National Space Society

Position Paper:

How Space Technology Benefits the Earth

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The purpose of this paper is to clarify and explain current and potential benefits of space-based capabilities for life on Earth from environmental, social, and economic perspectives, including:

A) Space activities having a positive impact today (such as Earth observation for weather and climate).

B) Space activities that could have a positive impact in the next 5 to 20 years (such as Datasat/Internet mega-constellations).

C) Space activities that could have a positive impact in the more distant future (such as widespread space manufacturing and industrialization).

Background

The world already benefits greatly from space technology, especially in terms of communications, navigation, Earth observation, and economic activity related to government funded space programs. Humanity's outer space capability has grown remarkably since 1957 when Sputnik was launched. Since then, we have witnessed humans land on the Moon, 135 flights of the Space Shuttle[1], construction of the International Space Station (ISS), and the launch of more than 8,100 space objects[2], including dozens of exploration missions to every corner of the solar system. In June 2019, the U.S. announced an accelerated schedule to permanently return humans to the Moon in 2024[3]. Many other nations are also focused on a return to the Moon. With an explosion of more than 2,000 commercial space companies[4], including those building communications satellites, orbital launch vehicles, rovers for the Moon and Mars, orbital habitats, space manufacturing platforms, and space greenhouses, the world's commercial space capabilities are quickly expanding beyond our satellite industry, which over the last year already brought in more than $277 billion in global revenues[5].

One reason for this recent explosion in space-related activity is the plunging cost of launch to low-Earth orbit (LEO). Launching to LEO in the past has been among the most expensive elements of any space endeavor. Historically costs have averaged more than $10,000 per kg

of launched mass. Recently, however, space companies including SpaceX, Blue Origin and United Launch Alliance (ULA) have been successfully pursuing reusable launch vehicle technology that promises to significantly reduce the launch cost to LEO. SpaceX's recently debuted Falcon Heavy now boasts the lowest cost in the industry, below $1700 per kg to LEO[6]. SpaceX's long-term ambitions, as well as that of many others, are to lower this cost to $100 per kg or less[7]. Such low launch costs will continue to dramatically change the economics of many space business models, enabling a new era of capabilities once thought prohibitively expensive.

Other technologies, such as manufacturing materials in space from resources found on the Moon, Mars or asteroids, could further improve the economics of space activities by dramatically reducing the amount, and hence cost, of material launched from Earth. A prime example is sourcing rocket propellant in space from water-rich regions of the Moon or asteroids, which could lower transportation costs to locations beyond LEO.

Space Activities with Positive Impacts Today

1. ***Earth Observation for Weather Prediction and Climate Monitoring*:** Accurate weather prediction enabled by space systems has become a critically important element in our daily lives, impacting government, industry, and personal decision making. Satellites used for weather prediction almost certainly save thousands of lives each year by giving the public storm warnings. Although no one can say exactly how many lives are saved every year, it is worthwhile to note that in 1900 a hurricane hit Galveston, Texas killing 6000-12,000 people because they had no forewarning[8]. Earth observing satellites also monitor greenhouse gases and other crucial climate indicators, as well as overall Earth ecosystem health. Without this kind of environmental information coming from satellites, plans for dealing with climate change would have no scientific basis.

2. ***Earth Resources Observation*:** Earth observation provides information and support for agricultural production, fisheries management, freshwater management, and forestry management—as well as monitoring for harmful activities or events, such as illegal logging, animal poaching, fires, and environmentally pernicious mining.

3. ***Space-based Communication Services*:** Space communication capabilities positively impact almost every aspect of human civilization. Satellite technologies have already revolutionized banking and finance, navigation, and everyday communications, allowing international and long-distance national phone calls, video feeds, streaming media, and satellite TV and radio to become completely routine. (See point 1 under the next heading for where we are advancing in this area.)

4. ***Space-based Positioning, Navigation, and Timing (PNT) Services*:** Global PNT satellite systems, which can pinpoint a location to within a few meters (or much better) anywhere on the Earth's surface, have enhanced land and sea navigation,

logistics (including ride-hailing services), precision agriculture, military operations, electrical grids, and many other industrial and societal aspects of Earth life[9]. Space-based location services built into mobile phones and used by applications on mobile phones ranging from maps to dating services have become so intertwined with modern life that abrupt cessation of PNT services would be viewed as catastrophic.

5. ***Increasing Economic Opportunities in Expanding Commercial Space and Non-Space Sectors*:** Aside from long-standing commercial satellite services, our expanding space industry, moving beyond exclusive dependence on limited government budgets and cost-plus contracting, brings with it economic opportunities, not only to those working directly in the space sector, but also to non-space actors, including many small businesses. Put another way, an expanding commercial space industry will not only result in high-tech jobs, but also everyday jobs connected to construction, food service, wholesale and retail, finance, etc. throughout the communities hosting commercial space companies.

6. ***Inspiration for STEM Education*:** Beyond economics, a healthy space sector will continue to inspire people young and old about new frontiers, discoveries and technologies, and foster interest in STEM (science, technology, engineering and math) disciplines, which helps create a scientifically literate society able to participate in an increasingly technology-driven world.

7. ***International Space Cooperation Countering Geopolitical Tensions*:** Joint space projects among nations are sometimes the only positive force countering mutual suspicion and geopolitical rivalries. The International Space Station is a prime example of such a project, a source of pride to all nations involved. Cross-border business-to-business relationships also serve the same purpose. We are a global community and space endeavors, public and private, are making us more interdependent and interconnected.

8. ***Space Spin-offs for Earth*:** Since the dawn of the space program, there have been more than 2,000 examples[10] of space-developed technologies that have since found beneficial uses on Earth, including cordless power tools, freeze-dried food, flame-resistant firefighter gear, the integrated circuit, lightweight insulation, improvements to kidney dialysis, lightning detection, and automated credit card transactions[11]. NASA tracks spinoffs each year across a wide range of topics spanning transportation, public safety, consumer goods, energy and environment, information technology, industrial productivity, and health and medicine[12]. Future health-related spin-offs will foreseeably come from the dealing with the medical issues of isolated populations in deep space.

Space Activities with the Potential for Positive Impact in the Next 5 - 20 Years

1. ***Datasat/Internet Mega-Constellations*:** This is an emerging business with huge potential, which will possibly enhance the efficiency, capacity, and security of a variety of services to Earth-based business customers by drastically cutting communications latency, while increasing throughput and global coverage. Data satellite (datasat) constellations, planned for launching mostly to LEO, will benefit the business end-users of services from the banking, maritime, energy, internet, cellular, and government sectors[13]. A related aspect of this service business is focused on everyday internet end-users and will provide high-speed, high bandwidth coverage globally, benefitting billions of people[14]. Thousands of LEO satellites are being planned by SpaceX, OneWeb, Telesat, Amazon, Samsung, and others[15].

2. ***Space Manufacturing of Materials Hard to Make on Earth*:** At this time there are only a few materials that can only be made in the microgravity environment of space and have sufficient value back on Earth to justify its manufacture even at today's high launch costs. The hallmark example is ZBLAN, a fiber optic material that may lead to much lower signal losses per length of fiber than anything that can be made on Earth. This material is being made experimentally on the ISS by Made In Space, Inc.[16], with two competitors also working on similar products. Other on-orbit manufacturing projects underway on the International Space Station include bio-printing, industrial crystallization, super alloy casting, growing human stem cells, and ceramic stereolithography[17].

3. ***Fast Point-to-Point Suborbital Transport*:** Supersonic air transport has been around since the Concorde flew in the 1970s, and more recently, several companies have begun exploring technologies for even faster transport using so-called "hypersonic" airplanes. SpaceX has announced its intentions to utilize its Starship/Super Heavy rocket system currently in development to leapfrog these companies and provide point-to-point (P2P) "suborbital" travel that temporarily leaves Earth's atmosphere only to reenter a short time later somewhere else on the planet[18]. The potential saving of travel-time using this technology is enormous, allowing access to anywhere on Earth in less than one hour.

4. ***Space Tourism*:** This is another area with enormous potential for growth. There are now several start-up companies whose sole mission is to provide low-cost access to the edge of space. Some are using suborbital rocket technology that affords a few minutes of weightlessness about 100 km above the surface[19], while others use high-altitude balloons to more inexpensively provide access to high altitudes without becoming weightless[20]. The desire among ordinary people to travel into space is strong. A recent survey[21] indicated that more than 60% of Americans would do so if they could afford a ticket. Space tourism, including Earth and Moon orbiting hotels,

sports arenas, yacht cruises, and the like could soon become open to millions of people with the falling cost of space access.

5. ***The Overview Effect:*** A well-known phenomenon experienced by many persons who have traveled into space and gazed back on our world from above is the "Overview Effect"[22], usually described as a sudden but lasting feeling of human unity and concern for the fragility of our planet[23]. The effect was first widely publicized in 1968 when U.S. astronaut William Anders, during the Apollo 8 mission, took a snapshot of the whole Earth rising above the desolate lunar surface. Anders *Earthrise* photo provided conservationists with the iconic illustration they needed, and on April 22, 1970, 20 million people turned out for the largest civic event in U.S. history: Earth Day[24]. Therefore, simply affording people the opportunity to experience the overview effect firsthand could lead to powerful shifts in attitudes toward the environment and social welfare and could become an important "side benefit" of a growing space tourism industry.

6. ***Asteroid Impact Prevention*:** With increasing knowledge of the space environment, humanity has become aware that asteroids with the potential to do great harm will sporadically enter Earth's atmosphere and reach the surface. While an early-warning system is an obvious first response to this threat (even this capability is nowhere near operational), some asteroids may pose so deadly a threat that deflection is the only way to avoid devastating loss of life on Earth. Several technologies to accomplish this task have been studied, but the capability is still in its infancy. A side benefit of investing in such a capability is that the more we learn about such "killer" asteroids the better we can identify valuable asteroids for mining.

7. ***Space Solar Power:*** In space, sunlight is unfiltered by Earth's atmosphere and at orbits of sufficiently high altitude sunlight can shine more than 99% of the year. The principle of space solar power (SSP) is to capture this abundant sunlight, and then after conversion into microwaves or laser light, beam it to the Earth's surface where ground-based receivers re-convert the energy into electricity.

   Such a system can provide electricity much of the day (in some cases, virtually 24 hours per day). Moreover, due to its vantage point in space, power can be beamed to virtually any location on Earth (within line-of-sight of the satellite) and can be directed at a moment's notice to locations thousands of km apart, or even to multiple locations simultaneously through the use of phased array technology. An early application could focus on supplying power to isolated communities, as well as for disaster relief.

   With reductions in launch cost and mass production of SSP modules, SSP has the potential to eventually cost only a few cents per kW-hour, i.e. *less* than the cost of electricity from current centralized power systems[25]. As it matures, and especially as units in modular SSP systems begin to be mass produced from in-situ space resources, it will be able to replace much of baseload electricity as well as peak

electricity generation, due to its ability for power to be sent wherever it is desired on demand[26]. Moreover, with SSP providing baseload power, there will be less need for energy storage using batteries or other systems that could impact the environment negatively.

8. ***Space-Based Data Centers*:** Together with the communications network itself, data centers are the beating heart of the internet that drives much of today's economy, but they consume vast and increasing amounts of electricity. Today, data centers are increasingly located in cold climates to take advantage of lower operating temperatures and cooling loads, and there have been serious discussions of locating data centers underwater for similar reasons.

   Another option could be to place servers and their power supplies directly in space, using the virtually unlimited solar energy (see earlier discussion on SSP) there to remove the burden of Earth-based electricity systems to power them. While cooling may be more challenging (the vacuum of space is a very good thermal insulator), there are several advantages, including increased physical security, decreased signal transmission times, and superior performance of spinning disk drives in microgravity[27]. It is possible that space-based data centers could eventually become cost effective, resulting in lower electricity demand and carbon emissions on Earth.

9. ***Space Mining of High-Value Elements*:** The focus of most space mining companies today is targeting water that will provide rocket propellant in Earth orbit, helping lower the cost of deep space operations. Other plentiful materials such as iron and other metals will be valuable for in-space construction, avoiding the expense of launching structures from Earth. However, space mining could eventually mature to the point that other valuable elements could be obtained as a natural byproduct of the large amounts of processed material, justifying the high cost of producing them in space. Prime examples are the platinum group metals (platinum, palladium, rhodium, rhenium, osmium and iridium, collectively called PGMs[28]), which can fetch prices of $30,000 or more per kg today. It is possible that some other elements, such as "critical materials" listed by the U.S. Department of Energy[29], may reach similar price levels in the next two decades, and become amenable to space mining. Delivering large amounts of material from space can be inexpensive if they are returned using space-manufactured ablative heat shields[30] that can be recovered from controlled landings in shallow water. Space mining techniques will be also different from water-based approaches frequently used on Earth, and instead would mainly rely on thermal separation and multistep processes to aggregate small percentages of metal typically found in terrestrial ores into higher and higher concentrations[31]. For example, many asteroids contain very high concentrations of high value metals amenable to mechanical separation[32].

10. ***Closed-Loop Ecosystems, Material Recycling, and In-Situ Resource Utilization*:** Limited physical resources and inherently high cost of operating in space naturally pushes system designs toward efficient utilization and recycling of vital gases, water, nutrients, and other materials, both for life support and for other uses.

Efficient re-use and/or recycling of plastics, aluminum, steel and other structural materials confer great benefits. Once these systems have been matured for space applications, the potential to apply these technology solutions on Earth is enormous, saving energy and material resources, and shifting people's outlook from once-through to circular economic thinking. Moreover, there is a need for large-scale space operations to rely as much as possible on in situ resources, literally using the rocks and regolith around which the rockets land as the raw materials for construction, life support, and other needs. If such processes can be developed in space with a high degree of efficiency and reliability, there is also potential for them to be customized for use on Earth for construction and processed goods.

11. ***Intensive Organic Agricultural Techniques***: As the size of crews in space increase, and especially as bases are constructed on distant worlds such as Mars, it will be impractical to sustain these populations using imported food. This situation will require the development of high-density, water-efficient, low-energy, fully organic agricultural methods that operate on a closed cycle. Such techniques can be anticipated to have widespread application back on Earth to increase food production.

12. ***Science Projects and Programs that Can Only Be Done (or Be Done Better) in Space*:** Beyond the science and technology projects and programs listed above, there are others that can only be carried out in space locations. For instance, the Earth's atmosphere filters out infrared light, so infrared telescopes can only be placed in space[33]. The lunar far side is protected by that body from electromagnetic emissions coming from the Earth. For that reason, with the proper precautions and infrastructure in place, it could be an ideal location to monitor low-frequency radio waves from space[34]. Many other kinds of telescopes benefit from being located beyond the Earth's atmosphere. Freed from Earth's gravity, extremely large on-orbit structures could also be assembled, such as modular arrays for radio and optical interferometry telescopes and other types of receivers or transmitters. Finally, risky biological experiments could be carried out in isolated laboratories in deep space or on the Moon, protecting Earth populations with a vast expanse of hard vacuum.

Space Activities with Potential for Positive Impact in the More Distant Future

1. ***Widespread Space Manufacturing and Industrialization*:** Eventually, the falling cost of space-based manufacturing, and the rising cost of Earth-based manufacturing (due to increased scarcity, environmental impacts, labor standards, etc.) may cause many if not virtually all extractive industries and their downstream manufacturing processes to move into space. The impact of such a change would be profound, as it would shift the side-effects of these activities to locations in space without biological ecosystems, endangered species, or human populations to negatively impact. The vastly larger domain of outer space would provide virtually

unlimited space, energy and materials on which to operate. Provided that such industrial activities are done responsibly so as not to pollute or otherwise compromise the ability of future generations to use the resources, this could be critical to permanently restoring and preserving the health of the Earth.

2. ***Waste Disposal in Space*:** As the reliability of space launch improves, it will be possible to dispose of toxic substances away from Earth. For example, in a century or so, space launch should be very reliable, making it possible to dispose of nuclear waste materials into the Sun or in an orbit around the Sun. Storing nuclear wastes on Earth for hundreds of years is a much simpler problem than the current much greater challenge of storing them for tens of thousands of years. This change in perspective could make the cleanup of nuclear debris much more tractable.

3. ***Construction of a Space-Based "Sunshade" to Reduce Global Warming*:** The severity of climate change may necessitate radical approaches, such as the reduction of sunlight reaching the Earth's surface in conjunction with greatly reduced greenhouse emissions. Known in climate change circles as "solar geoengineering" or "solar radiation management" (SRM)[35], most approaches rely on injection of aerosol particles into the stratosphere, though others increase cloud reflectance, or directly block sunlight in space. First suggested by Early (1989)[36], the concept of placing a fleet of spacecraft in orbit near Earth to reduce incident solar radiation and thereby lower surface temperatures received increased attention after Roger Angel published an influential paper in 2006[37]. While no identified SRM method can perfectly cancel the effects of climate change (and can do nothing to halt ocean acidification), SRM may be the only way to quickly lower global temperatures. The advantages of space-based approaches include the absence of unwanted chemical interactions in Earth's atmosphere, and the ability to be quickly "turned off" if unforeseen consequences were detected. Launching trillions of tiny spacecraft to form a vast "sunshade" over the planet is not feasible today, but could become possible with decreased launch costs, development of ultra-lightweight "solar sail" materials, and mass production of spacecraft.

4. ***Physical Benefits of Low Gravity*:** While currently very speculative, a number of physical maladies that could be described as "aggravated by Earth gravity" (including obesity, joint pain, osteoporosis, etc.) might be partially or completely eliminated in a lower-gravity environment such as found on the Moon, Mars or in artificial gravity environments (i.e., a rotating habitat) in Earth orbit. Low gravity is to be distinguished from "zero" gravity (technically, "microgravity") such as found on board the ISS, which has been shown to almost universally result in negative health effects. Research in this area is still in its infancy, due to the almost complete lack of funding for artificial gravity centrifuges in orbit to study these effects in humans. If funding materializes and positive outcomes are found, spending time in low gravity could become highly desirable, driving significant numbers of people to visit or even live in space.

5. ***Mass Migration of the Human Population into Space*:** One of the main drivers of space development is to provide new locations for people to live, work, and explore. While currently only very few people have been able visit space, the space community today is on a clear path to grow a commercial space tourism industry and establish small but permanent human outposts on the Moon and Mars. Very large space hotels would be quite similar to small space settlements in Equatorial LEO (ELEO—close to Earth and near the equator) where radiation levels are very low by space standards. The biggest difference may be the rotation rate as hotel guests want just a little pseudo-gravity to keep the silverware in place, whereas settlements want 1g so children grow up strong. Over time small habitats may lead to very large space settlements (e.g., "O'Neill cylinders") built with space resources and capable of hosting populations in the millions. Eventually, such settlements could enable a vast migration of people from Earth to the ultimately much larger regions of space, reducing pressure on Earth's finite land and resources.

6. ***Opportunities for Social, Economic and Political Experimentation*:** As space settlements would be environmentally separated from each other, there is the possibility of trying new ideas without negatively impacting others. Furthermore, such activities cannot destroy indigenous cultures or damage local ecosystems for the simple reason that there aren't any (with remote potential for microbial life on Mars and several moons). Notwithstanding the decimation of indigenous cultures and the horrors of slavery, the expansion of Western culture into the New World provided opportunities to set up new social, economic and political systems. Besides further developing Western style democracy into the form familiar to us today, New World settlers discovered local resources, which they brought back to Europe in the form of trade items that enriched European economic, cultural, and social life. The widespread migration of humans into space settlements would provide similar opportunities to experiment, driven by the collective frustrations of people across the world feeling powerless to change their broken systems. Success in the space domain would likely result over time in the back-transfer of new approaches and products to Earth, but without the danger of exploiting native populations.

Conclusion

NSS believes that the benefits humanity currently derives from space, plus the vast anticipated benefits described in this paper, overwhelmingly support the case for space development and settlement.

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