

An Integrated Strategy for Growing the Space Economy

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The Global Space Economy By the Numbers

Market Size

- Valued at hundreds of billions of dollars encompassing both civil and defense applications
- Estimated to reach trillions of dollars by 2030s

Key Players & Industries

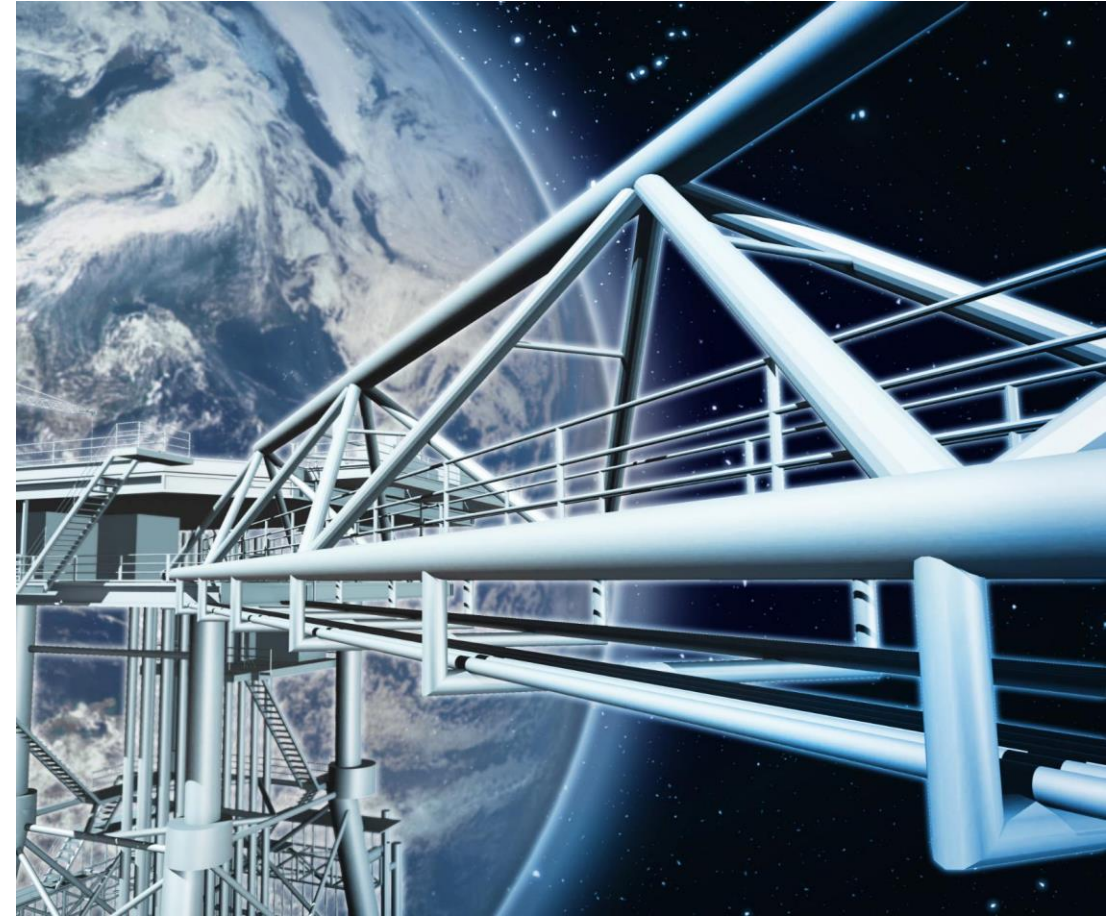
- Governments and now increasingly private industry
- Manufacturing
- Launch Services
- Satellite Technologies
- Ground Services
- Space Exploration
- R&D
- Defense applications dominate public investments

Growth Trends¹

- Global public investment grew by ~2% from 2024 to 2025 (~\$137B)
- Global private investment grew by ~50% from 2024 to 2025 (~\$12.4B)
- U.S. dominated the private investments (~\$7.3B)

The Vision of Future Space Economy

- Using the microgravity environment to
 - Manufacture high-tech materials (fiber-optics, ceramics, super-alloys, crystals, pharmaceuticals)
 - Bio-fabricate such as organs using 3D printing
 - Manufacture microsattellites, instruments, space-system components
- Service and repair satellites
- Orbital debris removal
- Space tourism
- Outer space resource mining
- Moon, Mars and beyond exploration



Key Challenges to Progress



- Current space economy is Linear
 - Linear: “take-make-dispose”
 - Circular: “reuse-repair-recycle”
 - Regenerative: “generate resources, self-sufficient, Earth-independent”
 - Need to progress from Linear → Circular → Regenerative
- Lack of global standards and protocols for both hardware and software
- Lack of long-term coordinated strategy among government, industry, private investors

An Integrated Strategy for Growing the Space Economy: The Five Pillars

1 - Modularity



3 - Interoperability



Elements 1-4:
Foundation of
Circular Space
Economy

5 - Resource Generation



2 - Standardization



4 - Maintainability



Element 5:
Foundation of
Regenerative
Space Economy 5

Modularity



Characteristics

Space system designs that use standardized components with “**plug-and-play**” interfaces for subsystems.

Advantages

- P-n-P designs enable ease of servicing in orbit, whether be repair or upgrade of satellites
- Flexibility of design avoiding “one-of-a-kind” component
- Lowers non-recurring engineering costs (NRE)
- Allows rapid manufacturing and scalability
- Allows rapid integration of complex components



Standardization

- Standardization principles establish requirements and interfaces for efficient design, development and operation of space systems, e.g. International Docking System Standards (IDSS) developed by NASA, ESA, and other countries
- Enables scalability by avoiding long lead times and high cost of developing unique capabilities for each system
- As commercial space stations are being implemented by NASA via the CLD program, standardization of key features is crucial for interoperability



Interoperability

- Enables diverse space systems to seamlessly perform together while sharing resources, **regardless of manufacturer or operator**. Examples include rendezvous and docking, ECLSS, Comm, PNT, software
- Improves overall capability, safety, reduces costs
- Interoperability (or lack thereof) came into focus during the Boeing CST-100 Starliner mission
- Success hinges on government and industry coordination and adoption of standards
- Intellectual property laws currently can limit sharing of technology and full interoperability potentials



Interoperability of space systems is crucial when designing the Lunar infrastructure. 8

Maintainability

- Space systems must be designed with maintainability in mind, e.g. accessibility of components and ease of component exchange requiring modularity
- Maintainability enables systems to be restored to operational status or be upgraded with new technology
- Crucial to space sustainability, as the number of satellites in orbit are growing exponentially
- Commercial startups such as ThinkOrbital making progress in developing technologies for in-space repair.



The Hubble Space Telescope was repaired and upgraded by Astronauts during 5 space missions from 1993 to 2009.

Resource Generation

- Ability to generate resources either in Earth's orbit or on another planetary bodies known as In-Situ Resource Utilization (ISRU) is essential for permanent presence in space and the sustainability of the space economy.
- Power and propulsion lead the priority commodities for sustained presence and ISRU to build Lunar or Martian infrastructure.
- Some business models centered on bringing precious resources (e.g. He-3) back to Earth.



Image Credit: The Martian

Industry Comparisons



Marine Commerce*

- The creation of modular standard shipping boxes coupled with industry adoption had sweeping consequences on economic growth
- Adoption of standardized containers made it possible for any cargo to travel on any truck, train, or ship seamless
- Decades of technical and international negotiations, until McLean open sourced his patent on corner fitting royalty free leading the path to standardization



Space Telecommunication

- Reusable hardware, increased launch frequency, rideshare led to cost cutting
- Production at scale and minituarization

* The Box: How the shipping container made the world smaller and the world economy bigger, by Marc Levinson

Strategy Implementation

- **Coordination and Adoption by Industry**
 - Industry associations such as CONFERS can lead coordination together with OSC, NASA, etc.
 - Create governance model followed by standards development and adoption
- **Research & Development**
 - Gov provide high-risk funding for low TRL and have a stake in profits to re-invest
 - Gov cost share with private entities
- **Policy & Acquisition Strategy**
 - Architecture should be aimed to advance the space economy
 - Instead of IP restrictions across separate procurements, incentivize technology sharing and adoption of standards to compensate for vendors' short-term economic goals
 - CLD development is a turning point for this strategy
- **Business Models**
 - Structured financial engineering and integration (FE&I) is needed similar to SE&I in developing space systems
 - Consortium of key public and private funders is needed akin to a market depot, integrating investors with suppliers
 - Microgravity manufacturing example
- **Regulations**
 - Parallels with the aviation industry starting in early 1900s which spun applications to military, commerce, and tourism
 - Currently FAA Office of Commercial Space Transportation to ensure safety, FCC to regulate satellite communication, NOAA's CPSRA issuing licenses for commercial remote sensing satellites
 - Consortium of regulation experts needed to work with industry consortium in an integrated manner to ensure not only safety but the growth of the space economy
- **Next Generation Workforce**
 - Fundamental need for developing STEM careers to grow the space economy



Conclusions

- Presented an integrated strategy for growing the space economy while ensuring space sustainability for future generations
- Strategy is anchored by 5 key pillars: **modularity, standardization, interoperability, maintainability, resource generation**
- Execution of this strategy **requires close coordination among governments, commercial space industry, and private funders**
- Success relies on voluntary adoption of the 5 pillars supported by **incentivized acquisition strategies, targeted policies, and robust regulations.**
- **R&D is the foundation of the strategy** and must be supported through **innovative business models** for funding high-risk technology development.
- The sustainability and evolution of this strategy is contingent upon **comprehensive STEM workforce development** and retention initiatives.