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National Space Society

A Space Agenda for the 21st Century

Why the Nation Should Invest in Space

The National Space Society (NSS), an independent, educational, grassroots, non-profit organization dedicated to the creation of a spacefaring civilization, believes that:

- The effort to explore and develop outer space is a positive good for the nations of the world as it opens new horizons of opportunity and resources beyond the limits of Earth.
- By continuing to explore space, we ultimately develop knowledge and technologies for living on Earth.
- The world faces a variety of problems, from soaring energy production costs to increasing demands on the world's resources to economic and political disturbances, but resources from space can offer significant solutions to many of those problems.
- By providing destinations for human exploration, NASA will enhance our economy by stimulating young people to study engineering and science.
- By providing destinations for human exploration and by increasing emphasis on Commercial Orbital Transportation Services (COTS), NASA can stimulate a robust domestic space industry that can lower costs for access to and operations in space.

How the Obama Administration Can Use Space to Improve the Future

The U.S. Government has a long history of building and maintaining large infrastructure projects to help promote the general welfare, such as roads, canals, railroads, electrical power systems, interstate highways, airports, or spaceports. Future examples of such infrastructure could include space power systems, orbital water/fuel depots, deep space navigation and communication systems, and outposts capable of supporting basic science, applied technology research, and private commerce.

NSS firmly believes that the long-term viability of a spacefaring civilization must include private enterprise. Given the challenges of operating commercial enterprises in space, and given market immaturity, the government can play a key role similar to the one played in stimulating railroads with land grants, by providing a market though its space exploration activities. As soon as commercial space services are offered comparable to previous NASA-provided services, NASA should procure those services. NASA would then be free to focus on exploration and providing research and development to benefit people around the world. As individuals and businesses begin to access space resources and expand civilization beyond Earth, government must continue to explore and provide the fundamental building blocks needed to expand humanity's frontiers.

Therefore, to join in this rich history of progress, NSS believes the Obama Administration should do the following:

1) **Support NASA as it aims for the Moon, Mars, and Beyond**: Since the end of the Apollo program, America's human spaceflight program has been locked in low Earth orbit. President Obama should continue to support the Constellation Program as it pursues the direction endorsed in the 2005 and 2008 NASA Authorization acts – sending humans to the Moon and then on to Mars. The goals of this program need to be achieved as quickly and efficiently as possible, by using common, upgradable hardware and other means to expand the space economy and to give taxpayers the best value for their tax dollars. The progress that has been made thus far in implementing the Constellation Program is the result of substantial research

and analysis, and the nation is already deeply invested in these efforts. Halting that progress would risk squandering the nation's investment and further lengthen the gap in America's human access to space.

2) **Reduce the Human Spaceflight Gap:** Current projections show that the United States may not be able to send humans into space for at least five years (2010 – 2015). During this time, the nation would be reliant solely on Russia to send our astronauts to the International Space Station (ISS). Not only must the President act to reduce the gap by ensuring that NASA has the requested level of funding, but he should provide additional funds to accelerate the Constellation program and the Commercial Orbital Transportation Services (COTS) program's Option D to reduce this gap. This gap cannot be solved by "simply" extending the life of the Space Shuttle past 2010, since the Shuttle cannot be used to provide "life boat" capability for the ISS. The gap must be closed by bringing new capabilities online sooner.

How the Obama Administration Can Advance Space Development – The National Space Industry Act

Thanks to past investments in basic technology, system design, manufacturing and operational techniques, there are many innovative uses of space systems now emerging that will support our economy and well-being. In the process, these new industries will produce new jobs and could underpin our economy well into the next century.

For example, ISS can provide a unique combination of microgravity and vacuum (not reproducible at any price on Earth) to benefit wealth-generating applications in pharmaceuticals and materials science. As another critical example, space-based solar power offers the potential for a clean and unlimited energy source in future decades. Additionally, most of what we currently know about climate change is the direct result of NASA collecting data about Earth's environment and other worlds. New systems will provide even greater insights and capabilities that will be needed to respond to environmental challenges. New communications and remote sensing capabilities, and new uses of the Global Positioning System (GPS), are also primed for rollout in the near future.

In short, civilization could now open Earth orbit to significant commercial development. However, in the early 21st century, the U.S. is confronted with substantial foreign commercial space competition for launch, systems, operations, products, and services, and the new reality of the emergence of new, highly competitive players (China, India, Brazil, etc.). As a result of this changing world, the real question today is: How can the U.S. best reap the opportunities and benefits offered by this vast frontier, and its vast economic potential, in a challenging international environment?

NSS believes that the time is ripe for innovative federal policies that will stimulate the nascent commercial space industry and thus propel our nation to the forefront of these efforts.

Three Fundamental Challenges

The American space industry faces several fundamental problems that must be addressed today if the U.S. is going to maintain its technological lead and its competitive edge in the development of new space industries:

1. **The cost of transportation to space:** The current average cost to low Earth orbit (LEO) is approximately $10,000 per pound, a price that has not significantly changed in the past

three decades. Reducing this cost and the cost of exploration beyond LEO will promote development of many new space-produced products and services.

2. The U.S. aerospace labor force: As fewer talented young people choose space-related fields as a career, the United States is experiencing a diminishing capability to compete and to reap the potentials and benefits of space. Further, the U.S. workforce is shrinking in many technical fields. Fostering an environment that encourages students to pursue these competencies benefits not only the aerospace industry, but the nation as a whole.

3. **A lack of private investment:** Space is perceived by many as being a risky investment. This perception must be changed by lowering the risk factors and by increasing the attractiveness of profit opportunities to private investors. Private investment is key to responding to new markets and creating new space products and services.

NSS believes that the answers to these challenges lie in passing the "National Space Industry Act." This legislation would be modeled on the Air Mail Act of 1925, which so effectively stimulated the development of our civil aviation industry.

Proposed Legislative Framework

1. **Minimum purchases of services at a maximum set price:** The federal government shall purchase, in each of the next twenty (20) fiscal years, cargo delivery services to Earth orbit to a minimum parking orbit of two hundred (200) nautical miles; provided, however, that the delivery of such services shall be at the price of $2,000 per pound, successfully delivered. Under no circumstances shall the federal government be obligated to pay for unsuccessful operations, launch, and/or delivery. The total obligation of the federal government to purchase such services shall be limited to a maximum of 200,000 pounds of cargo per year. The government agrees to provide payloads for these flights, including but not limited to payloads consisting of experimental satellites from universities, NASA, and industry, human life-support consumables (food, water, oxygen, and/or fuel) for ISS, and other low-risk payloads. The government may, in any given year, and at its discretion, purchase additional cargo delivery flights (beyond the maximum of 200,000 pounds of cargo per year) at the same price per pound.

2. **Workforce enhancement:** The federal government will provide, in each year of this act, 50 educational grants of $1 million to $2 million each to universities in each of the 50 states, to enable such institutions to build research satellites as student projects and to train a new generation of space engineers and scientists. These satellites will be launched at government expense as part of the cargo delivery services purchased under this Act.

3. **Guaranteed long-term funding:** The federal government shall set aside funds sufficient to pay for five years' worth of the maximum delivered cargo mass. Said funds shall be placed into an interest-bearing escrow account in the first fiscal year after the enactment of this legislation, and shall be replenished by annual additions to the account as funds are successfully claimed. Funds not successfully claimed through successful deliveries of cargo to orbit shall, at the end of each of the last five fiscal years of this Act, be returned to general federal funds.

4. **Stimulating U.S. space enterprises:** The federal government shall establish a twenty (20) year tax exemption on any products produced in or services provided from space by a U.S. corporation (excluding any launch or in-space services provided on or before the

date of enactment of this Act). This tax exemption shall also apply to any revenues derived from launch services provided by United States companies during that same period, provided that said launch services are provided at a price of not more than $2,000 per pound delivered to orbit.

5. **Building infrastructure to support exploration beyond Earth orbit:** A single substance – water – can be a catalyst for a revolution in the economics of space operations. A regular source of liquid water in LEO can make a space economy both operable and economically viable. It can provide radiation shielding, oxygen, and drinking water for astronauts. Constellation Program system enhancements can greatly mitigate mission risks and evolve into a system that greatly enhances mission capability. Further consideration will be given to other markets for water in orbit and how it could be used as an on-orbit commodity to transform orbital operations. The US Government should build an orbital water/fuel depot. For details please refer to the attached section ESAS Evolution Enabling Expedited Earth-orbit Economic Enhancement.

6; **End the Space Shuttle Program in a timely and orderly manner:** Due to the risk and cost of extending the Space Shuttle Program with additional missions this should be minimized as an option for closing the US manned spaceflight gap. Additional missions would require certification of new vendors, requalification of parts and expensive small lot purchases. A more robust COTS Option D program with a solicitation to encourage new participants should be given strong consideration for closing the gap. This would further stimulate new development in the aerospace sector.

Rationale

Reducing Launch Price. Launch prices can be lowered by increasing the flight rate, which can enable the space industry to achieve significant economies of scale. A $2,000 price per pound for cargo is a reasonable target for encouraging innovation in the space industry, given guaranteed payment upon successful delivery to earth orbit.

This act provides incentives to private industry to develop lower-cost access to space **at no risk to the federal government.** If no company can deliver at the stipulated price (which would be a threefold to fivefold improvement over the current expendable launch vehicle or "ELV" prices), the federal government pays nothing, and the experimental satellites will not be launched by the U.S. government. However, in the event that private industry is successful and does provide the sought-after capacity, the maximum the federal government would pay in any one year would be $500 million ($400 million for launch services and $100 million for grants to universities) – about the cost of a single Shuttle flight, which delivers much less cargo to orbit. **In other words, for the price of a single Shuttle flight, the federal government could put as much cargo into space as a year's worth of Shuttle flights.**

The Commercial Orbital Transportation Services (COTS) program. COTS is an important first step to reorienting national launch services procurement policy, and should help reduce launch costs. But this program alone is insufficient stimulus to the private sector, because it focuses exclusively on ISS supply. The National Space Industry Act would build on the COTS model, but would go farther, by providing a larger guaranteed government market that would

attract additional launch service competitors, as well as stimulate a private market for their services.

ISS is poised to begin full operations as an international research laboratory. The National Space Industry Act may also reduce the overall cost of supplying the ISS and future lunar outposts, thus freeing NASA resources to concentrate on its other goals. At the same time, it can help America obtain the greatest possible return on its investment in ISS, by putting access to that resource within affordable reach of more players in the private sector as well as NASA. Revenue tax exemptions for U.S. launch service providers will improve their competitiveness in the global launch services market.

Developing the Space Workforce. This program will inspire and attract the next generation of space engineers, and will provide them with the necessary hands-on experience in building spacecraft and payloads. Without such an influx of the younger generation into our workforce, the United States can not and will not maintain its position as a leader in aerospace and other fields.

Nurturing New Industries. The tax exemption for space-based goods and services is based on the proposition that lowering costs will stimulate investment. The tax exemption lowers the risk barrier to investors until new space-based ventures can establish themselves. But once established, like the civil aviation industry, the new space industry will be a strong source of tax revenue.

Building Space Infrastructure: One or more government-developed orbital water depots can facilitate space commerce for existing and developing space launch vehicles. For example, future versions of the Ares V Earth departure stage could be designed to be reusable, enabling lower-cost exploration of the Moon, Mars, or other destinations. These depots could also support private ventures, expanding the space economy.

What the Nation Stands to Gain from Space Technologies

A common response to the NSS mission is that "there are more important things to do here on Earth." With respect to the pressing problems of the day, we believe that exploring, developing, and settling the solar system *are* among the more important things a nation should do. If we are serious about finding solutions to the problems facing this world, we sometimes must look beyond it.

The world needs energy. The sun produces 1.3 kilowatts of energy per square meter of surface area. That would be the power carried by sunlight falling perpendicular to the surface of the Earth, if the atmosphere did not scatter, absorb or reflect any of it. To date, we have only tapped a tiny fraction of that energy, filtered through our atmosphere. On the ground solar energy cannot be collected over night. It is very expensive to store power overnight. In contrast, In contrast, space based power can provided from geosynchronous orbit on a 24/7 basis.

The nations of the world need metals and other materials to support our increasingly industrial civilization. The resources of this Earth are limited, and however we attempt to conserve them, they will someday run out. The asteroid belt contains 3.6×10^{21} kilograms of material, or about 4 percent of the mass of the Moon, much of that made up of nickel-iron asteroids holding the basic materials needed for steel, but also volatiles like water and precious metals like platinum.

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The nations of the world face the danger of war and the destruction that comes with it. Asteroids like the one that exploded over Tunguska, Russia in 1908 or more recently over the Mediterranean in the late 1990s (If it had arrived a couple of hours earlier it would have exploded over India and Pakistan at the height of their tensions) arrive with little to no notice and can produce explosions resembling and rivaling nuclear weapons. Without precise knowledge of where those asteroids are and (eventually) some technology to deflect them, a fragile peace or tense conflict could rapidly escalate into a devastating war.

Our world economy is competitive, and that competition is driven by high technology. Space exploration pushes technology to its limit, and so is a critical part of our nation's competitiveness. At a time when U.S. leadership in the world economy is being questioned, the federal government would be acting against its best interests if it reduced funding for basic research or interfered with private-sector applied research to create the new discoveries necessary to keep the nation technologically competitive and financially solvent. Only a rich and prosperous nation can afford to make good on the social welfare and national security commitments we have made to our people.

Our nation's future and the future of the world will depend on finding better, sustainable, high-technology solutions to the problems currently facing us. Our resources will always be constrained. However, it makes little sense to stop spending on the things that offer us the chance to succeed, whether those things come in the form of research, technology development, or education for our citizens. When people ask, "Can we afford space?" the answer is most decidedly yes. The more important question is: "Can we afford not to go?" and the answer is most definitely no.

Conclusion

The National Space Society is committed to the nation's success through space technologies. The National Space Industry Act can serve the same function for the commercial use of space that the Air Mail Act of 1925 served for commercial aviation. By providing a guaranteed market for lower cost transportation services and by helping to attract investment capital to emerging space industries, the Act can accelerate a new commercial sector that will pay huge dividends to the national economy in the coming century. The Act will also help attract the "best and the brightest" in our universities to the challenging disciplines of science and engineering. The jobs created in this new sector, and the tax revenues it will generate once operational, more than justify the investment the government makes today to ensure our leadership in aerospace for the next generation. And water depots in orbit offer the first of many positive steps toward providing the fundamental infrastructure that American citizens and businesses need to prosper in the next century.

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Attachment

ESAS Evolution
Enabling Expedited Earth-orbit Economic Enhancement

Executive Summary:

This paper offers the proposition that a single substance – water, can be a catalyst for a revolution in the economics of space operations. Historically space projects have been designed on the basis of individual mission requirements in isolation from potential synergistic approaches that could vastly improve the prospects for numerous space projects. The program/project manager has no choice but to watch the bottom line, precluding him or her from developing systems that could accomplish a greater good. This is where the use of water could become an enabling substance to transform the space economy. Regular liquid water can make on-orbit fuel depots both operable and economically viable. It can provide radiation shielding, oxygen, and drinking water for astronauts. This paper suggests Constellation Program systems enhancements as a follow-on program growth option that can greatly mitigate mission risks and evolve into a system that can greatly enhance mission capability. Further consideration will be given to other markets for water in orbit and how its use as an on-orbit commodity can transform transportation for orbital operations.

Constellation Context:

The current Constellation systems architecture that NASA plans to use to go to the moon is to launch a heavy-lift cargo rocket larger than Saturn V known as Ares V. The Ares V bears the Earth Departure Stage (EDS) and the Altair lunar to low Earth orbit (LEO). Ares I, the crew launch vehicle, must then launch within a very tight launch window of 72 hours before the liquid hydrogen (LH_2) fuel in the EDS has boiled off to the point that the mission and a billion dollars' worth of hardware are lost. The prospects for a loss of mission are high due to any number of factors that could produce a launch delay beyond the critical 72 hours. Even tough the Constellation Program may decide to launch Ares I first for risk mitigation – the boil-off of cryogenic fuels will remain problematic.

The current Constellation systems architecture was baselined in NASA's Exploration Systems Architecture Study (ESAS), which favored the Ares I/Ares V vehicles over the thousands of launch alternatives studied over the prior two years. Those studies typically involved more launches of smaller vehicles to put the necessary "chunks" of hardware in orbit to go to the moon. The NASA team that integrated those earlier concepts referred to hardware as "chunkatectures." These chunkatectures risked a loss of mission due the loss of any one launch vehicle in the series of flights required to get all the pieces in place. The architectural constraints imposed by launching a vehicle in numerous small chunks was further complicated by using complicated interface hardware to link them all together. However the death knell to the launch salvos and their chunkatectures was that each chunk that carried fuel to orbit was subject to boil-off problems. Delays in any one of launches in the salvo could mean a billion-dollar loss of mission. The risks for the approaches considered were so high that a loss of mission was more likely than not. This was clearly unacceptable. ESAS provided the appropriate answers to mitigate these risks.

The one shortcoming of those pre-ESAS launch studies was that none of them considered the use of an on-orbit fuel depot. A fuel depot would have enabled tanks to be filled or topped-off just prior to Earth

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departure. Many people feared that an on-orbit fuel depot would have appeared to Congress like a Trojan horse attempt to build yet another space station. It was wisely deemed ill-advised to develop an architecture that required an on-orbit infrastructure to make it viable. Indeed the ESAS selection appears to be viable—at least in the short run.

Solution Set:

Despite the reluctance of the ESAS planners to consider on-orbit refueling, a smaller fuel depot could still be added to the architecture as a growth item that could initially be used top off the EDS prior to departure from LEO. This fuel depot would be built so that it could expand to provide the capability to fuel the total capacity of the EDS. According to Dallas Bienhoff of Boeing "one, maybe two tons of useful surface payload," is about all the current Constellation Architecture can place on the lunar surface.[1] He further asserts that:

> Adding a propellant depot in Earth orbit that could fill the tanks of the EDS and Altair could dramatically change the architecture and improve its performance. In such an architecture, the EDS could perform not just the translunar injection (TLI) burn but also the lunar insertion burn, something that under ESAS would be performed by the descent stage of Altair. That greatly increases the amount of mass that can be landed on the Moon: 51 tons, according to Bienhoff, virtually all of it in the form of additional useful payload. "The other thing that it does is enable a two-sortie opportunity for a single mission," he said, if the full lander—both descent and ascent stages—returns to lunar orbit from one site and refuels from the EDS before landing at another location on the lunar surface, rather than carry a heavier cargo payload. "Two sites in one mission: that's what a depot enables." [2]

Given the upcoming constraints in federal discretionary funding due to increases in entitlements such as Medicare, Medicaid, and Social Security that will be incurred as the Baby Boom generation retires, NASA will have to find alternatives to lower the costs of space exploration. On-orbit fuel depots might just provide the ticket to risk mitigation, cost reduction, and financial burden sharing with other agencies and commercial interests needed to ensure the long-term viability of the Constellation program. It is understood an orbital fuel depot has problems that must be addressed as well.

Economic Enabler:

Most fuel depot concepts revolve around the launch and transfer of cryogenic fuels—liquid oxygen (LOx) and LH_2—to the depot, cryogenic long-term storage at the depot, and transfer of the cryogenic fuels to other vehicles. An alternative to this approach is to use water. Water is easy to handle, easy to launch, easy to store, and easy to transfer to or at the depot. Any number and types of vehicles can be used to launch water. Reliability of these vehicles need not be high. Launch crews and range safety would not have to deal with large payloads of cryogenic fuels. This would greatly reduce the costs of operations. Payloads lobbed into orbit could be picked up by an Orbital Maneuvering Vehicle (OMV) or Orbital Transfer Vehicle (OTV) and taken to the depot. The very existence of the depot would create market opportunities for the OMV and OTV for satellite servicing, satellite boost to Geosynchronous Orbit (GEO), and a range of other services. Fuel burn-off of water while the payload awaits pickup by the OMV or OTV

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would not be a concern, and water transfer from the launch vehicle payload tank to depot tanks is not particularly hazardous.

Water stored at the depot could be electrolyzed and converted into LOx and LH_2 as required. The depot's cryogenic storage tanks would employ sunscreens and robust insulation along with just-in-time manufacture of the cryogenics to manage boil-off.

Making Markets Materialize:

The Constellation Program represents an enormous potential market for on-orbit fueling. Other markets that appear to be sufficient to establish a fuel depot include provisioning fuel to loft Earth-observing resources (for NOAA) and defense satellites into higher orbits, and for inserting communication satellites into GEO. These potential markets are enticing when coupled with the prospects for satellite servicing. This could lead to large communications platforms in GEO, which would provide power and station keeping such that a communications company would only have to launch their transponders and antennas. The antennas could be large enough to enable tiny receiving antennas on ground – much smaller than Direct Broadcast Satellite (opening up a whole new range of applications) – more on what may enable this latter.

LH_2, due to its low molecular weight, is the preferred fuel for high-specific-impulse (I_{sp}– roughly pounds of thrust per pound propellant consumed) solar-thermal propulsion system and nuclear thermal engines. This could be the key to economic transportation in cis-lunar space, to the asteroids, and on to Mars and beyond.

Water has a lot of potential markets on orbit. It can be injected into resisto-jets providing I_{sp} far better than the best cryogenic engines. Resisto-jets are small motors with extremely hot electrodes that provide explosive expansion for certain liquids like regular water. The thrust is not that high, but it is sufficient for satellite reboost and attitude control. For human habitation H_2O is nature's necessity. ISS, the moon-base, expeditions to Mars, Robert Bigelow's orbital platforms, and all other human endeavors in space can make ample use of water. Water is required for drinking, and growing and preparing food. Water can be used to make the oxygen we breathe. Water makes great radiation shielding, ballast to manage center of gravity, and is a good medium for thermal management. A gallon of water weight eight pounds. In space, where it costs $10,000 per pound to launch payload to orbit – a gallon of water is worth roughly $80,000 today.

Transportation Transformation:

The potentially lower degree of constraints on how water could be launched to the depot and the potential demand for water could provide an additional market factor to foster the emergence of commercial low cost launch providers. This, along with simple competition, may provide a force to bring down the price of water and fuel in orbit. As these new launch systems mature and expand into other markets, they can be expected to exert a strong downward force on launch prices.

Lower launch prices, coupled with the capabilities of second-generation solar thermal orbital transfer vehicles, should make mining of asteroidal resources a reality. A system to mine asteroids for water and

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other resources may be justified on the basis of planetary defense alone. It takes much less change in velocity (energy known as delta-vee in orbital dynamics) to get to an asteroid than to the moon. The mission time is longer but an inefficient high thrust decent/ascent suite of engines is not required – neither is a lander! Until such time as the growing market for water and bulk materials on-orbit spurs the development of a coil gun to loft water, the asteroids can be expected to provide water much cheaper to orbit than can be provided from Earth or even the moon. These developments will further drive down the cost of on-orbit fuel and human operations in space. As coil guns come on-line asteroid mining will shift to helium-3 and strategic metals. The maturing commercial launch services will shift to launching equipment needed for on-orbit processing and launching the personnel required to operate these systems. Processing these materials will create a demand for more on-orbit processing capacity. ISS and Bigelow-type platforms may represent the beginnings of that capacity. All of these capabilities can in turn enable the communications platforms in GEO alluded to earlier more practical. The resulting expansion of orbital infrastructure and lower cost materials on-orbit will increase the feasibility of orbital tourism. As the prices for tourist trips to orbit drops the pool of potential tourists expands providing an even larger market for the industry.

Long Look:

As soon as asteroid mining opens up, many other markets may emerge. Helium-3 fusion, which is potentially far safer and more practical than the deuterium-deuterium fusion sought by most of the fusion energy community today, may then become practical. Strategic metals, in particular platinum-group metals, are plentiful in metallic asteroids. Platinum-group metals will be crucial as catalysts for fuel cells if we move to a hydrogen-based economy. Even if cold-fusion were to pan out – fuel cell electrodes are palladium, a platinum group metal. Asteroidal resources are crucial for our future demand for these strategic metals. This is true even for today's state-of-the-art use of these metals. Platinum-group metals are the catalysts in catalytic converters which are required to clean the exhausts of gasoline engines. Platinum is also the catalyst for that makes fuel cells work which will be required for an efficient hydrogen based automotive transportation system. Today's exponential price increases of key strategic metals is a reflection of the fact that we are running out of these resources on Earth. Fortunately they are plentiful in the asteroids.

All of these activities could collectively create more market forces for lower-priced services, which would synergistically ratchet up the nation's overall space system capabilities. It is in this fashion that the government can be expected to continue exploration, and that orbital tourism can prosper. The possibilities in orbit will be revolutionary – especially with the application of in-situ resources to boot-strap the process. The eventual product of asteroid and lunar mining and their associated growing on-orbit processing infrastructure, coupled with growing GEO communications platforms, could be Space Solar Power Satellites (SSPS) that can beam energy directly to Earth.

The transportation transformation heralded by a water depot on orbit can be the beginning of a revolution that eventually could bring clean abundant energy and material resources to Earth while enabling evolutionary expansion of human habitation into the cosmos.

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Recommend reading: "Space Resources - Breaking the Bonds of Earth" by John S. Lewis and his wife Ruth A. Lewis.

End Notes:

1. Foust, J.; “Propellant depots: an idea whose time has (almost) come”, The Space Review, 12 May 08, http://www.thespacereview.com/article/1127/1

2. Foust, J.; “Propellant depots: an idea whose time has (almost) come”, The Space Review, 12 May 08, http://www.thespacereview.com/article/1127/1