

RECOMMENDATIONS FOR IN-SPACE INFRASTRUCTURE INITIATIVE: Enabling In-Space Infrastructure to Provide Economic and Societal Benefits

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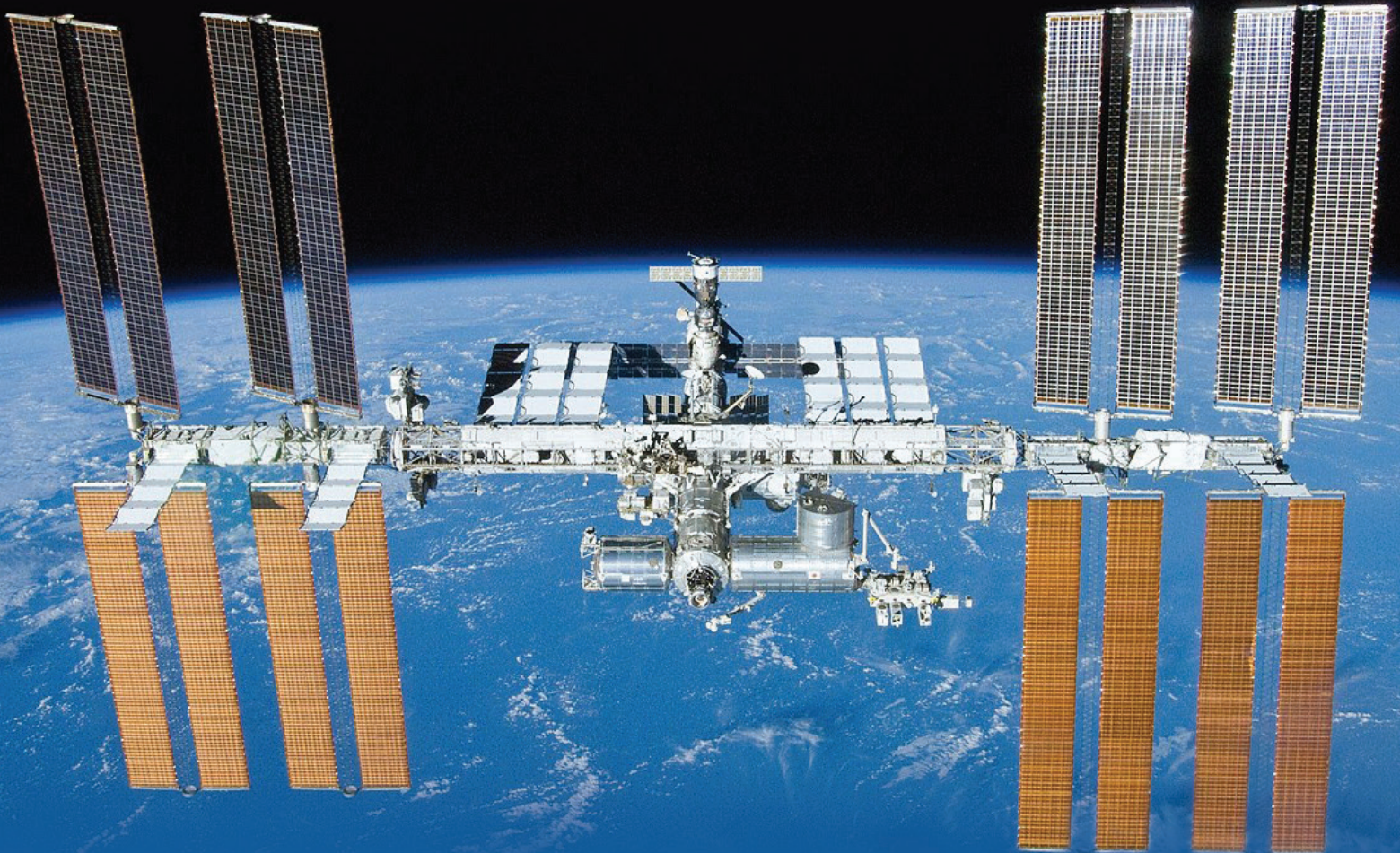
STATEMENT OF ATTRIBUTION

This paper was written in 2018, submitted to AIAA for review in January 2020, and approved by the AIAA Public Policy Committee in January 2020. The AIAA Space Exploration Integration Committee (SEIC) members are nationally and internationally renowned aerospace professionals with expertise in one or more space exploration-related disciplines. The SEIC also recruits students and young professionals who desire to serve the aerospace community at large and to become valuable assets to the community. This statement reflects the views and opinions of SEIC members and is not necessarily a position of AIAA at large.

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EXECUTIVE SUMMARY

Expanding our economic sphere beyond Earth will bring humanity greater prosperity and security. A space-based economy has already taken root. There are hundreds of communications satellites in geosynchronous orbit, the Global Positioning System has made terrestrial navigation with cell phones commonplace, weather satellites warn us of approaching hurricanes, wealthy tourists are paying for space adventures, and the International Space Station has welcomed numerous commercial initiatives. The prospects for further economic expansion into space seem full of promise with plans to send human exploration missions beyond Earth orbit to open new frontiers. To enable this process we start by asking a few fundamental questions: Why should we try to stimulate this economic expansion? What are the benefits to society? What steps can best facilitate it? By drawing on parallels from history, we argue that enabling in-space infrastructure will stimulate economic expansion and generate significant benefits to people on Earth. In-space infrastructure would consist of the systems and services operating in Earth's neighborhood to facilitate commerce, exploration, and scientific discovery. We postulate that there is an immediate need for at least a "critical mass" of in-space infrastructure to be planned, funded, and implemented to expedite broader, efficient, and easy access to cislunar space for all interested stakeholders/participants, and lay the foundation of a vibrant space-based economy. Since a fully developed space economy will have worldwide significance and impact, we further suggest that a global advocacy for development of an in-space infrastructure should be initiated.

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HISTORICAL PERSPECTIVE

Investments in infrastructure directly contribute to long-term economic growth. There are numerous examples from U.S. history where government infrastructure investments have resulted in large economic benefits for the nation [1, 2].

Transcontinental Railways — The Railway Act of 1862 was signed into law by President Abraham Lincoln on July 1, 1862. It authorized land grants and the issuance of 30-year government bonds (at 6%) to private railroad companies to construct and operate a transcontinental railroad. The economic impact of the transcontinental railway was significant; the flow of goods over the rail line in 1869, its first year of operation, was over \$50 million (almost \$1 billion in today's dollars [3-5]). Over 7,000 new towns [5], cities, and settlements were established along the rail line including Denver, Cheyenne, Laramie, Salt Lake City, Reno, and Sacramento. Domestic and overseas trade boomed because manufacturers in the East and Midwest could reach the Pacific coast and Asian markets for the first time. The 30-year bonds were paid off in full, on time, so the only cost to the government was the land, but it was now producing significant tax revenue from the new cities and farms.

Electrical Utilities — The establishment and growth of electric power in the United States is a triumph of engineering and technology, of government-industry partnerships, and of the engagement of a positive economic feedback loop that over decades provided substantial benefits to investors, industry, and the public [6]. The era of the electric utility began in 1881 with the issuance of a franchise from New York City to the Edison Electric Illuminating Company for the sale of electric light [7]. At that time, electricity was too expensive for most people to afford. During the 20th century, electric power emerged as a dominant economic advantage for industries and as an enabler of improved living standards for the public. The electrification of America drove a significant transformation, making electricity the nation's most capital-intensive industry.

Interstate Highways — The Federal Aid Highway Act of 1956 authorized construction of the Interstate Highway System, a network of freeways that forms a part of the National Highway System of the United States (75,932 km, as of 2010 [8, 9]). One percent of the nation's roads are interstate, but they carry about one-quarter of all vehicle miles driven in the country [8, 9]. The cost of construction has been estimated at \$425 billion (in 2006 dollars), making it the "largest public works program since the Pyramids" [10]. The system has contributed in shaping the United States into a world economic superpower and a highly industrialized nation by enabling easy trucking connections between large and small towns throughout the country. Trucks currently move about 75% of the total freight compared to 14% by rail.

Internet — The Internet evolved from the original ARPANET that was constructed by the Advanced Research Projects Agency (ARPA) in 1969. The ARPANET linked just four nodes: University of California at Los Angeles, SRI (in Stanford), University of California at Santa Barbara, and University of Utah. By 2015, the Internet linked over 16.3 billion nodes and generated \$4.9 trillion in global economic value [11]. The success of the Internet is its speed and flexibility. The limited government investment provided initial proof of concept demonstration.

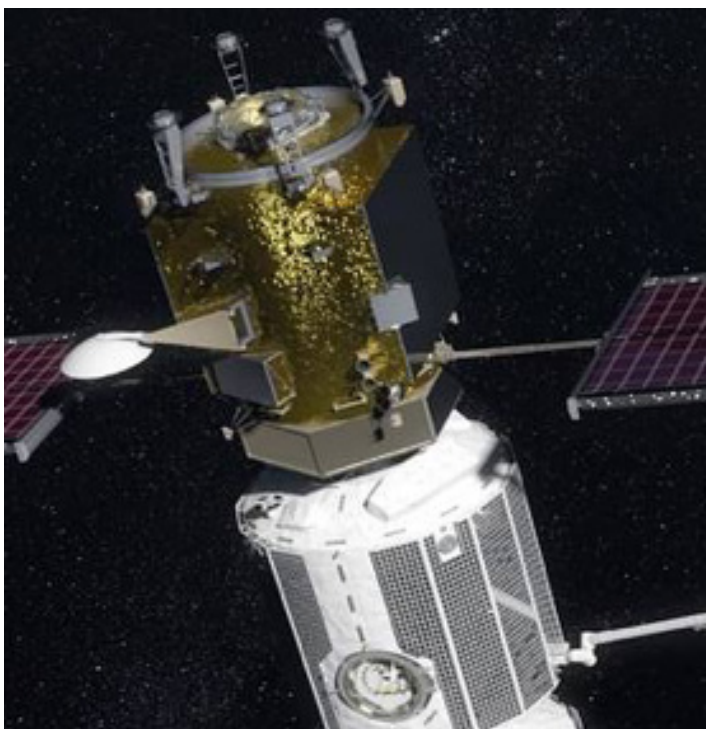


THE SPACE ECONOMY

Historical accounts of the economic benefits of infrastructure investments lead us to conclude that investments in in-space infrastructure will likewise stimulate booms in the growth of a space-based economy. In-space infrastructure consisting of the systems and services operating in the Earth-moon neighborhood will facilitate commerce as well as enable human exploration, which pushes the frontiers of the economic sphere outward. A fully functional space-based economy is going to be complex to establish, primarily due to its inherent international nature. To promote economic development, the space infrastructure must achieve a critical mass that fosters a self-sustained path of economic growth and profitability. The initial cost of this critical mass in-space infrastructure will be high and initially serve government-funded exploration and science missions. As such, the space economy does not conform to the classic free market model. Initially, the investment will be “government investment only” and “government investment with public-private partnerships,” where allowed by the political and economic structure. Governments with open economies can encourage public-private partnerships to share the costs of building the foundations of in-space infrastructure. Policies and results will encourage additional private sector investments.

The role of international governments [12-16] would be to:

- 1) Create government-industry partnerships (where possible) or government entities to define, build, and operate various elements of space infrastructure.
- 2) Establish regulated monopolies or other institutional means to create encouraging economic environments for government/private investment.
- 3) Recognize the potential of government as a consumer, at least initially, in pursuing space exploration goals.
- 4) Develop advanced technologies and systems that improve the economic productivity of the infrastructure and of users of the infrastructure.
- 5) Create and grow new commercial markets and applications that stimulate commerce, generate wealth, provide societal benefits, and increase demand.
- 6) Create positive economic feedback loops that encourage greater build-out and use by progressively shifting supply and demand.



ADVOCACY

With the emergence of many signature infrastructure concepts [17], such as NASA's Deep Space Gateway and NextSTEP, the Moon Village, and United Launch Alliance's CisLunar-1000, an umbrella advocacy campaign for building in-space infrastructure would be a most appropriate and timely endeavor. While on the U.S. national level, a combination of legislating action, advocacy, and outreach activities by nongovernmental entities and public and private partnership coordination bodies may be effective, this effort would benefit from an international coordination mechanism similar to the International Space Exploration Coordination Group (ISECG).

National Advocacy: An advocacy campaign should start at the grassroots levels within interested nations. It is imperative that relevant advocacy groups are organized, and a comprehensive legislative outreach campaign is launched. Strong and effective advocacy by nongovernmental stakeholders would be most helpful, and efforts should address the following key elements:

- **Public-Private Partnerships:** Planning, design, and implementation of in-space infrastructure will be a long-term and expensive undertaking, and it would be prudent to use innovative approaches with long-term planning and funding to maintain continuity over several decades.
- **Critical-Mass Elements:** Primary building blocks of in-space infrastructure, which would be essential to kick-start the in-space economy, may need to be identified by a combination of public and private advisory bodies.
- **Space Laws:** A legal framework should be established to govern space mining and property rights to encourage private use/development of the solar system's resources.
- **Standardization:** Design standardization would be required for ease of interoperability and seamless expansion, similar to NASA's docking standards for ISS.

Evolving Role of NASA: Over the past decade, the role of private industries has been changing in the current government-is-the-customer economy. NASA has been actively engaging the private sector, especially in terms of launch vehicles, space habitats, and now lunar exploration capabilities. However, construction of the in-space infrastructure would require a different mode of operation in funding (a combination of public and private sources) and in management (planning, design, and implementation). NASA should assume the roles of executor of in-space infrastructure implementation, coordinating body for public-private partnerships, planning body, and initiator/facilitator for international dialogs/cooperation. These expanded roles for NASA would require some legislative action (a new Space Policy Initiative). For this to happen, it is essential that grassroots advocacy by professional bodies, academia, industry, and the public at large are effective in bringing this campaign to the attention of legislative bodies.

International Outreach and Coordination: From a logistics and economic point of view, international cooperation is a must in this endeavor and is likely to be the most complex issue to manage. Countries would always want to have control over their public funds, even in an international setting. Public-private partnerships may only work in a limited set of world economies. Some other mechanisms must be explored to attract funding from countries where the public-private partnerships are not a viable model. Lessons learned from ESA and ISS models may provide some guidance in this regard. As a starting point, formation of a new international organization, modelled after the ISECG, could be considered. This organization, in an informal nonbinding advisory capacity, could help bring the space agencies under one umbrella working group, and could function as a brain trust to formulate strategies, roadmaps, and implementation plans for in-space infrastructure, as ISECG does for space exploration. This organization could also coordinate its activities with certain existing international organizations, such as the International Organization for Standardization (ISO).

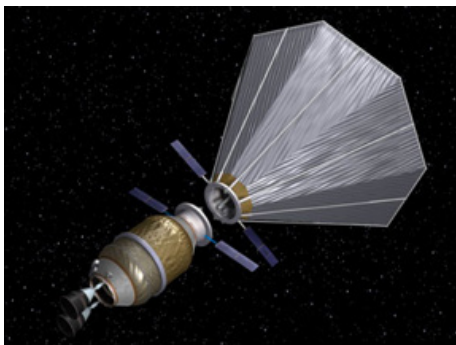
RECOMMENDATIONS

In the not too distant future, the space economy where the global population is the customer is destined to dwarf the current space economy. Historical accounts of the economic benefits of infrastructure investments lead us to conclude that investments in in-space infrastructure will likewise stimulate booms in the growth of a space-based economy. Today, we have the collective ability to accelerate this process. In-space infrastructure consisting of the systems and services operating in the Earth's neighborhood will facilitate commerce as well as enable human exploration, which pushes the frontiers of the economic sphere outward. We have postulated that there is an immediate need for at least a critical mass of in-space infrastructure to be planned, funded, and implemented to facilitate broader, efficient, and easy access to cislunar space for all interested stakeholders/participants, which will lay the foundation of a vibrant space-based economy. However, it will require a considerable effort on our part for it to become a reality: intense advocacy by relevant stakeholders (legislative bodies, industry, academia, social thinkers, to name a few), comprehensive planning and economic analyses, establishment of relevant global and national coordinating groups, and, most importantly, public-private partnerships/governmental interventions to implement the final recommendations agreed upon by all parties. The time to act is now.

- It is our opinion that a national and international In-Space Infrastructure Initiative should be launched to stimulate and accelerate the growth of a larger space-based economy.
- It is recommended that a new international organization, modelled after the ISECG and the International Astronautical Federation (IAF), is constituted and is charged to develop integrated government and commercial roadmaps for in-space infrastructure and pursue a global advocacy campaign. Included with the roadmaps would be technical and policy recommendations, including decision dates for their implementation.

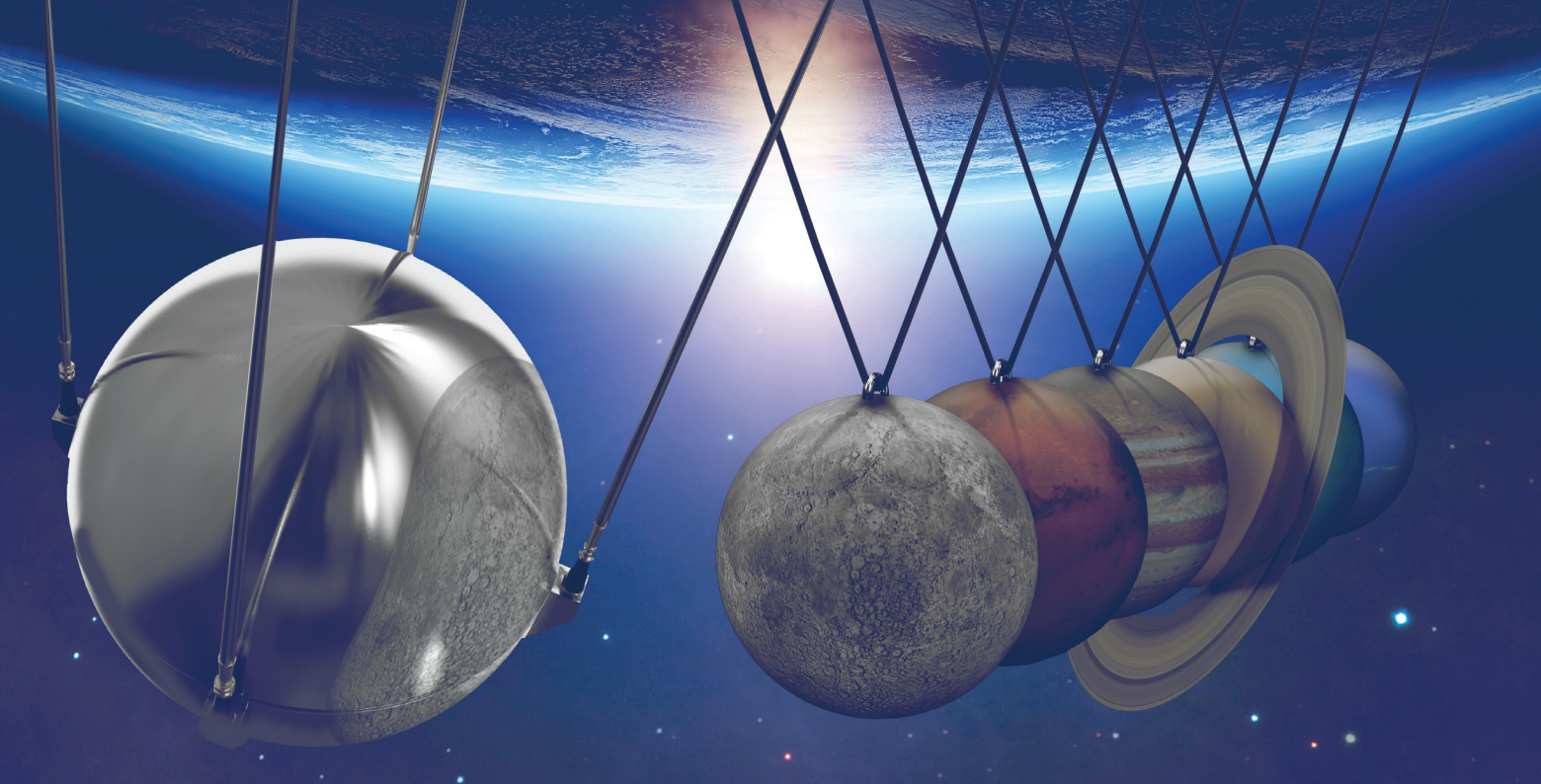
(For example, the roadmap could call for a global Space Policy Initiative for building the foundations of in-space infrastructure. Such an initiative could encourage governments to establish in-space infrastructure development as a central goal of their nation's space program. The roadmap could call for coordinating policies, legal frameworks, interoperability standards, plans, and investments across the world's space agencies, and for identifying opportunities for collaboration.)

- A strong and effective advocacy by nongovernmental stakeholders would be most helpful to the legislative process. The American Institute of Aeronautics and Astronautics (AIAA), working with other national professional organizations, is in an excellent position to engage relevant stakeholders and should launch a vigorous grassroots campaign for a global Space Policy Initiative on in-space infrastructure.
- The establishment of in-space infrastructure will require securing near- and long-term funding streams and a prudent planning and implementation strategy to have the in-space infrastructure up and running in an appropriate time frame. In the near term, key infrastructure investments would be mostly funded by the government to achieve the critical mass to jump-start new markets to emerge, with investments flowing through a combination of commercial and public entities depending upon whatever the national and international agreements would allow. The implementation strategy should be based on an incremental approach: near-term elements (critical mass; based on technologies which are readily available now), followed by markets and technological innovations to emerge in 10–30 years attracting investment dollars. Thirty years and beyond would be a time when the initial in-space infrastructure already established starts to facilitate major space development activities, with a fully developed space economy. This incremental approach example may serve as a brainstorming stimulant when the final planning and implementation strategy begin to crystalize.



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