"Profitable industrial activities to be developed in Earth Orbit"

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ABSTRACT

The industrialization of Earth orbit will become feasible and profitable as soon as the new Space X fully reusable vehicles will be available, likely during 2022. With Starship-likes orbiters the ticket to orbit will drop from the current >40 $m to < 1 $m. Passing such threshold manned activities in space will be convenient and profitable, more than full robotic activities. Robots and artificial intelligence are not reliable for complex operations, since they would be with no solutions for any unexpected situation. And telemetry is not possible for distances longer than LEO. Furthermore, the scope of space exploration/settlement is not to expand a population of robots in space, but to assure new space and resources to humans, for human development in space. Follow some industrial activities which could be developed in Earth Orbit, in a time compatible with a reasonable return of investment, e.g.: space debris and wreckages recovering and reuse; in orbit satellites and spacecraft assembly and maintenance: deployment, reconfiguring, life extension, orbital reposition, refueling, disposal; Earth to/from Orbit transportation for passengers and cargo; orbital space tourism; orbit to orbit transportation; low gravity products, e.g. medical items, biotech labs, hybrid metals, industrial crystals; space traffic management; space weather monitoring; space based solar power; orbital hotels for tourists and business travelers; fueling, park and servicing stations; orbital workshops, hangars, yards; space farming and agriculture; orbital real estate; orbital sport, entertainment and culture. The necessary conditions to be developed asap, in order to allow the above development: to boost the development of low cost fully reusable passenger transportation, safe and comfortable vehicles; life protection in space from cosmic radiations, artificial gravity; space safety; safe and comfortable re-enter in the atmosphere; green environment in space habitats. This paper includes large parts from a paper presented by the author (and several co-authors) to the 2018 IAC in Bremen "Building in Space: first steps in civil expansion beyond Earth"[1].

PAPER

1 Premises

1.1 2020's, a critical age, for civilian space development

Since the beginning of this Century, some fundamental initial steps were achieved, on the path of expanding civilization into outer space. In summary:

- 2002 Elon Musk founds Space X
- 2004 ScaledComposites wins the X-Prize, birth of the New Space industrial segment, kick-off the downsizing of cost to orbit.

- 2011 1st Space Renaissance Congress – analysis and proposed strategy: space tourism as strategical development line for the opening of the space frontier
- 2015 kick-off reusable rockets
- 2016 2nd Space Renaissance Congress – analysis and proposed strategy: civilian space development, geo lunar space industrialization.
- 2017 SpaceX leads the global launch providers, lowering the launch cost of one magnitude order
- 2018 Space Renaissance focuses on enabling technologies to allow untrained civilians to travel, work and live in space, launch of the Civilian Space Protocol initiative
- 2020 Space X kicks off the development of Starship, the first fully reusable space vehicle, targeting $20/Kg cost to orbit
- 2021 Covid19 Pandemics operates a total reset on global economy, NASA chooses Space X to develop the Artemis Moon Lander.
- 2021 Space X is going to launch a Starship prototype in orbit, recovering both the first stage, the SuperHeavy, and the Starship itself, second stage.

If the above sketched roadmap will not be interrupted, the cost of a seat to orbit will soon fall under 1 million. That is considered the threshold, to begin moving workers – no longer trained astronauts – to Earth orbit, and kick-off profitable industrial activities.

Of course, in order to allow civilians to travel, work and live in space, several issues should also be resolved, such as protection from cosmic radiations, artificial gravity, smooth acceleration and safe re-enter into atmosphere, green environments in space habitats.

Yet, industrial development in Earth orbit is key, to attract raising investments, and make the space industry and market to become and be acknowledged the leading sector in the global economy.

Which are the most promising industrial activities to be developed in Earth orbit? What are the probabilities they can really kick-off during next 10 years, within 2030? Let’s have a look.

1.2 Industrial development areas propaedeutic to civil expansion into outer space

There’s a number of industrial activities, besides space tourism, which can give a return of investment in a reasonable times[2]. Therefore such activities, if properly prioritized, can work as a powerful booster of an expansionist program. Recovery and reuse of space debris and wreckages is the very first one[3]. Such a program, at least in its recovery part, is also very much needed, for the sake of orbital safety[4]. Once we will have proper orbital infrastructures, targeted to capture orbital debris, the logical following step will be to re-process them, getting powders to be input for 3d printing. Space debris will then constitute a big materials platform for orbital ISRU, the very first bricks of the orbital factories. Assembly of satellites and vehicles in orbit is the second large industrial perspective[5]. Needless to say, assembling satellites and spacecrafts in orbit will meaningfully decrease the cost of systems design (because the designed systems will be simpler, and the subsystems will be less in number), construction and launch[6]: a first step towards a self sustaining space industrial development. Furthermore, there’s a number of in-orbit operations[7]: transport and maintenance of satellites in orbit[8] [9], refueling stations, repair shops[10], orbital sites, orbital yards, spaceports, habitats[11]. And, of course, all the activities tied to space tourism, such as hotels and lodging facilities, passengers transportation systems (Earth-Orbit, inter-orbit, Earth-Moon). Products from zero gravity, asteroid[12] and lunar mining[13] are other very promising industrial activities, on which several startups were already born[14]. The commercial use of the ISS could be the very first step on such a program[15], though it is not endowed by artificial gravity, and likely to transform it for AG would cost more than building a new infrastructure, properly designed for civilian activities.

1.3 Priority to enabling technologies

To enable geo-lunar industrialization, it is necessary to press the accelerator on a series of technologies. We aim to properly stress the importance of humanism[16], as a necessary background for any scientific and technological design and development. Starting from the need of real persons is key. First of all, technicians and business men need to travel in space in raising number. Yet, considering that a) the governments don’t want to raise the budget of space agencies, and b) commercial space market is growing and quickly becoming a primary actor in the space economy, the cost of the transport vehicles shall be reduced. And this process has begun, lead by Elon Musk and his Space X company. Moreover, the vehicles should be properly designed to transport civilian passengers, and not requiring any astronautic training[17]. Accelerations should not exceed those of a normal airliner, not too much at least[18]. In this respect, collaboration between civil aeronautics and space vehicles developers is highly useful[19]. Softer and safer atmosphere return technologies are required[20]. Protection against cosmic radiation[21] is top priority, and so artificial gravity[22] [23]. Jeff Bezos, in his plan for geo-lunar space region settlement and industrialization, supports the O’Neill’s concept of big rotating infrastructures, endowed with 1G simulated gravity[24]. Last, but not least, men cannot live in a full metal artificial environment: any space habitat, be it constructed on a celestial body surface or in orbit or in a Lagrange point, shall be endowed with vegetable terrestrial life[25], not only for food production, but also for the sake of environmental / psychological health. That means to accelerate the experimentation of artificial ecosystems in closed environments.

2 Building in Space: innovative technologies for the in-orbit construction and operations of space infrastructures

In the NewSpace ecosystem, the future of Human Space exploration and settlement is now of great interest not only for Space agencies and the connected traditional aerospace industries, but also for NewSpace entrepreneurs and the civil society at large. This NewSpace paradigm promises economic benefits and valuable opportunities for social and cultural developments related to space activities.

The future strategies that could accompany the transition from the traditional space exploration approach, towards innovative concepts, include the construction and maintenance of orbital infrastructures directly in space, also by reusing space debris and by exploiting space resources.

The exploration of new planets, the construction of a Moon base, the successful completion of a long duration mission to Mars, the continued operations of the International Space Station, all require innovative manufacturing and repair technologies, that could well operate in space and suit a variety of systems, such as crew pressurised modules, radiators, fluid systems, pipe lines and truss structures, engines and aero-shells.

This idea of “space industrialization” would require a number of innovative concepts and technologies[26], some of which are already close to becoming potential game changers: reusable launch systems and sub-orbital transport for civil passengers; Additive Layer Manufacturing (3D printing) and innovative welding processes; on-orbit assembly and servicing; new solutions to better live and work in Space.

Not to forget, innovative business and economic models will be required together with the advances of technology to foster and support the technological developments needed. All revolutions, as well as consistent evolutions, have come along with economical and societal changes, that also in this case will have to be studied and addressed.

2.1 Removing and reusing Space Debris: a huge orbital value. Requirements for abiotic space predators, to harvest abiotic space resources.

Space debris are exponentially growing in Earth orbit, as old inactive satellites collide each-other and break up in smaller parts, increasing the number of dangerous objects traveling at 27,000 Km/h. The progressive miniaturization of satellites allows the last generations to decay from orbit at the end of their operative life, and to burn during re-enter in atmosphere. Large wreckages remain in orbit, however, and of all the man-made objects in low Earth orbit (LEO), 95% are space junk. Nowadays it is practically impossible to count, track and classify all of the objects in orbit: the tracked objects larger than 10 cm are 23,000, 500,000 the objects between 1 and 10 cm, the number of particles larger than 1 mm exceeds 100 million. The alive satellites are 3,500. The debris issue becomes more and more a threat to space travel and any orbital activity. Developing programs targeted to recover and reuse dismissed satellites and orbital garbage in general is not only urgent, but long time overdue. Yet, it will be an excellent business enterprise[27].

The Kessler syndrome (also called the Kessler effect, collisional cascading, or ablation cascade), proposed by NASA scientist Donald J. Kessler in 1978, is a theoretical scenario in which the density of objects in low Earth orbit (LEO) due to space pollution is high enough that collisions between objects could cause a cascade in which each collision generates space debris that increases the likelihood of further collisions. One implication is that the distribution of debris in orbit could render space activities and the use of satellites in specific orbital ranges difficult for many generations.[28]

Several initiatives are on their way to give in orbit demonstration of the viability of cost effective technologies that can be used to observe, capture and destroy space debris.

Dangerous space debris smaller than 20 cm can be removed by means of technologies such as computer vision, artificial intelligence, and the Internet of Things (LCADR, by OrbitGuardians[29], California). ClearSpace[30] (Switzerland) will launch in 2025, its mission to remove large dismissed satellites. Astroscale[31] (Japan) focuses on End-of-Life (“Don’t add any more debris to the orbital environment”), Active Debris Removal (“Bring down large debris that are currently in orbit”), Life Extension (“Service GEO satellites reaching end of life or useful in a new orbital location”), In Situ SSA (“Acquire data to better understand the characteristics of objects in orbit”).

The mission of this kind of companies includes a wide range of in-orbit services, including orbital debris removal, in-orbit transport, and satellite life extension. All of these services in the current first stage will be: (i) automated, (ii) limited to removing debris. Some current issued business plans on the subject of space debris mitigation and removal[32] only consider as opportunities the social ROI and the "market" limited to governments and space agencies[33]. That is of course a very worth undertaking, long overdue.

Yet, a real business, characterized by consistent ROI, can start only when the debris-removal companies will extend their capabilities, going manned, when fully reusable vehicles will be operative, reducing the cost to orbit. Such a development will allow to kick-off the true industrial activity tied to space debris, i.e. turning them into a resource, by recycling and reusing this huge orbital value[34].

Such evolution will turn the economy of space debris removal from the current passive status, only surviving thanks to government contracts, to an exciting active balance, when orbiting materials will be recycled, to generate powders for orbital farms, based on 3d printing, and fuel for spacecrafts[35].

Writes Johan Swanepoel: "the graveyard orbit is effectively an abandoned junkyard with no caretaker. The law currently isn't on the side of a collective solution to space junk. Even if an out-of-control satellite is heading towards one that's functioning and worth billions of dollars, international agreements forbid action to remove it without the owner's permission, even if a space drone could intervene and take it to the graveyard orbit".

Still writes, Swanepoel: "By repairing, repurposing or recycling satellites and "space junk" at a facility in Earth's orbit, this material could help build future spacecraft or exploration outposts, like a base on the moon. Using what's already floating around up there means there are no launch costs and using those resources will reduce space junk. It's the equivalent of building a home in the UK from local materials rather than importing bricks from Australia. Recycling satellites could provide not just raw materials for more construction in space, but a revenue stream to fund it. My research showed that an orbit 150 km further out that GEO Gateway Earth would have access to the whole of GEO. From there whole satellites could be taken by space drones into the floating recycling centre for a tune-up if needed. Providing these services could bring in over USD$8 billion per year, but the space laws that would govern this work are outdated and need revising. Luckily, this is something the UN are already working on, and our members are working with them to overcome barriers."

From the abstract of a recent paper[36] presented to the 8th European Conference For Aeronautics And Space Sciences (EUCASS): "We recommend a model addressing this issue and qualify debris as abiotic space resources and argue that it can be recycled and converted into fuel for other space ventures such as producing metal for on-orbit 3D printing. This could produce a commercially viable solution for incentivizing debris removal. We acknowledge mandatory property insurance and absolute third party liability insurance, both in orbit, to fund such operations through insurance salvage clauses facilitating title claim and sustain return on investment."

We found interesting concepts about space debris reusing and recycling in a deep study by NASA too[37], intended for education purpose. Hoping NASA will give proper priority to this issue in the next months and years.

Cleaning orbit from debris, and turning them into a big business, requires both legal evolution and technological development. Abiotic space resources calls for abiotic space predators. We will need big "space whales", to eat and metabolize small debris like sea whales eat plankton[38], and we will need restless agile "space sharks", seeking and catching big wreckages, avoiding them to collide, explode and produce new small debris.

2.2 Satellites in orbit assembly, transport, maintenance, fueling

As a natural evolution of the space debris removal activities, in orbit satellites assembly will come next. Satellites can be built in orbit, integrating parts received from Earth and directly produced in a space farm, by 3d printing, using in situ orbital resources, i.e. powders, produced re-processing space debris materials. Satellites can as well be deployed, reconfigured, extended in their life, repositioned to other orbits, refueled, and finally disposed[39].

Assembly of satellites and vehicles in orbit is a large industrial perspective, that will decrease the cost of design, construction and launch: a first step towards a self-sustaining space industrial development. There's a number of profitable in-orbit operations, that will become very profitable when traveling to orbit will cost less and will be safe and comfortable: refueling stations, repair workshops, orbital yards, spaceports, habitats.

Orbital factories, supported by robotic systems, and operated by human technicians, will lead to a substantial reduction in many sources of expenditure. Firstly, every ground-assembled satellite needs expensive automation for the deployment of photovoltaic panels and communication antennas[40]. Such automated mechanisms are very expensive, since they must be robust enough to withstand the great vibrations and huge accelerations of the launch. If the assembly of the satellite will be done in orbit, we can get rid of such mechanisms. And the weight to be dispatched to orbit will be less. Secondly, with the exception of orbital telescopes, any satellite maintenance is very expensive in the current paradigm, therefore unfeasible. The components are therefore very costly, since they shall be resistant to cosmic hard radiation, and responsive to the most restrictive fault tolerance and fault avoidance requirements.

Orbital workshops could take care of the satellites' location as well as of their periodic maintenance and repair, which would allow the use of commercial components at a much lower cost. Finally, orbital workshops could take care of the satellites de-commissioning at the end of their lifecycle, so they would also save automated decommissioning systems, at least for larger machines. The decommissioning subsystems of the smaller satellites could be programmed to return to the nearest collection station at the end of their life. It goes without saying that the periodic maintenance of the satellites would lengthen their life, resulting in a further reduction in overall costs and parallel increase in profitability.

Summarizing: any automation that we can avoid onboard the satellite reduces the cost of design, components, development, testing, integration and launch. But it's not over here: we talked about recycling. And here we close a first circle: with the material output of the scrap processing plants we will feed the orbital factories, which can produce parts of satellites in orbit, by means of 3d printing, further reducing the development and launch costs! Here, the frontier begins to produce on its own, and then to start a real exo-economy, though still tied to Earth by a robust umbilical cord …

So far, we have only talked about two orbital industrial threads, space scrap recycling and in-orbit satellites assembly. But urgently need to start get the ball rolling! A myriad of jobs and trades will be born around and supporting civil industrial activities in space. Just think only of the vast constellation of jobs that were born following the development of the web and the development of renewable energy sources … scared about artificial intelligence? It does not make sense! The world is so varied, and the environment of outer space even more so, that we can not do without human intelligence, creativity and flexibility – provided that it was convenient to do without, and we saw that it is not. Above all, we can never ask for a machine, apart from seeing a danger for which it was not programmed, to have insight into the potentials that become evident in the most inscrutable ways to human mind, often re-emerging after a day of depression and pessimism … or in front of a spectacular rise of blue Earth from the lunar horizon …

Listed here in bulk, a series of industrial activities that can all be done on a 20-year horizon, thanks to new enabling technologies such as reusable launch systems, and additive manufacturing: large orbital solar energy collection facilities, fueling stations for geo-lunar and interplanetary transports, lunar and asteroid raw material processing plants, orbital, lunar and lunar orbital hotels, orbital yards for construction and assembly of spacecraft for various destinations, low and zero gravity hospitals, lunar and asteroid minerals mining, spinning orbital villages, lunar research, exploration, and industrial infrastructures.

2.3 Hydroponics techniques for the cultivation of healthy products in space

Agriculture plays an important role in the history of the civilizations. It is known that agricultural production depends on the natural condition of the environment, in particular from seasons and geographical situation, as well as from unforeseen events such as drought, floods, diseases, frost, excessive heat, etc... These variables raises difficulties in traditional cultivation. In recent years, pollution of soils and groundwaters with fertilizers and pesticides added many criticalities to the process. The resources are running low and the shortage of farmland is an increasing issue, also due to the massive migratory flows from the countryside to the urban centers, the consequent expansion of urban centers and the worrying climatic and geological changes.

Hydroponics systems, made of sterile, hermetic and fully computerized greenhouses, are developed to serve both space and Earth hard environments, where cultivation en-plein-air is not possible or critical. Companies such as Ferrari Farm[41] (Italy) and Eden Grow Systems[42] (USA). These new generation and high technology solutions allow the cultivation in conditions of absolute sterility, regardless of the external environment. By means of "electronic cultivation" technology, commanding and controlling in continuous real time all of the climatic and nutritional parameters, higher productions and higher qualitative standards are obtained, as well as the advantage of cultivating in every place: space, or environmentally extreme locations on a planet, above ground or under ground, in containers, in confined environments, and in long-term space missions and space colonies.

2.4 Space Tourism

The space tourism market is forecast to reach $1.3bn by 2025, growing at a CAGR (Compound Annual Growth Rate) 12.4% during forecast period, 2020-2025, according to IndustryARC[43], considering space starting at an altitude of 100 km above the surface of the earth. Recent reports refer increasing number of customers interested in space travel[44]. Such trends will likely know further growth thanks to the decline in the cost of space tourism, along with technological advancements such as reusability of rockets and improved ergonomics of the vehicles.

Cost reduction is not the only lever needed to initiate civilian expansion into space. It is also necessary that traveling and living in space was at least as easy and safe as traveling by plane or cruise ship. And this is where space tourism enter the game. In fact, space tourism represents a different approach to spaceflight, one that starts from aeronautical experience rather than the astronautical one. Working on aspects of safety, ergonomics, comfort of vehicles is key. On such path, as well as on the one undertaken by Space X, there are several challenges to overcome, for example: protection from solar and cosmic radiation, artificial gravity and green environment in the habitats, the safety of the re-entry into the atmosphere, accelerations bearable even by those who have not had astronautical training.

Another study, by ReportLinker, expects Global Space Tourism Market -- estimated at $651 Million in 2020 -- to Reach $1.7 Billion by 2027, growing at a CAGR of 15.2% over the period 2020-2027. The main score will be done by Suborbital Tourism, one of the segments analyzed in the report, projected to record 15.6% CAGR and reach $1.5 Billion by the end of the analysis period. China, the world`s second largest economy, is forecast to grow at 19.3% CAGR, reaching a projected market size of $401.6 Million by the year 2027. Among the other noteworthy geographic markets are Japan and Canada, each forecast to grow at 11% and 13.2% respectively over the 2020-2027 period. Within Europe, Germany is forecast to grow at approximately 11.9% CAGR.

Select Competitors (on a total 42 Featured) include: Airbus Group SE, Boeing Company, Excalibur Almaz, Limited (Isle of Man), Space Adventures, Space Island Group, Spacex, Virgin Galactic, Zero 2 Infinity S.L.

Virgin Galactic is the most advanced enterprise, almost eligible to be cleared by the FAA (the US Federal Aviation Administration) for transporting civil passengers at suborbital altitude. SpaceShipTwo is just a few tests away from achieving the green light for commercial flights, to be initiated hopefully in early 2022. It should come as no surprise that so much testing is needed before getting cleared for commercial flights. We are not talking here about civilian tourists signing releases to space agencies - effectively giving up their civil rights, and agreeing to be treated as military astronauts - to spend a week on the ISS. Here we are much closer to the conditions of a regular commercial air flight. The acknowledge of compatibility with the relative regulations will be in itself another quite meaningful step, for the development of civil astronautics. After the forerunner will have achieved such a milestone, we can expect the number of investors to significantly further increase, and the market as well.

Blue Origin, the company founded and owned by Jeff Bezos, is also moving in this direction. The company’s operations have evidently experienced a notable acceleration, after Bezos left the direction of Amazon to dedicate himself primarily to the space competition. The New Shepard, a reusable suborbital vertical take-off vehicle, intended to transport astronauts and scientific payloads, will make its first flight with 6 passengers on board in 2021. The vehicle consists of a rocket, which returns to earth on its own propeller, and a seven-seat capsule, without pilot, which returns to earth through a parachute system. Bezos has announced that many more flights will follow.

If the space tourism market and industry will really take-off before 2030, it will be a robust vector, together with the Earth orbit and Cislunar space industrialization. The Morgan Stanley's prediction of a 1 trillion worth space economy in 2040 will then be far below the real size, which could more realistically be at least 3 trillion.

Also to be considered the development of all the activities tied to space tourism, such as hotels and lodging facilities, spaceports, logistics, food & beverage, fueling, services and passengers transportation systems (Earth-Orbit, inter-orbit, Earth-Moon).

2.5 Zero Gravity Medicine and Space Hospitals

According to the (US) National Institutes of Health (NIH), true microgravity cannot be truly simulated on Earth[45]. Exo-medicine and laboratories in microgravity have the potential for enhancing the study of many medical issues, including normal or pathological physiology and metabolism, cell repair processes and tissue regeneration that occur naturally or are enhanced through medical interventions following injury or aging. Already, several research successes have been achieved in the National Laboratory on the ISS. Findings and inferences thus far indicate that there is a rich potential to explore new and potentially game-changing insights and applications in a range of areas, that includes but is not limited to protein crystallization, 3-D tissue cultures, tissue regeneration, DNA regulation, drug and vaccine development, stem cells, and treatments for diseases such as cancer and other life-threatening and debilitating conditions. Experience with crystal growth in microgravity shows potential to yield much better results. In roughly 40 space investigations, close to 50% of the cases showed better protein crystals than any produced on Earth. Protein crystallization has three major revenue-generating applications: structural biology and drug design, bio-separations, and controlled drug delivery. There are also potential applications for new drug development. The potential return on investment is significant. Discoveries may lead to shorter development time for intellectual property. Time to market in developing, testing, and designing new products, drugs, treatments and therapies may be shortened and human health benefits may be realized sooner.

Several studies demonstrate how a low gravity environment was of great help, during the rehabilitation process after a stroke[46]. One of the biggest forces patients face during the recovery process is gravity. The weight, even just an arm or leg, of a patient's own body can be one of the biggest challenges of recovery after a stroke. Gravity and body weight makes recovery more difficult for stroke and brain injury survivors because muscles are weak, balance is shaky and gravity is constantly pulling downward. Those who lack neuromuscular control because of a stroke, brain injury, orthopedic surgery or other conditions cannot always counteract this force. The same concept applies to any disease affecting the capabilities of walking or however sustaining a person's own weight. Of course a medical infrastructure in Earth orbit can be construed as a number of concentric rings, progressing from a central hub at zero G, to increasing artificial gravity, up to 1G at the extreme periphery. It is reasonable to forecast a growing market of people interested to be cured in space, as soon as the traveling cost will be affordable, at least for wealthy people in the first stage. An obvious additional condition will be that vehicles will be properly designed for civilian passenger transportation, endowed with low acceleration, comfort and safety.

2.6 Space Based Solar Power

Space Based Solar Power is the obvious source of electrical power for space customers from Earth orbit and beyond, a fundamental pillar of Civilian Space Development. Many studies also investigated, since 1960's, the possible use of SBSP for feeding Earthly customers, by means of microwave transmission. Among some recent references, "Space-Based Solar Power: a near-term investment decision"[47] reports about some experiments conducted by the U.S. Air Force's X-37B, experimental space plane launched in May 2020. An experimental solar power module from the Naval Research Laboratory (NRL) intended to demonstrate power generation and conversion to radio frequency energy that could be transmitted across long distances. Despite research on SBSP is developed also by several Countries outside the US – such as Japan, China, Russia, India, South Korea, little investments were so far targeted to implement operative plants.

Another possibility to feed energy from space to Earth is laser transmission. A study dated March 2021[48] develops description of such a solution, that's endorsed by National Space Society[49] as well. According to the analysis reported by this source, 160,000 TWh are consumed annually, over 60% comes from fossil fuels, world population is expected 9.7 bn in 2050, with a predicted 50% increase in energy consumption. According to NSS, SBSP has the potential to dwarf all the other sources of energy combined. They argue that space-based solar power can provide large quantities of energy with very little negative environmental impact. It can also solve our current energy and greenhouse gas emissions problems.

The race to leadership in this domain appears more oriented to compete to dominate cislunar space, than to get leadership in energy providing to Earth. In general terms, energy innovators still seem to be less confident in SBSP, to address global energy security and greenhouse gas emissions challenges. The assessment about real convenience of SBSP is also facing the current cost of terrestrial photovoltaic, ultimately lower than any other fossil or renewable energy sources. The high investment required to put in orbit a solar power plant, combined with the terrestrial solar energy lowering cost, is the main reason for the difficulties of Earth Serving SBSP to take off.

Several concerns are also being forwarded, about the possible military use of energy beamed transmission, a powerful weapon, with capability of big destruction, both in space and on Earth. The interest of military parts appears to be higher than civilian players. Both the Air Force Research Laboratory (AFRL) and the Department of Defense (DOD) National Security Space Office (NSSO) are currently working on this theme, involving Northrop Grumman with research contracts.

No doubts, yet, that Space Serving SBSP will start its impetuous development when 100% reusable space vehicles will be available, as a key sustainable factor of civilian space infrastructure construction and exercising.

2.7 Advanced propulsion systems and Space mobility

In line with the NewSpace economic trend, it is becoming important to also ensure new and cheaper ways to access space, including new models of space transportation, both in orbit and to orbit.

In this context also the mission requirements are changing, in line with new visions of both space agencies and private actors. For example building spaceports in the lunar surroundings and Moon or Mars villages is becoming more and more a topic of discussion. Space mining and deep space missions are also becoming part of the NewSpace paradigm and require particular attention.

Both the technological and the economical feasibility are key drivers in the space propulsion arena and some innovative concepts are being developed by several companies. Some of the most promising propulsion systems and related fuels:

- **Nuclear Thermal Propulsion** (NTP)[50], more than twice as efficient as chemical propulsion systems. Used fuels are hydrogen and uranium. Most useful for moving in space, not for launch from Earth. It can be mined on asteroids, and on the Moon. Hydrogen can be extracted from lunar regolith.
- **Nuclear Fusion Propulsion**[51], a theoretical system which could provide efficient and long-term acceleration in space without the need to carry a large fuel supply. Main fuels are deuterium, tritium and helium 3. Helium 3 is largely available on the Moon.
- **Nuclear A-Neutronic Propulsion**[52] [53], would allow to reach Jupiter in 18 months, vs. the 6 years taken by the JUNO mission in 2016. Lithium-6 is the best nuclear fuel for aneutronic fusion, namely a fuel cycle practically free from radioactive elements.
- **VASIMR**[54], an electrothermal thruster under development for possible use in spacecraft propulsion. It uses radio waves to ionize and heat an inert propellant, forming a plasma, then a magnetic field to confine and accelerate the expanding plasma, generating thrust. It is a plasma propulsion engine, one of several types of spacecraft electric propulsion systems.

ACRONYMS

Acronym	Description
AFRL	Air Force Research Laboratory
AG	Artificial Gravity
CAGR	Compound Annual Growth Rate
DOD	Department of Defense
EUCASS	European Conference For Aeronautics And Space Sciences
FAA	Federal Aviation Administration
GEO	Geostationary Earth Orbit
IAC	International Astronautic Congress
ISRU	In Situ Resource Utilization
ISS	International Space Station
LCADR	Low Cost Active Debris Removal
TIAALEO	This Is An AcronymLow Earth Orbit
NASA	National Aeronautic and Space Administration
NSSO	National Security Space Office
NTP	Nuclear Thermal Propulsion
ROI	Return Of Investment
SBSP	Space Based Solar Power
SSA	Space Situational Awareness
UK	United Kingdom
UN	United Nations
US	United States
VASIMR	Variable Specific Impulse Magnetoplasma Rocket

REFERENCES

1 Adriano V. Autino, et Al, "Building in Space: first steps in civil expansion beyond Earth", https://spacerenaissance.space/wp-content/uploads/2018/10/IAC18-D4-2-12-47829.pdf

2 Autino, A.V., "Seven million and a half kg of gold in orbit" https://spacerenaissance.space/blog/2017/06/20/seven-million-and-a-half-kg-of-gold-in-orbit/

3 Aglietti, Guglielmo S. "RemoveDebris mission, from concept to orbit" https://sritac.spacerenaissance.space/wp-content/uploads/2018/07/RemoveDebris_ASTRA_v3.pdf

4 Portelli, C. "Difficulties in mitigating risks from space debris and future remedies for preserving the space environment" (Italian language) https://sritac.spacerenaissance.space/wp-content/uploads/2018/07/SRITAC2-2.2_Portelli.pdf

5 Boyd, Iain D. et Al, "On-Orbit Manufacturing and Assembly of Spacecraft", https://www.ida.org/idamedia/Corporate/Files/Publications/STPIPubs/2017/P-8335.pdf

6 Patané, Simon C. et Al, "Archinaut: In-Space Manufacturing and Assembly for Next-Generation Space Habitats", http://spacearchitect.org/pubs/AIAA-2017-5227.pdf

7 Swarts, P., "On-orbit operations the next frontier for space, experts say", https://spacenews.com/on-orbit-operations-the-next-frontier-for-space-experts-say/

8 Abhishek KRISHNA et Al, "In-Orbit Maintenance The Global Picture", http://chaire-sirius.eu/wp-content/uploads/2016/10/Krishna-et-al.-2016-In-Orbit-Maintenance-The-Global-Picture-Unknown.pdf

9 Joshua P. Davis, et Al, "On-orbit servicing: inspection, repair, refuel, upgrade, and assembly of satellites in space", https://aerospace.org/sites/default/files/2019-05/Davis-Mayberry-Penn_OOS_04242019.pdf

10 NASA Goddard Space Flight Center, "On-Orbit Satellite Servicing Study", https://sspd.gsfc.nasa.gov/images/NASA_Satellite_Servicing_Project_Report_2010A.pdf

11 Wang, B., "Gateway Foundation Spaceport envisions large scale space construction", https://www.nextbigfuture.com/2018/06/gateway-foundation-spaceport-envisions-large-scale-space-construction.html

12 Scott Pepis, et Al, "The Valuation of Startups in New Markets: an Applied Case in Asteroid Mining", https://ijbssnet.com/journals/Vol_9_No_4_April_2018/2.pdf

13 Lempriere, M., "Mining the Moon", https://www.mining-technology.com/features/mining-the-moon/

14 Jet propulsion Laboratory Caltech, "How Moon mining could work" https://www.jpl.nasa.gov/infographics/infographic.view.php?id=11272

15 Werner. D. "NASA's ISS Director explains the role commercial industry could play in operating ISS. Spoiler: Station is not for sale." https://spacenews.com/nasas-iss-director-on-role-commercial-industry-operating-iss/

16 Autino, A. – "Facing the 21st Century's Civilization Challenges by the Tools of Astronautic Humanism" https://spacerenaissance.space/media/papers/Facing-the-21st-Century-Civilization-Challenges-by-the-Tools-of-Astronautic-Humanism.pdf

17 Snead, M., "An engineer's view of what low-cost, reusable, commercial passenger space transportation means http://www.thespacereview.com/article/3152/1

18 G. Harry Stine, "Space Power Chapter 3: Space Transportation", http://space.nss.org/space-power-chapter-3-space-transportation/

19 Memorandum of Cooperation among US FAA, Italy ENAC and ASI https://www.faa.gov/about/office_org/headquarters_offices/ast/programs/international_affairs/media/

20 ESA blog, Reentry: accurate navigation is everything http://blogs.esa.int/rocketscience/2015/02/05/the-facts-on-reentry-accurate-navigation-is-everything/

21 Feretti, Luigina, "Cosmic radiation protection and SR2S project", https://sritac.spacerenaissance.space/wp-content/uploads/2018/07/SRITAC2-2.2_Feretti.pdf

22 Bethany Brookshire, "Staying grounded in space requires artificial gravity", https://www.sciencenewsforstudents.org/article/staying-grounded-in-space-requires-artificial-gravity

23 Bill Paloski, "Artificial Gravity", https://www.nasa.gov/johnson/HWHAP/artificial-gravity

24 Brian McGleenon, "The O'Neill Cylinder: Jeff Bezos' vision for an 'incredible civilisation' in space supporting entire ecosystems", https://medium.com/@lynwerkledges/the-oneill-cylinder-jeff-bezos-vision-for-an-incredible-civilisation-in-space-fef75b499710

25 Bloom, H., "Garden the Solar System Green the Galaxy", http://howardbloom.net/wp-content/uploads/2018/03/garden-the-solar-system-green-the-galaxy.pdf

26 Ferretti, Stefano, "Technologies for the construction of space infrastructures", https://sritac.spacerenaissance.space/wp-content/uploads/2018/06/Ferretti-Technologies-for-the-construction-of-space-infrastructures-FERRETTI.pdf

27 A. V. Autino, "Seven million and a half kg of gold in orbit" https://spacerenaissance.space/seven-million-and-a-half-kg-of-gold-in-orbit/

28 https://en.wikipedia.org/wiki/Kessler_syndrome

29 Orbit Guardians, Eliminating Space Debris, https://orbitguardians.com/

30 Clear Space Today https://clearspace.today/

31 Astroscale https://astroscale.com/

32 Eniko Molnar, Stella Virve, “Space Debris Removal as an Effective Business Model - Challenges and Opportunities”, https://chaire-sirius.eu/documents/a2b653-molnar-virve-2016-space-debris-removal-as-an-effective-business-model-challenges-and-opportunities-unknown.pdf

33 Space Ventures Investors, “How We Can Invest in Space Debris, the Businss of Cleaning up Space Junk?”, https://spaceventuresinvestors.com/html/space-debris.html

34 Johan Swanepoel, “Space junk: a recycling station could be cleaning up in Earth orbit by 2050”, https://theconversation.com/space-junk-a-recycling-station-could-be-cleaning-up-in-earth-orbit-by-2050-119787

35 Amrith Mariappan, et Al, “Theoretical studies on space debris recycling and energy conversion system in the International Space Station”, https://onlinelibrary.wiley.com/doi/full/10.1002/eng2.12317

36 Maria Lucas-Rhimbassen, et Al, “Conceptual model for a profitable return on investment from space debris as abiotic space resource”, https://chaire-sirius.eu/documents/c798f8-eucass-fp0602-1906190421.pdf

37 “Transportation and Space: Reuse and Recycle”, https://www.nasa.gov/pdf/475488main_HEP_II_HS_10-12.pdf

38 Vr Sanal Kumaret Al, “Dual-head Electromagnetic Variable Sweeping Speed Space Broom for Space Debris Mitigation” https://www.researchgate.net/publication/308007289_Dual-head_Electromagnetic_Variable_Sweeping_Speed_Space_Broom_for_Space_Debris_Mitigation

39 Adriano V. Autino, et Al, “A Position Paper on Civilian Space Development and Space Technology” https://spacerenaissance.space/wp-content/uploads/2016/12/SRI_Position_Paper_December_2016.pdf

40 A. V. Autino, “Our interview with Jeff Greason – Are the major space agencies supporting the development of civilian astronautics?” https://spacerenaissance.space/our-interview-with-jeff-greason-are-the-major-space-agencies-supporting-the-development-of-civilian-astronautics/

41 Pontetti, Giorgia, “Hydroponic Farming: everywhere on Earth and above” https://sritac.spacerenaissance.space/wp-content/uploads/2018/07/SRITAC2-FERRARI-FARM.pdf

42 Eden Grow Systems, https://edengrowsystems.com/

43 “Space Tourism Market - Forecast(2021 - 2026)”, https://www.industryarc.com/Report/19394/space-tourism-market.html

44 Northern Sky Research, “NSR: Space Tourism & Travel Market to Generate $7.9 B, Projecting to Fly 41,000 Passengers by 2030” https://www.globenewswire.com/news-release/2021/01/05/2153057/0/en/NSR-Space-Tourism-Travel-Market-to-Generate-7-9-B-Projecting-to-Fly-41-000-Passengers-by-2030.html

45 https://en.wikipedia.org/wiki/Exomedicine

46 Sydnie Bahl, “How Rehab Hospital’s Zero Gravity System Helps Stroke Victims”, https://www.flagstaffbusinessnews.com/how-rehab-hospitals-zero-gravity-system-helps-stroke-victims/

47 James A. Vedda, Karen L. Jones, “Space-Based Solar Power: a near-term investment decision”, https://aerospace.org/sites/default/files/2020-10/Vedda-Jones_SolarPower_20201006_0.pdf

48 Green Match, “Space-Based Solar Power: The Future Source of Energy?”, https://www.greenmatch.co.uk/blog/2020/02/space-based-solar-power

49 “SPACE SOLAR POWER, The Way Forward for Clean, Limitless Energy”, https://space.nss.org/space-solar-power/

50 Office Of Nuclear Energy, “6 Things You Should Know About Nuclear Thermal Propulsion”, https://www.energy.gov/ne/articles/6-things-you-should-know-about-nuclear-thermal-propulsion

51 Wikipedia, https://en.wikipedia.org/wiki/Fusion_rocket

52 Gary Pajer, et Al, “Modular Aneutronic Fusion Engine”, https://www.osti.gov/servlets/purl/1062659

53 Alfonso G. Tarditi, “Aneutronic Fusion Spacecraft Architecture”, https://www.nasa.gov/sites/default/files/atoms/files/niac_2011_phasei_tardittianeutronicfusionspacecraftarchitecture_tagged.pdf

54 “Variable Specific Impulse Magnetoplasma Rocket”, https://en.wikipedia.org/wiki/Variable_Specific_Impulse_Magnetoplasma_Rocket