied research carried out by scientific institutions, design bureaus, engineering companies as well as individual scientists and enthusiasts in the following areas:

- addressing global biospheric challenges of our time through geocosmic means;
- prospects for the technological development of near space under the uSpace geocosmic program with the motto "Earth – for Life. Space – for Industry";
- organizing safe, large-scale cargo and passenger flows along the Earth–Near Space–Earth route to develop the space industry for the benefit of Earth's civilization;
- design features and exploration of biological and environmental solutions to ensure the sustainable functioning of the Earth's biosphere, preserve biodiversity on the planet and develop hard-to-reach areas with unfavorable living conditions;
- specific aspects of the social organization of linear cities (uCity);
- peculiarities of international and intercultural relations and the creation of international alliances for the implementation of the uSpace program;
- challenges in the use of social media in the implementation of the uSpace program and the search for effective solutions;
- advancement of plant production technologies under the EcoCosmoHouse project and on orbital stations intended for long-term human habitation in space;
- research and design work within the development of a self-supporting geocosmic aircraft – the General Planetary Vehicle – and its ground and orbital infrastructure: transport, energy and information systems.

Based on the results of the VII Global Conference on Near Space Industrialization, the Organizing Committee and participants have adopted the following resolutions.

1. Acknowledge the high scientific and technological level of the presentations delivered at the conference.

2. Emphasize the exceptional global significance of the program for the large-scale exploration of near space and the reorientation of Earth's industry toward a biospheric vector of civilizational development.

3. Highlight the importance of the global geocosmic project to create the General Planetary Vehicle as the only technically feasible and, therefore, key transport and logistics solution for the industrialization of near space.

4. Given the scale of the work presented at the conference, recognize the critical importance and urgency of fostering cooperation among countries, international organizations, leading global companies, research institutions and universities to implement the uSpace program.

5. Approve the updated edition of the EcoSpace program presented by World Engineer Anatoli Unitsky.

6. Actively expand collaboration among participants of this conference.

7. Make every effort to launch joint projects and advance the EcoSpace program with the aim of comprehensively addressing the current global civilizational challenges: infrastructural, resource-related, energy, food security, environmental, socioeconomic, demographic, geopolitical and other issues.

8. In partnership with autonomous nonprofit organizations N.I. Veduta Strategic Planning Scientific School and the Motherland of the Future nonprofit organization as well as the Artificial Intelligence in the Economy section of the RAS Scientific Council for AI Methodology and Cognitive Research, initiate the establishment and launch of uSchool, aimed at training engineering specialists for a biospheric civilization. The school is to be located within the Aquarelle EcoPark. Subsequently, create the Motherland of the Future technopark within the same territory, intended to implement a sociocultural and cybernetic approach to the education and upbringing of adolescents and youth. This project will be positioned as a pilot initiative for the Union State, focused on training specialists for the new economy.

9. To attract a broader community of researchers engaged in the industrial development of near space, ensure regular participation in relevant international events, organize presentations and deliver scientific reports on the progress and achievements of the uSpace program.

10. To publish the proceedings of the conference. Ensure its distribution to national and leading specialized libraries worldwide, and promote it in digital format on relevant scientific platforms and portals. For participants whose work is included, provide formatting and publication of their contributions as scientific articles in accordance with applicable requirements.

11. To elevate public awareness and support, and to use the most effective means to promote and implement the uSpace geocosmic program, organize the VIII Global Conference on Near Space Industrialization in 2025. Select the most suitable international venue, invite strategic partners interested in the rapid industrialization of near space and ensure the participation of key international organizations, leading research centers, heads of state and national leaders.

The Organizing Committee of the conference extends its sincere appreciation to all participants, speakers, guests as well as to the organizations and their representatives whose contributions made this event possible. Special thanks go to Anatoli Unitsky, Chairman of the Board of Directors of the Unitsky Group of Companies, the principal investor in the uSpace program and the conference's main sponsor.

We express our gratitude for their significant contribution to the development of the uSpace program to the UNIDO Centre for International Industrial Cooperation in the Russian Federation, represented by its head Igor Kozhin; the International Municipal BRICS Forum; the Russian Academy of Sciences; the National Academy of Sciences of Belarus, especially its Aerospace Activities Department; the Ministry of Foreign Affairs of the Russian Federation, in particular the Trade Representation of the Russian Federation in the Republic of Belarus; the Roscosmos State Corporation; the Skolkovo Foundation; and Far East and Arctic Development Corporation.

Special recognition and gratitude are extended to Mr. Nitin Gadkari, Minister of Road Transport and Highways in the Government of India, for his participation in the conference and his support of this scientific forum.

Conference Organizing Committee,
Sep/14/2024, Maryina Gorka

Шкала уровня развития цивилизаций
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Glossary: Terms and Definitions

Abbreviation **uST (UST)** stands for the central brand of Unitsky Group of Companies (UGC); it combines the names of Unitsky String Technologies (uST), the parent engineering company Unitsky String Technologies Inc. (UST or UST Inc.), uST transport and infrastructure complexes / Unitsky String Transport as the physical embodiment of uST transport and infrastructure solutions.

Active protection system (APS) is a generator of electrostatic field where negatively charged debris of space garbage create resonant vibrations in it.

Artificial atmosphere is a specially selected mixture of gases, which ensures regular breathing and gas exchange in living organisms, including humans, who are in an enclosed ecosystem; has the same quality as the Earth's atmosphere. The gas component of the EcoCosmoHouse (ECH) space is an artificial atmosphere.

Biofuels are various types of combustible products derived from plant raw materials. Their main advantages are renewability and accumulation of solar energy coming to Earth.

Biological balance is the preservation of dynamic stability of natural complexes (biogeocenoses) over a long period of time, i.e., relative balance of stability of species composition, number and productivity of living organisms.

Biological diversity is the natural diversity of life in every manifestation as well as an indicator of the complexity of the biological system, the diversity of its living components. Biodiversity is considered at the hierarchical levels of life organization with the following main ones: molecular and genetic, organism and species, biogeocenotic and biospheric.

Civilization technogenic fork is a stage of development of the Earth's technosphere, which, when achieved, makes the technogenic human civilization face with a historically important choice of two mutually exclusive scenarios of action:

1) Earth's civilization continues to develop conventional technogenic vector, limited only by the planet's size and resources. At the same time, resource consumption does not change dramatically because the world economy relies on obsolete and resource-intensive technologies (primarily, century-old transport and logistics technologies). As a consequence, the point of no return from degradation, extinction and death of human civilization will come in about two generations (in the third quarter of the 21st century);

2) the beginning of near space industrialization, gaining access to its unlimited resources, infinite space, matter and energy as well as new technological resources: weightlessness, deep vacuum, technological purity (without dust and microorganisms) and cosmic radiation. Mandatory requirement: inefficient transport and infrastructure technologies, power industry, habitat (cities), infrastructure and agriculture used on the planet, which pose the greatest threat to the Earth's biosphere, must be replaced by better communications and eco-oriented technologies.

EcoCosmoHouse for civilizational panspermia (ECH-Arc) is a cosmic structure with an enclosed biospheric ecosystem designed for interstellar flights. Shaped like a rotating body, a spindle with a length ranging from 500 to 2,000 m and a diameter of 200 to 500 m, it is capable of preserving Earth life, including a crew of 1,000 to 10,000 people, for transportation to exoplanets. The ECH-Arc not only represents a miniature Earth's biosphere but also functions as an incredibly complex, autonomous aircraft capable of sustaining itself for thousands of years. It encompasses its own energy systems, engines, fuel reserves, nonrenewable resources (not involved in the biospheric cycle), engineering communications, repair facilities, residential and industrial spaces, agricultural technology, agro- and aquacultures, flora, fauna and fertile soil. Additionally, it includes a society with a kindergarten, a school, a university, a medical facility and workplaces for a hundred specialties, etc.

EcoCosmoHouse on planet Earth (ECH-Earth) is a structure on Earth designed for autonomous and unrestricted long-term residence of a human settlement with calculated density. The inner enclosed space of the ECH-Earth provides conditions for the development of ecosystems, has a necessary set of the planet's biosphere properties in this regard and additional technological processes that are modeled to ensure human needs for existence (parameters of the atmosphere and habitat, food resources, etc.). The ECH-Earth is an Earth biospheric model of the ECH in terms of creation and arrangement of internal space and all relevant components (biosphere, technologies, process interconnections, etc.) with an enclosed cycle of matter (living and mineral), energy and information.

EcoCosmoHouse technological platform (ECH) is the construction of buildings in space with an internal inhabited space, isolated from the external aggressive space environment. There is an enclosed ecosystem of the Earth's type in the ECH, including artificially produced gravity, living fertile soil, flora and fauna (comprising microflora and microfauna), atmosphere with adjustable parameters (temperature, humidity, etc.) for unlimited long-term, autonomous, eco-comfortable living and activity of both individuals and groups of them and many thousands of settlements in equatorial orbits of the planet as well as in open near space and deep space.

EcoHouse technological platform is an eco-oriented construction of residential and industrial buildings and structures on Earth with adjacent space open to the external natural (biospheric) environment, filled with natural and cultural (organic farming) ecosystems, in which atmospheric, soil and water parameters are regulated by the Earth's nature. The soil from under the buildings during their construction is transferred to the roofs and floors to be then enriched with living humus. Greening is based on the principle that all construction on the planet is meant to increase the area of fertile soil and its fertility.

EcoSpace is the program to provide for the development of eco-oriented biospheric technologies in order to transform the main sectors of the Earth's industry, infrastructure, power industry, transport and agriculture. It assumes bringing the hazardous part of the Earth's industry out into near space to secure the balance in a perfect world represented by BioSpace, TechnoSpace and HomoSpace triunity, which together form a complex of optimal conditions for sustainable growth and further development of the Earth's technogenic civilization in cosmic direction.

BioSpace is a restored and balanced planetary biospheric ecosystem open to space, which no longer experiences the devastating human-made effects of the Earth's technosphere and continues to evolve by the laws of evolutionarily established terrestrial nature. It comprises:

- natural and cultural (organic farming) ecosystems on the planet land, including aquatic ones (lakes, rivers, etc.);
- oceanic, marine and atmospheric ecosystems with the possibility of eco-friendly external control of weather, climate and other systems of the planet through natural methods;
- flora and fauna of terrestrial and aquatic ecosystems (including microflora and microfauna) with their biodiversity preserved and currently available;
- Earth's humanity with each individual being healthy and happy.

TechnoSpace comprises newly created industrial components:

1) Earth's industry which is based on novel eco-oriented technologies and consisting only of the technological industries necessary for humans within the Earth's biosphere;

2) space industry, including energy-consuming, resource-intensive, hazardous and other industries that are moved outside the Earth's biosphere, which acquire an absolute competitive price and quality advantage as part of the space technological environment;

3) the GPV geocosmic transport complex, providing environmentally friendly transport and logistics link between the Earth's and space components of the industrial TechnoSpace with cargo, energy, information and passenger flows of industrial scale;

4) artificial intelligence to manage the above components 1–3 under the multilevel control of HomoSpace.

HomoSpace is an advanced world sociopolitical system based on the consolidation of the international community of biological humans (but not digitized biorobots-convergents) around a single governing center accumulating the territorial, financial, economic, scientific, human, military and political potential of all participating countries. This will open the gate to inexhaustible and accessible resources of space and through space-oriented economy of the technogenic civilization on Earth will create new sociopolitical and economic conditions for the most complete implementation of sustainable development of biological humanity,

including social justice, equality, freedoms, harmonious development as well as the right of every inhabitant of the planet for a worthy long and happy life. HomoSpace is developed and governed by people using artificial intelligence as an assistant and advisor (but not a leader). The main value of HomoSpace is the humane attitude of Human and his spirituality as a sociobiological quintessence created by the Universe (God) as a result of billions of years of life evolution in the space home named Planet Earth.

Ecosystem is a biological system (biogeocenosis) consisting of a community of living organisms (biocenosis), their habitat (biotope) as well as a system of connections that exchange substance and energy between them.

EcoTechnoPark is a demonstration and certification center for uST transport and infrastructure solutions, built in the Republic of Belarus (Maryina Gorka).

Equatorial Linear City (ELC) is the Earth's component of geocosmic transport and communication complex which locates the GPV takeoff and landing overpass (uWay) with the whole infrastructure required for the GPV to fly and for servicing global geocosmic cargo and passenger flows. This city represents a harmonious blend of cluster settlements with the natural environment of land and ocean areas of the planet. The settlements are interconnected by uST tracks and stretch along the equator.

Food solar bioenergy (FSBE) is power industry based on the integrated consumption and processing of biomass of greenery that has absorbed the energy of the Sun to produce biofuels, animal feed and food for humans.

General Planetary Vehicle (GPV) is a geocosmic self-supporting reusable torus-shaped spacecraft for non-rocket near space industrialization encircling Earth in the equatorial plane; it ensures industrial cargo and passenger flows (millions of tons of cargo and millions of passengers per year) from Earth to near-Earth equatorial orbits and back; it is based on the only possible (from the point of view of physics) environmentally safe and energy-efficient geocosmic transportation technology which uses only internal force of the system (spacecraft) and electric energy.

GPV takeoff and landing overpass (uWay) is a takeoff and landing, energy and communication overpass complex for geocosmic transportation, located along the equator and combined with a linear eco-settlement of new generation.

Industrial Space Necklace "Orbit" (ISN "Orbit") is a multi-orbital transport, infrastructure and industrial-residential complex serving the Earth's humanity and covering the planet in the equator plane. It is a functional analogue of the Earth's ELC, however, located in space, as well as a range intended to protect from space threats (including meteorites) and a platform for the expansion of the Earth's civilization into deep space.

Linear city (uCity) is a cluster-type pedestrian urban settlement with its ground surface intended for people, animals and greenery; the development of residential, administrative, industrial and multifunctional clusters is implemented through the eco-oriented EcoHouse technologies; electricity and heat are obtained by the uEnergy technology; food supply is linked to the uGreen technology of organic farming; transport, energy and information communications are arranged above ground on the second level (elevated version) according to the uST technology. Linear cities are characterized by the absence of devastating human-made effects on the biosphere, high efficiency of urban economy and its autonomy as well as decent quality of life and working conditions for each resident.

Relict solar bioenergy (RSBE) is power industry based on the use of fossil brown coal and oil shale to produce clean energy and form living humus, which is necessary to restore the fertility of various types of soils.

Space-based solar power plant (SBSPP) is an orbital solar power plant using solar energy; it provides energy independence and biospheric environmental safety of the ISN "Orbit."

Space industrialization vector is a global re-equipment of the Earth's technosphere to eliminate its devastating human-made effects on the Earth's biosphere by transferring hazardous, energy- and resource-intensive industries into near space on low-Earth orbits. The space industrialization vector is also about using eco-oriented technologies to modernize that part of industry still on Earth and functioning in the biosphere.

Sustainable development is "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This concept was formulated by the UN World Commission on Environment and Development and is the basis of the UN goals and principles.

Sustainable Biosphere Cluster (SBC) is a competence center for desert greening. The SBC will be the basis for the implementation of the uGreen technology platform under the conditions of a hot tropical climate – an environment with negative impact factors (e.g., high temperature) affecting plant cultivation.

Sustainable-BioTech is an ecological system combining a set of innovative engineering, agro-, bio- and soil-forming technologies. Its main components are relict and organic raw materials as well as soil untouched by plowing and soil microorganisms, taken in a special way from the world Bank of fertile soils, located on the territory of Unitsky's Farm Enterprise (Maryina Gorka, Belarus). Raw materials are finally processed into a living fertile humus with the help of associations of soil microorganisms and a unique species of *Lumbricus* uTerris worms, specially bred in Unitsky's Farm Enterprise.

uBioSystem is an enclosed ecosystem with controlled technological processes (lighting, temperature schedule, air-blasting, water flow rate, etc.) for autonomous and long-term existence of a community of living organisms.

uEnergy technological platform is designed to generate green electric and thermal energy using:

- specially equipped thermal power plants for eco-friendly combustion of brown coal, shale, peat and other raw materials of organic origin in order to produce living fertile humus from their combustion waste;
- renewable energy sources, namely the solar energy on Earth and in space as well as the energy of wind and sea currents;
- hydrogen–oxygen pair as a fuel accumulator for the optimization of the planet power industry and space transportation.

uGreen technological platform is organic farming in a new logic of recreation and intensification of natural biospheric processes by direct borrowing and using natural soil ecosystems with their microflora, microfauna and biogeocenosis as well as in the logic of a complete rejection of any synthetic chemicals (fertilizers, plant protection agents, etc.), technologies of genetic modification and other elements of traditional intensive farming.

uMach is the concept of a hypervelocity uST transport and infrastructure complex. It is designed to travel at speeds over 1,000 km/h inside a forevacuum tunnel (with artificially reduced atmospheric pressure) to provide high-speed transportation for long (from 200 km) distances.

uNet transport and infrastructure network is an international transport, energy and information communication network created on the basis of uST transport and infrastructure solutions along uCities.

uSky Test and Certification Center is a research and production cluster of uST transport and infrastructure solutions, built in the United Arab Emirates (Sharjah).

uSocio is a new type of optimal social environment for small groups of individuals (2,000–5,000 people) which is based on stratification. In uSocio, due to the possibility of free choice of accommodation, the following social needs will be fulfilled: sociocultural ties, common values, religious outlooks, respect of traditions, passion for the arts, development of ethnic and interethnic contacts, etc.

uSpace geocosmic program is a program of non-rocket near space exploration by means of the GPV, which will preserve the Earth's biosphere by taking the industry (technosphere) outside of planet Earth (beyond the biosphere).

uST technological platform is the construction (along uCities) of a new kind of transport, infrastructure, energy and communication networks uNet, created on the basis of prestressed (string) Unitsky's structures. It is designed to provide all necessary communication links between objects (and continents) on Earth; between objects in near space moving on circular equatorial orbits; between objects on Earth and those deployed in near space.

uTerra is a biohumus (crumbly and liquid – fertility elixir) produced using brown coal, ash, organic raw materials, inoculum, aerobic and anaerobic microorganisms to increase fertility and improve the quality of any soils, including desert sands.

Reviews for the Proceedings of the VII Global Conference on Near Space Industrialization

Review by Pyotr Vityaz,

Academician of the National Academy of Sciences of Belarus, Doctor of Engineering Sciences, Professor, Honored Scientist, Head of the Aerospace Activities Department of the National Academy of Sciences of Belarus, Deputy Head of the Space Research Agency of the National Academy of Sciences of Belarus

The Earth is a part of the Solar System, located in infinite outer space. The life on our planet is dependent on the processes that take place in its depths, as well as the influence of near and far space, and human activity. Therefore, when analyzing the reports from the VII Global Conference on Near Space Industrialization, we must consider this dependence, understand that everything is constantly moving, changing and has a beginning and an end to its life cycle. Many of these processes have been studied, but there are many more that require further study. We see an increase in the Earth's population, climate change and an increase in the number of human-made disasters. The environment is transforming, and this process is speeding up. For these reasons, the idea of industrializing near space, proposed by Anatoli Unitsky, the organizer, ideologist and inspirer of the conference, is not only useful but also timely. His concept "Earth – for Life. Space – for Industry" and the number of developments carried out by him and under his leadership in the fields of engineering and ecology, both in Belarus and abroad, are already being implemented.

The project of non-rocket near space industrialization is interesting, but today it sounds somewhat fantastic, since it requires not only solving many engineering, technological, economic and legal problems but also uniting the efforts of all humankind on planet Earth.

Analyzing the materials of these proceedings, I would like to note that they are presented in four sections, devoted to various areas, but have a single goal – the non-rocket industrialization of near space and the improvement of life on our planet.

The section "Geocosmic and Geotechnical Sciences, Technologies, Materials and Resources" contains reports on the environmental challenges of near-Earth space industrialization. As outlined in the work of V. Klyushnikov, these challenges include:

- satellite fragments, turning into space debris;
- aerosol pollution;
- electromagnetic pollution;
- light pollution of the sky;
- the impact of launch vehicles on terrestrial ecosystems.

Today, the greatest threat comes from space debris. This means that during intense exploration of near and distant space, it is essential to consider all types of potential pollutants and develop a system to eliminate and protect against them.

Anatoli Unitsky's report on waste disposal of space industrialization provides interesting solutions that could be used in the future in the exploration of near-Earth space.

The section "Energy and Information Geocosmic Sciences, Technologies, Materials and Resources" presents research conducted by Anatoli Unitsky and his disciples on the design and application of the General Planetary Vehicle as part of a unified energy system of Earth. These developments can be considered as models for necessary calculations that could be used to address specific challenges in outer space.

The electric discharge technologies and additional oxygen sources for internal combustion engines, which are described in the articles, are already part of our daily lives today.

Research into their development and expansion of applications, including in space, is therefore relevant.

In the section titled "Ecological and Biological Aspects of Enclosed Biospheric Ecosystems on Earth and in Space," the authors explored and examined the conditions and factors that influence soil fertility, increase crop yields and enhance plant resistance to disease. They also presented the advantages of Unitsky String Technologies Inc.'s solutions for reducing human impact on the environment and preventing soil degradation. It is also worth mentioning the research on the use of biotechnologies for the gradual restoration of desert soil, as well as the selection of microorganisms that can remain active in environments with high salt content. Their application simultaneously with organic fertilizers can be useful for reclamation of salt marshes. In addition, such microorganisms can be used for biological wastewater treatment, waste disposal and maintenance of ecosystem autonomy.

The material also included experiments on the rearing of quails within an enclosed ecosystem. The necessary prerequisites and conditions for such a setup were investigated, and a proposal for optimizing poultry nutrition by incorporating chlorella microalga into the feed was put forward.

In order to maintain the psychological stability of people during prolonged stays in enclosed ecosystems, the authors suggest using essential oil compositions for aromatherapy sessions and incorporating them into natural cosmetics.

They also presented materials on the development and creation of equipment for plant cultivation in an enclosed ecosystem, featuring conducted experiments and recommendations regarding compliance with certain requirements for using such equipment.

The collection describes conditions for the formation and disposal of waste in enclosed ecosystems during prolonged human habitation, and identifies the main types of organisms (worms, bacteria, microscopic fungi, algae) that could be involved in its processing.

It also considers a variant of using biogenic elicitors and demonstrates their positive effect in comparison with synthetic agrochemicals in the cultivation of plants in enclosed ecosystems. One of the papers outlines methods for enhancing the nutritional value and productivity of crops through the use of uTerra soil fertility elixir.

The authors have also proposed constructive solutions for creating enclosed ecosystems on Earth, highlighting a circular tent with supporting flat strings (steel bands) and multilayer transparent fluoropolymer coatings made in the form of a flat string membrane as the optimal ones among them. This technology is interesting for the development of residential systems with artificial climate, and can also be used in space exploration.

The research direction of the section called "Social, Legal, Political and Financial Aspects of Human Civilization Development on Earth and in Space" is quite clear, however, the creation of legal conditions in modern society for the joint exploration of near and far space requires humanity to move to a new qualitative level of existence.

The path of Earth's civilization has demonstrated not only the development of science, technology and tools, but also the possibility for the extinction of all life on our planet. In this regard, the articles describe approaches to improving the lives of earthlings and the potential development of technology, equipment and society in the exploration of outer space. It is shown that interest in space, its study and exploration will increase dynamically, and the authors consider the industrialization of near space as one of the directions for promoting the development of new society.

Along this path, as Anatoli Unitsky suggests, it is necessary to implement a series of measures on planet Earth aimed at addressing the global environmental crisis. This should start with changing the way we build modern cities, transforming transport and infrastructure solutions and bringing harmful industries into near space. The scientist proposes to combine the efforts of humankind in order to separate the biosphere and the technosphere. This will ensure the preservation and development of life on our planet and create conditions for the harmonious interaction of human civilization with the biosphere. According to the authors of the conference proceedings, such an approach will lead to the consolidation and formation of civilizational patriotism on a global scale, therefore, it seems to be the only possible one with the current state of our Earth's technogenic civilization, its technologies, science and the whole society.

Anatoli Unitsky is confident and offers the following:

- Earth is for the biosphere, humanity and the eco-oriented technologies necessary for the Earth's technogenic civilization;
- space is for all environmentally harmful, energy- and resource-intensive industrial technologies.

In his opinion, the first step on this path is the creation of an effective geocosmic transport and infrastructure system along the Earth–Near Space–Earth route. The advantage of space as a place for the deployment of the industrial technosphere is related to the peculiarities of its environment, such as:

- lack of gravity;
- technological purity (absence of gases, dust, microorganisms and other contaminants);
- cryogenic and high temperatures;
- possibility of ultrafast cooling to ultralow temperatures;
- ability to create high temperatures using solar radiation.

In general, the conference and the presented reports on the non-rocket near space industrialization demonstrate the determination of the main investor and mastermind of the event – engineer, scientist, businessman, teacher, excellent organizer and moderator Anatoli Unitsky. He is also the founder of an international group of companies that

employs more than 1,000 highly qualified professionals, as well as a school for engineers, technologists, scientists and managers.

At the VI International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects," I enjoyed the atmosphere of the event. Many presentations and the exhibition of developments sparked my interest. That is why I attended the VII Global Conference on Near Space Industrialization and I would like to express my appreciation for the excellent organization of the forum. I was particularly impressed by the increased number of presentations from young scientists from Unitsky school and the overall high level of works. In fact, they have outlined a roadmap for the industrialization of near space, the creation of ecosystems during the construction of cities on planet Earth and the formation of new civilized and consolidated society.

The directions of development and the solutions presented to these problems are clear, but they are complex, which means they will require a new law and order at the global level. The construction of the General Planetary Vehicle and the launch into orbit of a system for industrializing near space has no analogues in the world in its design and engineering approach. The implementation of this project will change our world, help prolong life on the planet for future generations of earthlings and create conditions for space exploration in the interests of all humankind. In my opinion, this is still a philosophical idea that requires reflection by all peoples, consolidation of economic, environmental, legal, technological and industrial solutions and organization of their implementation. We see that life is changing rapidly. New technologies, such as artificial intelligence, are emerging alongside new materials and machinery. In some cases, things that were once fiction are now a reality and are being used by us.

In conclusion, I would like to mention that 2024 marks the 90th anniversary of Yuri Gagarin's birth, who was the first person in the world to open up space for humanity. Also, in the same year, Marina Vasilevskaya became the first citizen of the independent Republic of Belarus to fly into space and conduct research on the International Space Station. For her achievements, she was awarded the title of Hero of Belarus by the President of Belarus, A. Lukashenko.

The Belarusian space system of the Earth remote sensing is undergoing an upgrade. Work is underway on a new Belarusian-Russian spacecraft with a resolution of 0.35 m. A small satellite for monitoring the Earth's ionosphere has been almost assembled and is now preparing for launch. Several scientific and technical programs and space-related projects are also being implemented. Olga Mastitskaya, an employee of the National Academy of Sciences of Belarus, was a member of a six-person team participated in the SIRIUS-23 international annual isolation project, which was held at the Institute of Biomedical Problems of the Russian Academy of Sciences. These developments illustrate the dynamics of space exploration.

I wish Belarusian Anatoli Unitsky further success in continuing to address the challenges he has identified regarding the non-rocket near space industrialization and in applying the developments he and his team have made to enhance the lives of people in the Republic of Belarus, the Union State and globally.

The construction of the General Planetary Vehicle and the launch into orbit of a system for industrializing near space has no analogues in the world in its design and engineering approach. The implementation of this project will change our world, help prolong life on the planet for future generations of earthlings and create conditions for space exploration in the interests of all humankind.

Review by Yuri Pleskachevsky,

Corresponding Member of the National Academy of Sciences of Belarus, Doctor of Engineering Sciences, Professor, Honored Scientist of the Republic of Belarus

Global and Systemic Study of General Planetary and Near-Space Problems

In contrast to the six previous conferences, the term "global" appeared for the first time in the title of the seventh conference on the problems of non-rocket near space industrialization. According to S. Ozhegov's Dictionary of the Russian Language, "global" means covering the entire globe, complete, comprehensive. The outstanding engineer and thinker Anatoli Unitsky named his main engineering brainchild as the General Planetary Vehicle (GPV), and the term "global" referred to the widest set of problems, ideas, engineering projects and tasks, which, like the GPV, encircle the entire globe and concern, without exaggeration, all aspects of life and activity of humankind. Therefore, the terms "general planetary" and "global" are used quite reasonably.

The second peculiarity of the seventh conference is the division of the whole variety of problems into four sections. It is natural to assume that as the scope of work expands and deepens, the number of sections in subsequent conferences will only increase. Over the years, each of these sections may turn into independent conferences, which together will be aimed at achieving the main goal – the practical implementation of the greatest engineering project in the history of humankind called the General Planetary Vehicle.

The collection is opened by A. Unitsky's article "Eco-Space Program." The main provisions of this program are outlined in the author's previous publications, but in this article, he rethinks and systematically links all the provisions of the program into a single multifactor complex. Moreover, for the first time, he sounds the alarm so distinctly and urgently. Here are a few supporting quotes: "...the biosphere of our planet is filled with technological smog, threatening not only humankind but all life on Earth," "...we are now farther than ever from solving global ecological and socioeconomic problems," "...anthropogenic pressure on the biosphere continues to worsen."

Over the years, each of these sections may turn into independent conferences, which together will be aimed at achieving the main goal – the practical implementation of the greatest engineering project in the history of humankind called the General Planetary Vehicle.

The practical implementation of the EcoSpace program proposed by A. Unitsky will enable humanity to switch to a biospheric path of civilizational development. Meanwhile, the reviewer is forced to acknowledge that the light at the end of the tunnel, which had begun to glimmer, has faded. The hands of the Doomsday Clock are inching us closer to apocalypse every second: on January 28 of this year, they moved forward by a second and now indicate 89 seconds to midnight. Thus, in the entire 78-year history of this clock, its hands have never been so close to the collapse of civilization. But A. Unitsky and his team of like-minded supporters continue their noble work, backed by participants of all past conferences (and not only them), and one hopes that in due time, their efforts will be duly appreciated by our enlightened descendants.

In the section "Geocosmic and Geotechnical Sciences, Technologies, Materials and Resources" there are presentations, each of which could pave the way for new directions in scientific and technical exploration. This demonstrates the planetary-scale ideas of A. Unitsky, yet also highlights the challenges of calculation, modeling and implementation. One particularly noteworthy work by A. Unitsky is "Space Industry Waste Management." The author proposes that moving industrial production into space would halt the accumulation of waste on Earth, significantly improving its ecology. The most practical location for industrial facilities of both the first and subsequent technological processing stages, would be at Lagrange points L_4 and L_5 in the Sun–Earth system. It is natural to assume that there will be those who advocate for the purity of space. They should be preemptively reassured. All raw materials intended for processing will be sourced from nearby asteroids and the Moon, meaning that the components remaining after extracting materials usable in subsequent processing stages are not foreign to space. These remnants cannot be considered waste, as they will be repurposed for constructing walls, domes and other structures that protect industrial facilities and personnel from radiation and meteorites. A. Unitsky presents compelling calculations to support this approach.

In this section, special attention was drawn to the report by Doctor of Engineering Sciences V. Klyushnikov (TsNIImash JSC, Korolev, Russia), in which, for the first time, the forecast and analysis of the most significant environmental problems associated with the initial stages of near-Earth space (NES) industrialization, which will inevitably involve numerous launch vehicles launches before the full-scale operation of the GPV begins. Large-scale NES industrialization will lead to global impacts on the Earth's ecosystem. At the same time, the author of the article is forced to state that "due to the dissipativity and nonlinearity of the properties of the Earth's geospheres (geoenvironments)" it is impossible to predict unambiguously the results of the impact of numerous launch vehicles launches, we can only "to identify general trends that may lead to a worsening of the ecological situation on our planet."

Fundamentally new engineering solutions are contained in the reports devoted to the design and calculation of the electromagnetic suspension of the GPV rotor, the stability of the GPV overpass and its aerodynamics.

A purely theoretical article by R. Khachaturov on the so-called "relict" radiation has been somewhat artificially included in the scope of this section. This radiation represents the "bottom" of the Universe's temperature field, currently measured at 2.725 K and considered a remnant of the Big Bang. According to the reviewer, the author of the article justifiably questions the Big Bang theory as a whole, pointing out that its proponents overlook several indisputable factors, such as the chaotic motion of galaxies (for instance, the M31 galaxy is moving toward us) and the large-scale structural inhomogeneity of the Universe, which was established by academician Ya. Zeldovich – essentially, its cellular structure. It is worth noting that the filamentous cellular structure of the Universe, as described by Ya. Zeldovich, suggests an infinite number of explosions similar to the Big Bang occurring permanently in space (e.g., supernova explosions), and aligns more closely with an interference pattern than the depiction in Figure 1 of this article. Neither the single Big Bang theory nor the Hyperuniverse theory proposed by R. Khachaturov accounts for these factors, however, to be fair, the latter appears to be a more significant step toward understanding the true origins and transformations of the Universe.

In the section "Energy and Information Geocosmic Sciences, Technologies, Materials and Resources" we highlight the work of A. Unitsky, V. Garanin and A. Borovik, titled "Application of General Planetary Vehicle as Element of Unified Energy System of Earth." The implementation of the solutions proposed in the article primarily involves the creation of a unified global energy system. It is technically and technologically feasible nowadays to connect the planet's distribution circuits and to connect all generating sources and all consumers of electric power to them. Moreover, establishing such a unified system would significantly enhance the efficiency and mobility of generating capacities by allowing the flow of electricity in sync with the movement of the terminator line (day-night) across the Earth's time zones. To create this unified system, the political will of state leaders and their alliances is essential. Today, regrettably, the priorities of political figures are directed toward other goals.

In such a unified global energy system, the GPV is assigned a unique role: during the rotor acceleration phase to cosmic speeds, the GPV will consume energy, while during the descent and braking phase, it will act as a generator, supplying electricity to the unified energy system.

The article proposes a model of the unified energy system, incorporating the GPV as both a consumer and generator, external generating and storage stations as well as the planet's electricity consumers. The authors' main ideas are supported by compelling calculations.

Other articles in this section focus on developing structural and technological foundations for utilizing various energy sources and new technologies, both for the operation of the GPV and for powering terrestrial and orbital consumers.

The section "Ecological and Biological Aspects of Enclosed Biospheric Ecosystems on Earth and in Space" is distinguished by the multifaceted nature of the discussed and proposed solutions.

One of the most important parts of the EcoSpace program proposed by A. Unitsky is devoted to the restoration of soil fertility. This is the subject of the first article of this section, which proposes various biotechnologies of soil fertility restoration and maintenance, which have already been tested practically to a great extent, and which can be applied in difficult soil and climatic conditions as well as to ensure a high yield of lands to be used along the GPV overpass, the Equatorial Linear City, string rail transport routes, settlements on Earth and then in EcoCosmoHouses.

In the field of scientific interests and as subjects of experimental research of the authors of articles of this section – fertility of salt-containing soils, productivity of quail breeding in EcoCosmoHouse, features of technologies of cultivation of mushrooms and various plants (vegetables, fruits, medicinal herbs, etc.) under conditions of artificial environment.

According to the logic of the development of scientific thought and the solution of global problems covered by the peer-reviewed collection, the next section could be devoted to the production of foodstuffs and various beverages, specific due to their production and consumption in the conditions of closed biosphere space, different from the Earth's gravity and taking into account other peculiarities of EcoCosmoHouse functioning, but to the maximum extent meeting the taste, organoleptic and other usual for earthlings qualities.

Perhaps, such a section will appear in the problems of future conferences. Especially since the reviewer is aware of the already existing individual achievements of the scientific and practical school of A. Unitsky in this area of ensuring our life activity.

The section "Social, Legal, Political and Financial Aspects of Human Civilization Development on Earth and in Space" completes the collection. Each article of this section fully meets the general definition of the conference as "global." Reading the articles in this section evokes mixed emotions. On the one hand, the scale of the issues addressed is impressive and commands great respect, as does the deep concern for the current state of affairs in our home, known as planet Earth. On the other hand, there is a sense of unease when recognizing the still-unyielding trend that is leading humanity into a civilizational dead end and, if the last bifurcation point is passed unfavorably, to a nuclear apocalypse. However, the hope for a better future of visionary thinkers and progress-driven patriots of humanity, such as A. Unitsky and his associates, does not leave them even in these harsh conditions. Moreover, it encourages them to hold new global conferences and publish collections similar to this reviewed work, which undoubtedly deserves to be published in open print in its current form.

A. Unitsky and his team of like-minded supporters continue their noble work, backed by participants of all past conferences (and not only them), and one hopes that in due time, their efforts will be duly appreciated by our enlightened descendants.

Review
by Nitin Gadkari,

**Doctor of Sciences in Philology,
Master of Commerce,
Minister of Road Transport and Highways
in the Government of India**

“The authors, I feel, have demonstrated an in-depth analysis of the highly complex scientific and engineering challenges, and proposed original concepts with strong potential for practical implementation, addressing key aspects of the forthcoming industrialization of near-Earth space.

The centerpiece collection titled "EcoSpace Program" by Anatoli Unitsky is an exeptional scientific and engineering study that redefines the trajectory of modern civilization's development.

नितिन गडकरी
NITIN GADKARI

सत्यमेव जयते

आज़ादी का अमृत महोत्सव

मंत्री
सड़क परिवहन एवं राजमार्ग
भारत सरकार
Minister
Road Transport and Highways
Government of India

MESSAGE

I am delighted to glance through the Proceedings of the VII Global Conference on Near Space Industrialization. The authors, I feel, have demonstrated an in-depth analysis of the highly complex scientific and engineering challenges, and proposed original concepts with strong potential for practical implementation, addressing key aspects of the forthcoming industrialization of near-Earth space.

The centerpiece collection titled 'EcoSpace Program' by Anatoli Unitsky is an exceptional scientific and engineering study that redefines the trajectory of modern civilization's development. The author introduces the concept of spatial separation between the biosphere and techno-sphere, thereby mitigating anthropogenic environmental impact and opening new avenues for space exploration. Of particular significance is the detailed development of an all-planetary vehicle, designed to address the challenges of costly and environmentally hazardous rocket launches. The engineering calculations and feasibility studies presented in this work, suggest a high degree of technical viability. The concept of near-Earth space industrialization, including the relocation of harmful industries beyond Earth's biosphere, holds not only scientific merit but also profound socio-economic implications. The stated goal of this research is to usher in a new stage of technological evolution that will enable humanity to avert ecological catastrophe and achieve a new level of sustainable development. The study's in-depth analysis of energy efficiency, transportation logistics, and environmental safety further underscores its breadth and innovative nature.

A particularly noteworthy contribution is the research on the environmental impact of near-Earth space exploration, which, for the first time, comprehensively examines aerosol pollution, electromagnetic and light pollution, and the accumulation of space debris in the context of Earth's global ecological system. This approach aligns perfectly with the contemporary agenda of sustainable development and environmental security.

Another significant scientific contribution is the study of industrial waste management in the space industry. The author proposes utilizing Lagrangian points L4 and L5 for waste storage, along with its recycling into construction materials and elements of a space-based 'Noah's Ark' - a solution based on a well-founded analysis of space logistics and energy efficiency.

I feel special attention must be given to the studies on the motion control system and electromagnetic rotor suspension of the all-planetary vehicle. The proposed control system is an advanced hardware-software complex that ensures the optimal functioning of the rotor unit. In parallel, the development of hybrid electromagnetic rotor suspension technology marks a critical step toward the project's realization.

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I am happy to note that the collection also provides an impressive depth of analysis regarding the biotechnological aspects of space exploration. It features research on closed-loop ecosystems, humus-based technologies, the application of *Chlorella vulgaris* in orbital habitats, and the development of autonomous biosphere complexes. These studies form a scientific foundation for the design of long-duration space missions and the creation of self-sustaining space settlements.

Beyond technical and environmental considerations, the authors have also explored the humanitarian and social dimensions of near-Earth space industrialization. Topics such as human psychological adaptation to prolonged stays in artificial environments, models for social organization in space societies, and the development of specialized educational programs for training next-generation personnel highlight a comprehensive approach to planning the future of space civilization.

This collection of scientific papers represents a valuable contribution to the advancement of science and technology. Its findings will serve as a foundation for future national and international programs dedicated to near-Earth space exploration.

I express my sincere admiration for the depth and scope of the presented research. Undoubtedly, this collection marks a significant milestone in the exploration of near-Earth space, laying a solid foundation for future engineering and scientific achievements aimed at safeguarding our planet.

Given the high level of scientific rigor, engineering feasibility, and societal importance of this research, I strongly recommend the publication of the Proceedings of the VII Global Conference on Near Space Industrialization and encourage the scientific community to engage with the groundbreaking concepts presented within.

(Nitin Gadkari)

New Delhi
11th February, 2025.

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Review
by Vaibhav Dange,

**Master of Business Administration,
Expert on Public Policy Issues
in the Field of Infrastructure,
Clean Fuels and Transport,
former Advisor in the National
Highways Authority of India,
former Private Secretary
to the Minister of Road Transport,
Highways and Shipping of India**

The materials presented in the peer-reviewed collection of scientific papers from the VII Global Conference on Near Space Industrialization demonstrate a high level of analytical depth, covering almost all key aspects of near-Earth space industrialization. The collection includes research that revisits previously discussed issues as well as pioneering studies that introduce entirely new directions requiring further exploration.

The presented studies hold significant scientific and engineering value, making a substantial contribution to the development of space technologies.

Message

Dear colleagues,

The materials presented in the peer-reviewed collection of scientific papers from the VII Global Conference on Near Space Industrialization demonstrate a high level of analytical depth, covering almost all key aspects of near-Earth space industrialization. The collection includes research that revisits previously discussed issues as well as pioneering studies that introduce entirely new directions requiring further exploration. The performed calculations and proposed engineering solutions substantiate the feasibility of these projects, given contemporary materials and technological advancements.

Several studies address the pressing issue of space pollution and waste disposal, which remains one of the most critical challenges of our time. Particular attention is given to the environmental impact of the expanding space industry on near-Earth space, underscoring the urgent need for thorough investigation and the development of strategies to mitigate adverse ecological consequences. The exacerbation of environmental issues associated with space activities necessitates an integrated approach, fostering active research and innovative solutions from the scientific community. A significant contribution to understanding the scale of this problem and the imperative for its resolution is made in the work of **V. Y. Klyushnikov**. Furthermore, the reviewer highlights the work of **A. E. Unitsky**, who has proposed a novel concept for waste disposal within the space industry by utilizing regions of stable dynamic gravitational equilibrium, commonly referred to as **Lagrange points**. This approach opens new prospects for environmentally sustainable resource utilization in space, simultaneously addressing waste management and contributing to the advancement of space technologies, thereby ensuring their safer and more sustainable operation.

Additionally, the collection features studies on the **biotechnological processing of organic waste** in the context of establishing closed-loop ecosystems. This research is particularly relevant in the framework of sustainable development, as it offers effective waste management solutions applicable both on Earth and in space. The use of biotechnologies for waste recycling not only minimizes waste accumulation but also enables its conversion into valuable resources—an essential factor for long-duration space missions where resource availability is constrained. The findings presented in these papers pave the way for innovative approaches to sustainable space resource utilization and establish the foundation for a more ecologically responsible future,

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both on our planet and beyond. However, further investigation and support from the scientific community, along with governmental agencies, are required to ensure the harmonious coexistence of technological progress and environmental conservation amid the rapid expansion of space activities.

Of particular significance is the research addressing another pressing environmental issue—**desertification**. This phenomenon affects millions of people globally, posing severe risks to food security, economic stability, and ecosystem sustainability. The authors present an **innovative methodology for the stepwise restoration of desertified sandy soils**, aimed at large-scale implementation in the agricultural sector, particularly in arid regions. The advancement of biotechnological solutions for desert reclamation could become a key instrument in combating soil degradation, yielding a profound positive impact on global ecosystem restoration and biodiversity preservation for future generations.

Another noteworthy topic explored in the collection is the concept of **civilizational panspermia**, which examines space-based mechanisms for the proliferation of life and the potential emergence of extraterrestrial engineering civilizations. Additionally, several studies focus on **the physiological and psychological aspects of prolonged human presence in space**, addressing critical issues related to health, habitability, and overall well-being in extraterrestrial environments.

Furthermore, the work of **O. M. Zaretsky** merits special attention, as it delves into the fundamental challenges of ensuring **public safety during the construction of a planetary-scale transport system**. The study highlights the necessity for **international collaboration and the establishment of dedicated security frameworks** to mitigate a wide range of risks in emergency scenarios.

In conclusion, this collection offers a **comprehensive and multidisciplinary analysis of contemporary issues related to the industrialization of near space**. The presented studies hold significant **scientific and engineering value**, making a substantial contribution to the development of space technologies. Given its relevance and depth, I highly recommend this collection for publication in open-access media.

With regards'

(Vaibhav Dange)

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Review
by Elena Veduta,

**Doctor of Economic Sciences,
Professor, Head of the Department
of Strategic Planning and Economic Policy
at the Faculty of Public Administration
of M.V. Lomonosov Moscow State University**

Dreams of a better, fairer life and a new era of prosperity for our civilization are embodied in the engineering projects of Anatoli Unitsky – an extraordinary individual who is ahead of his time and sets a wide range of directions for scientific and technological progress.

The practical solutions for building a biospheric civilization presented in this collection help science move forward, achieve new discoveries and make impossible things possible – in other words, they unlock the vast potential of the human being as a creator.

Dreams of a better, fairer life and a new era of prosperity for our civilization are embodied in the engineering projects of Anatoli Unitsky – an extraordinary individual who is ahead of his time and sets a wide range of directions for scientific and technological progress.

The collection places significant emphasis on the ecology of both Earth and outer space. Without a doubt, these issues require close attention from the scientific community, since the quality of people's lives directly depends on the health of the environment – nature, society and the cosmic space. In the article "Global Environmental Problems of Industrialization of Near-Earth Space," V. Klyushnikov offers forecasts regarding the pollution of near-Earth space in the event industrialization begins. A. Unitsky expands on this topic in his scientific paper "Space Industry Waste Management," where he proposes high-tech, unparalleled solutions, including the placement of certain space industrial wastes at specific points in the Sun–Earth system, as well as the use of such waste as raw material for producing environmentally friendly building materials for application directly on Earth.

Reflecting on the future condition of our planet is essential right now – otherwise, humanity faces the threat of a global environmental catastrophe. Only human beings themselves can create a harmonious and fair life. To achieve this, it is time to adopt nature-based technologies and build life on Earth in agreement with the laws of nature, drawing on accumulated engineering experience and cybernetic control over the development of the global economy. The synergy of natural laws and engineering is embodied in the EcoSpace program, which, in the report by A. Unitsky and E. Petrov, is presented as "the basis and horizon for transformation of dominant socioeconomic model." The program outlines specific steps that humanity must take on the path toward a noospheric future, as envisioned by V. Vernadsky. This future cannot be imagined without knowledge of space, since the Universe itself is the global home of humankind – our aspirations and determination to explore the vast, restless expanses of the galaxies are directed toward it and beyond. In this context, the article by R. Khachaturov deserves particular attention. It highlights the key principles of the cosmological theory of the Hyperuniverse, based on which the laws of periodic changes in the size, velocity and acceleration of the expansion/contraction of our Universe have been derived as it moves cyclically along the four-dimensional hypersurface of the five-dimensional torus of the Hyperuniverse. The article also explains the nature of gravity and multidimensional time and discusses current data on the large-scale distribution of cosmic microwave background radiation.

The topic of deep space and the stages of human civilization's development related to its exploration is addressed in the article by A. Unitsky titled "Extraterrestrial Engineering Civilizations and Space Civilization Panspermia." The creation of space Arks on Earth, capable of carrying life to other planets, may become, over the next millennium, a primary direction driving scientific and technological, biological, socioeconomic, as well as moral and spiritual progress.

Outer space is not limited to distant galaxies and unexplored universes. Its exploration begins with research into the potential of near-Earth orbit to improve life on our planet. In this context, the article by A. Unitsky, V. Garanin and A. Borovik, "Application of General Planetary Vehicle as Element of Unified Energy System of Earth," is of particular interest. Unitsky's GPV addresses the global economic challenge of making cheap and renewable electricity universally accessible – a key factor for technological advancement in an era of total digitalization and qualitatively new industrialization.

In addition to the search for affordable and inexhaustible sources of energy, many countries around the world face the issue of food security and access to high-quality nutrition. A solution is proposed in the article "Biotechnological Restoration of Deserts as Method to Prevent Food and Energy Crises" by A. Unitsky, N. Zyl, A. Pauliuchenka and M. Parfenchik. Restoring soil fertility and reclaiming lands deemed unsuitable for agriculture, without the use of synthetic chemical agents, is a true nature-based technology with no existing analogues. To feed every human, thus ensuring their inherent right to life, is a genuine humanitarian mission being carried out, both scientifically and practically, by A. Unitsky's team. This mission is the foundation for peaceful human coexistence and prosperity.

Any engineering breakthroughs and technologies require the involvement of skilled professionals to be brought to life. A new approach to training specialists for a biospheric civilization is proposed by A. Poteryaiko and E. Fomenko. In their article "Personnel Training for Biospheric Civilization: Sociocultural and Cybernetic Approach," they emphasize the sociocultural component of educating and raising the next generation. However, the main tool for implementing any personnel policy is cybernetic economic planning, pioneered in Russia by Nikolay Veduta. It is this system that places a country's socioeconomic development on a trajectory of continuous improvement in people's well-being. Therefore, it defines the plan and forecast for professions most relevant to society, and enables accurate calculation of the resources needed to train specialists of the required quality and quantity.

It is worth noting that all articles in this collection are not only scientific and practical in nature, but also part of a broader philosophy known as "the biospheric civilization." The path toward it can be laid through cybernetic economic governance, in which the engineer – creator of new technological production methods – becomes the driving force of progress, accelerating civilization's movement toward improved quality of life on Earth and the cultural development of the individual.

Dear readers,

These proceedings have been prepared based on the materials of the VII Global Conference on Near Space Industrialization, which took place on September 13–14, 2024 in Maryina Gorka (Republic of Belarus).

The publication highlights the results of the annual activities of scientists, designers and engineers working on the implementation of the global uSpace geocosmic program. Each of the projects presented in the collection finds its embodiment and is being tested on the sites in Russia, Belarus and the United Arab Emirates. The industrialization of near space, namely the transfer of harmful industries to low-Earth orbit, is the only possible way to preserve the ecology of the planet as well as solve the socioeconomic problems of our time. This approach is designed to ensure a better future for next generations. Only by carrying out industrial exploration of near-Earth space can we fully expand into cosmos, unlock access to infinite resources for human civilization and create a foundation for the development of science and advanced technologies.

The uSpace program brings together the leading developments from a wide range of scientific disciplines, describing various aspects of human presence beyond Earth. It includes unique research and expertise in the field of space exploration, innovative modes of transportation, industry, biotechnology, sociology and philosophy, which are of interest and value to the global scientific community.

The global nature of the program implies the possibility of active participation of specialists from all fields and directions, providing effective communication for collaborative creative activities for the benefit of humanity.

Every day, we take a step closer to realizing the most ambitious space exploration project.

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Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Proceedings of the VII Global Conference on Near Space Industrialization, Maryina Gorka, Sep. 13–14, 2024 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; edited by A. Unitsky. – Minsk: StroyMediaProject, 2025. – 468 p.
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The articles in this collection reflect the themes and content of the presentations delivered at the VII Global Conference on Near Space Industrialization. The 2024 conference analyzed ways to address global challenges of our time using geocosmic means, presented an updated version of the EcoSpace program, covered topics such as the disposal of space industry waste and the origin of "relict" radiation, and introduced design solutions for a geocosmic transport and infrastructure complex. The conference also examined the aerodynamic characteristics of vehicles traveling at high speeds in tunnels and addressed biological aspects of ecosystem improvement on Earth and in space, including the use of biotechnology for desert restoration and waste recycling. It also studied the conditions for comfortable living in space settlements and discussed social, political and economic issues related to the industrialization of near space, such as the impact of space on humans, personnel training for a biospheric civilization, security challenges and the socio-economic development of countries in the context of space industrialization.

The volume includes works by leading engineers, inventors, scientists and representatives of public organizations from Belarus, as well as from neighboring and distant countries.

This publication is intended for a wide range of specialists working in fields such as transport communications, space research, astrophysics, ecology and biotechnology, as well as for researchers, laboratory staff, university professors, graduate students, master's students and undergraduates.

Scientific Publication

NON-ROCKET NEAR SPACE INDUSTRIALIZATION: PROBLEMS, IDEAS, PROJECTS

Proceedings of the VII Global Conference on Near Space Industrialization
(Maryina Gorka, September 13–14, 2024)

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