STATE OF THE SPACE INDUSTRIAL BASE
SSIB 2025

SUSTAINING SPACE LEADERSHIP: ECONOMIC STRENGTH AND NATIONAL SECURITY AT SPEED AND SCALE

Summary Report by:

NewSpace Nexus

In collaboration with Key Partners to support NewSpace Nexus in developing topic areas for the SSIB Conference

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Cover Photo: The W-2 spacecraft reentering Earth's atmosphere from the Koonibba Test Range in South Australia. ***[Photo: William Godwin | Credit: Varda Space Industries]***

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Gen Bratton Keynote at SSIB 2025 [Credit: NewSpace Nexus].

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Peter Garretson, A.J. Metcalf, Andrew Williams and Bucky Butow Panel presentation at the SSIB 2025 [Credit: NewSpace Nexus].

EXECUTIVE SUMMARY

This report is produced as part of NewSpace Nexus' mission to Unite & Ignite Space and accelerate the pace of space innovation. It is built on a structured, collaborative framework used in the State of the Space Industrial Base (SSIB) Conference and Workshop series to identify and address critical barriers impeding progress year over year, with the voice of industry fully represented.

CONTEXT AND PURPOSE

The report reflects input from hundreds of industry experts who convene annually at the SSIB Conference & Workshop series. It captures cross-sector perspectives, with an emphasis on removing barriers that space companies face, to grow a healthier space industrial base and national security innovation base at greater speed and scale.

It is the only industrial base report built through a multi-day series of workshops and presentations designed to enable co-development of solutions across industry, government, academia, and the investment community. This work is grounded in a comprehensive assessment of the current state from the prior year to benchmark progress and guide discussion. The SSIB "unconference" format enables candid structured dialogue focused on the most pressing issues constraining progress.

Valuable time and resources are lost when companies do not advance their innovations and government buyers do not find the suppliers with the capabilities they need. In this context, the report provides counsel to the Administration, senior policymakers across the executive departments, Congress, the venture capital and investor community, and the broader commercial space ecosystem. It is intended as a resource for Congressional staff, Executive branch officials, industry and technical practitioners—especially those engaged in national security space acquisitions—who must make near-term decisions under conditions of strategic, technological, and fiscal uncertainty.

This report is the seventh in a series of SSIB assessments produced since 2019. The earlier reports (2019–2024) were developed to illuminate vulnerabilities and opportunities across the U.S. space industrial base and to provide concrete, multi-year recommendations to policymakers, acquisition professionals, and industry leaders to accelerate the space of space innovation at speed and scale. This report is written with information from 2025. With the rapid pace of space activities some items may be out of date but will be captured in future editions.

Over time, the focus of these reports has evolved:

- 2019–2020 emphasized foundational space industrial base health and the need to treat space infrastructure as national critical infrastructure.
- 2021–2022 highlighted the acceleration of commercial capabilities, the rise of proliferated architectures, and the growing importance of in space servicing and logistics concepts.
- 2023–2024 shifted toward integration, how policy, regulation, acquisition, and finance either enable or inhibit the adoption of commercial capabilities into national security and civil architectures, and began to stress the importance of workforce, education, and community level impacts.

This 2025 SSIB report builds on that lineage. It retains the industrial base lens but focuses more explicitly on alignment: the degree to which U.S. policy, regulation, acquisition practices, infrastructure, and workforce systems are coherently supporting long term national objectives in space.

The report is organized around six working groups hosted through the NewSpace Nexus SSIB 2025 conference and workshops:

1. Space Policy and Regulation & Finance (SPRF)

2. Launch Capacity, Spaceport Infrastructure & National Environmental Policy Act (NEPA) Modernization

3. Space-based communications architecture – named Outernet in Working Groups

4. Space Mobility & Logistics/In-Space Servicing, Assembly & Manufacturing (SML ISAM/)

5. Novel Space Technologies

6. Space Education, Workforce & STEM

Each working group assessed the current state, identified key issues and challenges, highlighted inflection points over the next decade, and proposed actions and recommendations by timeframe (0–18 months, 3–5 years, beyond 5 years) and primary owner (Congress, Executive agencies, industry, finance, or international partners).

CROSS CUTTING DIAGNOSIS

Across the working groups, several themes recur:

1. Fragmented and lagging regulations.
   The United States still lacks a unified, enforceable mission authorization framework for novel space activities under Article VI of the Outer Space Treaty. Export control modernization is only partially complete. Implementation of 14 Code of Federal Regulation Part 450 has produced bottlenecks, workforce strain, and uncertainty for launch providers. NEPA implementation has become more fragmented following rescission of CEQ regulations. Collectively, these factors introduce avoidable friction, especially for new entrants and for activities such as SML/SML.

2. In August 2025, the Administration issued Executive Order 14335 ("Enabling Competition in the Commercial Space Industry"), directing streamlined launch licensing, spaceport infrastructure coordination, and a mission authorization framework for novel activities. In December 2025, EO 14369 ("Ensuring American Space Superiority") established ambitious goals including lunar surface nuclear reactors by 2030 and mandated acquisition reform prioritizing commercial solutions and Other Transaction Authorities. While these orders signal high-level policy intent, their effectiveness will depend on implementation, resourcing, and sustained political commitment across administrations.

3. Acquisition misalignment and unclear architectures.
   Acquisition cycles remain slow relative to commercial innovation. Overclassification and requirements processes that favor incumbent primes limit new entrant participation. The concept of government “anchor tenancy” poorly understood and is inconsistently applied. Most critically, there is no coherent, widely shared architectural vision for key areas such as space mobility and logistics or hybrid space

communications. Technology demonstrations proliferate, but many have no clear architecture to plug into.

4. Vendor concentration and single point vulnerabilities.
   DoD's heavy reliance on a small number of providers—most notably SpaceX for proliferated Low Earth Orbit (LEO) communications—creates strategic and operational risk. Similar concentration patterns exist in launch, certain critical components, and specialized services.

5. Infrastructure and environmental bottlenecks.
   Cape Canaveral and Vandenberg are operating beyond their original design with aging infrastructure, commodities constraints, workforce shortages, and community level housing and services pressure. NEPA and related environmental processes are often slow, duplicative, and inconsistent across agencies, complicating spaceport expansion and inland launch development. Nuclear capable payload processing infrastructure is already a bottleneck for anticipated missions.

6. Workforce as a binding constraint.
   The space workforce has grown rapidly, but domestic production of talent—across engineering, trades, operations, and data/AI roles—is not keeping pace with demand. Regional constraints (e.g., housing and healthcare in launch communities) and misalignment between training programs and employer needs exacerbate shortages. Outreach and STEM programs remain fragmented and over reliant on volunteer labor.

7. International competition and standards setting.
   China is aggressively pursuing large constellations and holds key positions in standards bodies (ITU-R, 3GPP). The European Union's Space Act and IRIS² program signal a deliberate effort to shape regulatory norms. At the same time, allied partners are exploring alternatives (IRIS², national constellations) partly in response to perceived overreliance on U.S. providers. U.S. arrearages in UN funding, including impacts on the Office for Outer Space Affairs, risk ceding diplomatic and normative leadership just as space issues gain prominence at the United Nations Security Council.

TOP LEVEL RECOMMENDATIONS

From the more detailed chapter level recommendations, the working groups identified a set of crosscutting actions that merit priority attention. Each is tied to specific owners; Chapter 8 provides a recommendations matrix for 2020-2024.

1. Establish a coherent mission authorization framework for novel space activities.
   Congress should provide clear statutory authority to a designated civil agency (likely Department of Commerce or DOC, in coordination with others) to authorize and supervise commercial activities not clearly covered by existing regimes (e.g.,

SML/ISAM, active debris removal, certain cislunar activities). This should build on, but not be limited by, the 2025 Executive Order on "Enabling Competition in the Commercial Space Industry."
Owners: Congress, DOC, Office of Science and Technology Policy (OSTP).

2. Complete and regularize export control modernization for space.
Finalize the current space related rulemakings and establish a regular review cadence (e.g., every 3–5 years) to avoid decadelong gaps. Ensure that refueling, on orbit servicing interfaces, and Rendezvous Proximity Operations & Docking (RPOD) enabling technologies can be discussed and exported to allies under clear, risk-based rules.
Owners: Department of State (DOS), DOC/Bureau of Industry and Security (BIS), Defense.

3. Articulate and resource "North Star" architectures for SML and hybrid SATCOM Architectures.
National security space stakeholders including industry should define objective force designs for space mobility and logistics and for hybrid/multivendor SATCOM architectures, including explicit roles for commercial capabilities. Civil agencies (e.g. NASA for exploration architectures) should do the same for their domains. These architectures should then drive requirements, experiments, and budgeting, rather than being after-the-fact rationalizations of ad hoc projects.
Owners: U.S. Space Force (USSF), U.S. Space Command (USSPACECOM), National Reconnaissance Office (NRO), National Aeronautics and Space Administration (NASA).

4. Reduce excessive dependence on any single commercial provider for critical services.
DoD should adopt policies capping the percentage of theater-wide capacity that any one commercial provider can supply for critical services (e.g., Proliferated Low Earth Orbit (PLEO), SATCOM), while retaining surge and contingency options. Source selections should explicitly score interoperability and multi-vendor integration.
Owners: DoD Chief Information Officer, USSF, DISA.

5. Modernize launch and spaceport infrastructure, including NEPA processes.

    - Enable longer-term lease authorities and dedicated grant programs for spaceports;
    - Recognize major spaceport projects as eligible for Fast-41 or similar expedited review;
    - Expand use of programmatic NEPA reviews and cross agency categorical exclusions; and
    - Support digital range modernization (e.g., Project Andor) with clear performance metrics.

Owners: Congress, DoD, NASA, Federal Aviation Administration (FAA)/Department of Transportation (DOT), CEQ.

6. Develop and professionalize a space logistics corps.
   National security space lacks the logistics profession found in other domains. USSF should establish doctrine, training, and career pathways for space logistics, including sustainment budgeting, "classes of supply" in space, and integration of servicing and refueling into operational concepts.
   Owners: USSF, USSPACECOM.

7. Scale workforce pipelines through regional consortia and work-based learning, leveraging successful programs, such as Pathways to the Stars.
   Federal agencies, states, and industry should expand paid internships, pre-apprenticeships, and apprenticeships tied to mission critical roles (engineering, trades, operations, data/AI) and build regional consortia that align employers, community colleges, and universities around shared skill standards.
   Owners: USSF, NASA, DOE, state governments, industry.

8. Fund and participate in industry-led standards bodies for hybrid satellite architectures and Space, Mobility and Logistics/ISAM.
   Government should fund and actively participate in industry-led standards efforts for interoperable SATCOM and ISAM interfaces, modeled on organizations like the WiFi Alliance or Bluetooth SIG, and coordinate with CONFERS and COSMIC.
   Owners: DoD CIO, USSF, NASA, DOC/(National Telecommunications and Information Administration) NTIA, Federal Communications Commission (FCC), State, industry.

9. Stabilize anchor tenant relationships where appropriate.
   Agencies should use anchor tenancy in a disciplined way—where there is clearly demonstrable broader market potential—and provide multiyear demand signals for services such as SML, Commercial LEO Destinations (CLDs), certain SATCOM capabilities, and potentially civil space situational awareness, while avoiding unnecessary government competition with commercial offerings.
   Owners: NASA, USSF.

10. Treat space relevant infrastructure and workforce as national security priorities.
    Spaceport infrastructure, critical supply chains, and key workforce hubs should be explicitly recognized in national critical infrastructure and resilience planning, with associated incentives and protections.
    Owners: Department of Homeland Security Cybersecurity and Infrastructure Security Agency (DHS/CISA), DoD, DOE, state and local governments.

KEY INFLECTION POINTS (2025—2030)

The report identifies several near- to mid-term developments that could significantly alter trajectories:

- Golden Dome development path. The design and acquisition choices for the Golden Dome missile defense architecture will shape requirements for proliferated sensing, resilient communications, and potential weaponization of space.
- Competitive balance in proliferated LEO communications. Amazon Leo's commercial entry, IRIS²'s ramp up, and Chinese mega constellation deployments (Guowang, Qianfan) will influence vendor diversity, standards setting, and allied perceptions of dependence on U.S. providers.
- SML/ISAM demonstrations circa 2026–2027. Success or failure of key servicing, refueling, and logistics demos (DARPA MRV/RSGS, AFRL/USSF missions, DIU initiatives) will determine whether SML/ISAM is seen as a routine part of operations or remains relegated to one-off experiments.
- NEPA and Part 450 reform outcomes. Legislative and regulatory changes, and the success of initiatives like Project Andor, will either unlock or constrain the ability of U.S. ranges and spaceports to sustain higher launch cadences.
- Workforce and community trajectories in key hubs. Housing, healthcare, and cost of living dynamics in launch regions and major space hubs will affect the ability to recruit, retain, and sustain the necessary workforce.

IMPLICATIONS FOR U.S. STRATEGY

The central conclusion of this report is that technical capability is no longer the primary bottleneck for the U.S. space industrial base. Instead, alignment—of policy, regulation, acquisition, infrastructure, architectures, and workforce—is the critical variable necessary to enable the speed and scale required to ensure national security and U.S. sustained leadership in space.

If the United States can:

- Clarify mission authorization and export rules for novel activities,
- Commit to coherent architectures for SML and SATCOM,
- Reduce single vendor dependence,
- Modernize spaceport infrastructure and environmental processes, and
- Invest in sustained, regionally grounded workforce systems,

then the United States can preserve and extend its position as the partner and flag of choice for space activities, while maintaining strategic and economic advantages in the face of intensifying competition.

Failure to act will not result in a static status quo. Other nations and blocs—the European Union, China, and others—are already moving to shape the regulatory, architectural, and normative environment for space. The decisions outlined in this report will determine whether the U.S. leads, follows, or is forced to adapt to frameworks designed by others.

A long exposure capturing the orbital launch of a SpaceX Falcon 9 and the first-stage booster's return to Cape Canaveral Air Force Station on Dec. 21, 2015. ***[Credit: SpaceX]***

CHAPTER 1: INTRODUCTION AND METHODOLOGY

The U.S. space industrial base is at an inflection point. Commercial and government space activities are more intertwined than ever, yet the frameworks that govern, resource, and sustain this ecosystem have not kept pace with the scale, diversity, and strategic importance of space operations. Space capabilities underpin U.S. and allied national security, economic growth, scientific discovery, and societal resilience. At the same time, the industrial base that produces and operates these capabilities is navigating shifting political priorities, emerging threats, and volatile financial markets.

This volume is the seventh in a series of Space Security and Industrial Base (SSIB) reports produced since 2019. The early reports (2019–2020) focused on establishing a baseline understanding of the U.S. space industrial base and argued for treating key space capabilities and infrastructures as elements of national critical infrastructure. The middle years (2021–2022) documented the rapid acceleration of commercial capabilities, the emergence of proliferated architectures, and the growing relevance of concepts such as in space servicing and logistics. The most recent reports (2023–2024) shifted attention toward integration—examining how policy, regulation, acquisition, and finance either enable or inhibit the incorporation of commercial capabilities into national security and civil architectures—and began to treat workforce and community level impacts as core industrial base issues rather than peripheral concerns. The present report builds on that history. Its central focus is alignment: the extent to which U.S. policy, regulatory regimes, acquisition practices, infrastructure investments, and workforce systems are coherently supporting long-term national objectives at speed and scale in space.

The 2025–2026 report period has been marked by significant Executive Branch action. In August 2025, the Administration issued EO 14335 ("Enabling Competition in the Commercial Space Industry"), addressing launch regulation, spaceport infrastructure, and novel activity authorization. In December 2025, EO 14369 ("Ensuring American Space Superiority") set ambitious exploration and national security goals while mandating acquisition reform favoring commercial solutions. These orders provide important policy direction but also underscore the tension between executive intent and the legislative, budgetary, and institutional realities examined throughout this report.

The intent is to provide a resource for policymakers, including Congressional staff and Executive branch officials, as well as technical practitioners, particularly, but not only, those engaged in national security space acquisitions and related policy implementation.

Consistent with prior years, the report is organized around a set of thematic working groups or a workshop:

1. **Space Policy and Regulation & Finance (SPRF)** – examining the overarching policy, legal, and financial environment shaping space activities, including export control, tariffs, acquisition practices, and mission authorization.
2. **Launch Capacity, Spaceport Infrastructure & NEPA Modernization** – assessing range and spaceport capacity, environmental and permitting processes, and infrastructure investment tools.
3. **Outernet (Space-based Communications)** – exploring the evolution of a diversified, resilient, and interoperable space based communications architecture.
4. **Space Mobility & Logistics / In-Space Servicing, Assembly & Manufacturing (SML/ISAM)** – analyzing current capabilities and gaps in rendezvous and proximity operations, servicing, refueling, in-space construction, manufacturing, and logistics.
5. **Novel Space Technologies** – evaluating emerging capabilities facilitating the transition from demonstrations to persistent, scalable operations.
6. **Space Education, Workforce & STEM** – evaluating the education and workforce pipelines required to sustain the space industrial base across technical, trade, and operational roles.

Each working group followed a common analytic structure:

- **Current State** – a concise snapshot of relevant developments since the 2024 SSIB report, including programmatic milestones, regulatory changes, investment trends, and international actions.
- **Key Issues & Challenges** – the principal constraints, friction points, and failure modes identified by participants.
- **Key Inflection Points** – upcoming decisions, demonstrations, or external events that could materially alter trajectories.
- **Key Actions & Recommendations** – specific, actionable proposals, differentiated by time horizon (0–18 months, 3–5 years, beyond 5 years) and primary owners (Congress, Executive agencies, industry, financial community, or international partners).

METHODOLOGY

The findings presented in this report are grounded in a combination of qualitative and quantitative inputs:

- **Workshops and Roundtables.** The SSIB convened multiday, in person and virtual sessions between April 2025 and early January 2026. These sessions included structured working group discussions, plenary keynotes, and targeted roundtables. Participants represented a cross section of the space ecosystem, including the DoD, USSF, NASA, DOC, DOT, FCC, Office of Space Commerce (OSCommerce), OSTP, industry primes and new entrants, investors, standards bodies, and academic institutions. These engagements provided critical texture on how policy and acquisition decisions are perceived outside of Washington.
- **Document Review and Data Analysis.** The working groups reviewed recent legislation, Executive Orders, regulatory proceedings, General Accounting Office (GAO) reports, Bureau of Economic Analysis (BEA) space economy statistics, and other public data sources. Prior SSIB reports (2019–2024) were systematically mapped against current findings to identify continuity, progress, and areas of persistent concern. Where relevant, working groups also drew on unpublished but vetted analyses (for example, cost modeling work conducted by The Aerospace Corporation) with appropriate caveats. Please note the delay in release of this year's report is a result of the government shutdown in Fall 2025 needed to finish the Launch Working Group covering the time period for calendar year 2025.
- **Cross Group Integration.** Many issues—such as mission authorization, export control, and workforce capacity—cut across multiple working groups. SSIB organizers and report writers worked to reconcile terminology, identify interdependencies, and avoid conflicting recommendations. Cross references are

provided throughout the report (e.g., between SML/ISAM and Launch/NEPA, or between Outernet and Workforce) to highlight these linkages.

The report is not intended to be exhaustive. Space activities and policies are evolving rapidly; specific programmatic details may change after the date of writing. Rather, the goal is to provide a structured, multi-year view of the space industrial base, rooted in practitioner experience and empirical data, and to identify concrete steps that policymakers and acquisition professionals can take to strengthen U.S. space security and competitiveness.

The chapters that follow present the findings of each working group. Chapter 2 begins with the Space Policy and Regulation & Finance landscape, providing the strategic context for subsequent discussions of launch infrastructure, communications architectures, in space logistics, and workforce development.

The U.S. Capitol Building at night. [Photo: Heidi Kaden]

CHAPTER 2: SPACE POLICY AND REGULATION & FINANCE LANDSCAPE (SPRF)

Working Group Co-Leads:

- Dr. Diane Howard, MITRE
- Andrew Berglund, The Aerospace Corporation
- Amanda Nguyen, Aerospace Industries Association (AIA)

Report Lead: Dr. Diane Howard, MITRE

"Acquisition reform is an enormous priority for this committee and for Congress ... How do we integrate those new, innovative companies into the Defense Department so we can take advantage of the technologies and the equipment that they're building?" - Rep. Adam Smith (D-WA), ranking member, House Armed Services Committee

2.1 BACKGROUND

The commercial and government sectors of space have historically been entwined; however, the relationship between them is evolving. The U.S. Government continues to be an anchor customer for the commercial space industry as it develops more capabilities, but roles are not as monolithic, or one size fits all, across all mission areas. Examples include CLDs and space, mobility, and logistics (SML) missions.

While government policy and regulatory regimes continue to shape public private interdependence, clearer and more consistent guidance and oversight would be beneficial. Particularly in areas such as on-orbit servicing and active debris removal, the absence of a streamlined, whole of government mission authorization framework continues to create uncertainty, inhibit investment, and complicate international coordination. This includes harmonizing eligibility criteria for companies participating in federal licensing and procurement activities. Explicit recognition of Foreign Ownership, Control, or Influence (FOCI) mitigated entities as U.S. companies—when operating under the terms of their mitigation agreements—would reduce barriers to entry and better align industrial base policy with national security priorities.

Strategic planning to obtain investment remains subject to market conditions, the political climate, and global and domestic competition, all of which are dynamic. New entrants to the space industrial base continue to struggle to close their business cases when they are unable to obtain U.S. Government support as a customer, investor, or grantor. This challenge is compounded by the lack of a consistent federal definition of what constitutes an “American company.” Companies that have successfully completed FOCI mitigation and operate under approved national security agreements continue to face policy ambiguity when seeking access to government contracts or programs. Clarifying this definition would ensure that such entities are recognized as trusted participants in the U.S. space ecosystem.

Consistent with prior years’ observations, SPRF working group stakeholders maintained the position that without a purely commercial market for emerging technologies, many companies rely on strategic government alignment to accelerate national capabilities when encountering the “Valley of Death” as they move from research and development of a capability to its commercialization (see Figure 2-1 below).

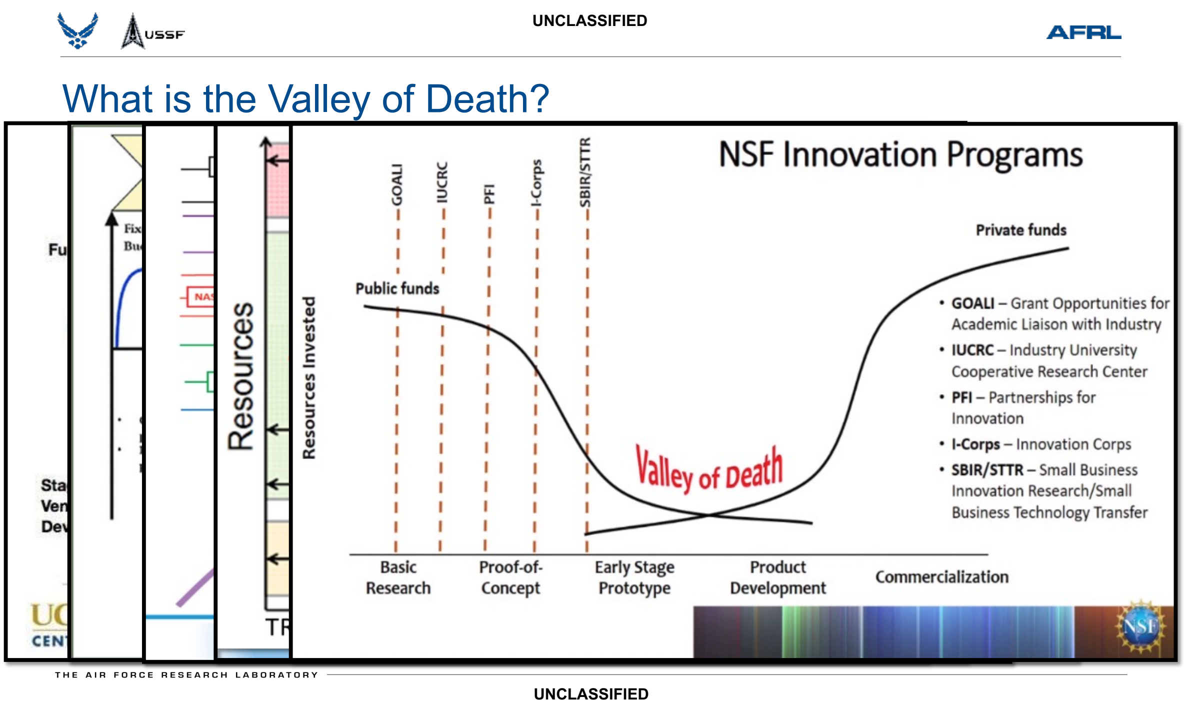


Figure 2-1 illustrates the Valley of Death timeline, presented by Dr. Andy Williams at the 2025 SSIB conference.

"Valleys of Death" arise from the risks of managing a new enterprise in a technically challenging scientific area (space) while competing for initial and follow-on funding in the period before a broader base of customers have integrated the emerging technologies into their own business models. It remains difficult for new entrants to compete against the major established aerospace companies (primes) and existing programs of record.

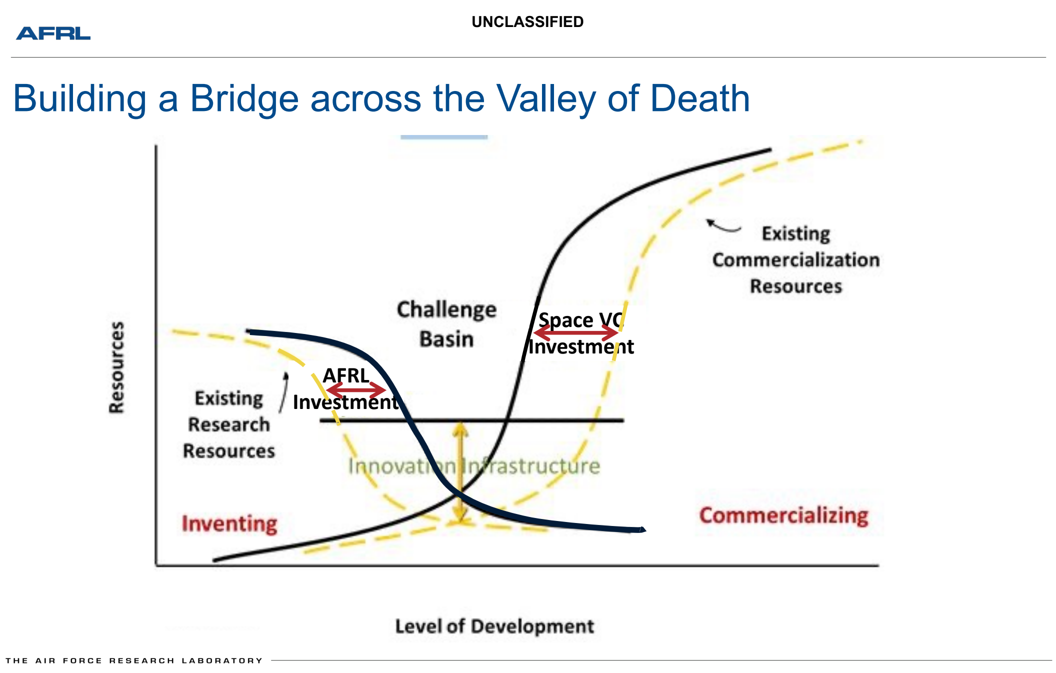


Figure 2-2 illustrates the relationship between resources and development level, presented by Dr. Andy Williams at the 2025 SSIB conference.

Metrics to better assess system readiness level, as well as a company's market development, could provide baselines for product and program planning. These metrics should incorporate factors such as licensing readiness, commercial market signals, and regulatory feasibility to inform federal acquisition and policy alignment. AFWERX offers two funding streams to assist companies in bridging the Valley of Death—the Strategic Funding Increase (STRATFI) and Tactical Funding Increase (TACFI)—and a number of other successful grant mechanisms through the Defense Innovation Unit (DIU) and SPACEWERX, including the Small Business Innovation Research and Small Business Technology Research (SBIR/STTR) programs, and the Mentor Protégé Program.

The U.S. Government has exhibited interest in small/proliferated capabilities in addition to, or in lieu of, large/exquisite capabilities and the DoD has increased support for experimentation and demonstrations. Use of Other Transaction Authority (OTA) continues to be strong. The reception from traditional banking and insurance stakeholders appears to be warming as they increase their awareness of space sector timelines, and as a result of seemingly more robust U.S. Government support and heightened visibility for space technologies.

Adhering to the format of years past, stakeholders participating in this year's Space Policy, Regulation & Finance Working Group (SPRF WG) highlighted successes that are benefiting the entire public-private enterprise or currently impacting the landscape, identified a series of challenges and inflection points faced by industry, and proposed actionable and prioritized recommendations for continued improvement.

2.2 CURRENT STATE

2.2.1 ECONOMIC AND INDUSTRIAL LANDSCAPE

Continuing a decades-long trend, aerospace and defense remain the leading export from the United States, producing the highest trade balance and the second highest level of exports among all manufacturing industries.

The Department of Commerce's BEA released its updated statistics for the U.S. space economy in March 2025. (Figure 2-3) These statistics "provide estimates of the space economy's contribution to U.S. current dollar and chained dollar ('real') gross output and gross domestic product (GDP) by industry, as well as estimates of private employment and compensation." The most recent update brings BEA's work forward to include 2023. That year, real GDP in the space economy grew by 0.6 percent, driven by growth across the board in all categories of government (7.9 percent). Federal national defense was the strongest, showing 12.7 percent growth. Research and development by both federal defense and nondefense accounted for much of this increase, mainly by NASA and the USSF.

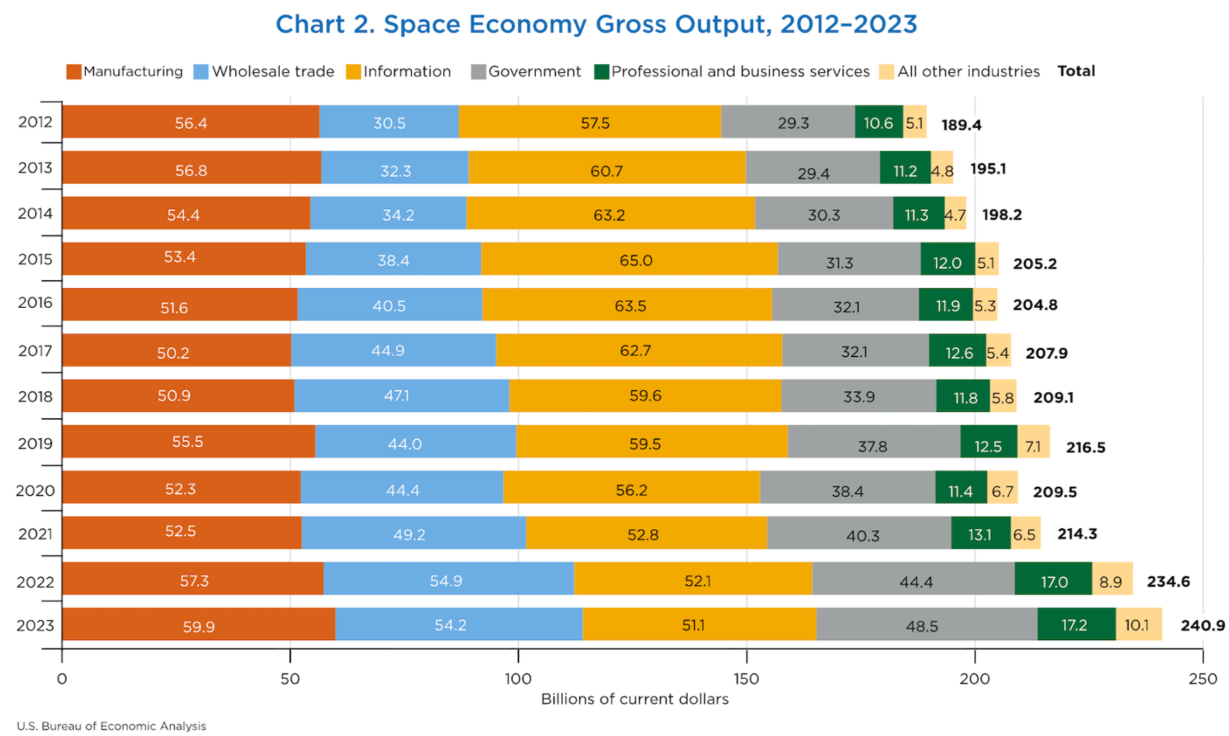


Figure 2-3. U.S. space economy GDP gross output 2012-2023. Real space economy GDP grew 0.6 percent in 2023, driven primarily by federal defense and civil R&D (BEA, March 2025).

Venture capital and private equity activity in space remains robust but more selective. Participants noted a shift toward later stage investments and larger checks for companies with demonstrated revenue or government backing. Venture Capital Operating Companies (VCOCs) continue to navigate Employee Retirement Income Security Act (ERISA) constraints through management rights structures, but space companies have been more focused on traditional concerns: the mismatch between space development timelines and typical venture fund horizons, capital intensity, uncertain market demand, and lingering skepticism following the Special Purpose Acquisition Company (SPAC) boom.

The FORGED Act (Fostering Reform and Government Efficiency in Defense Act) and the Streamlining Procurement for Effective Execution and Delivery (SPEED) Act were repeatedly referenced as important vehicles to reform defense acquisition, making the commercial procurement process the default method for the Pentagon, enabling non-traditional defense firms' greater participation, and reducing bureaucratic burdens. The SPEED Act passed from the House of Representatives just prior to the end of 2025 (18 December). Core pillars of the FORGED Act were folded into the Senate Armed Services Committee's draft of the National Defense Authorization Act for Fiscal Year 2026.

Some provisions from the Tax Cuts and Jobs Act of 2017 were made permanent in the One Big Beautiful Bill Act, including deductions for small business owners and caps on State and Local Tax deductions. These changes contribute to the overall tax environment in which space companies operate but were not seen by stakeholders as decisive in themselves.

2.2.2 LEGISLATIVE AND REGULATORY LANDSCAPE

Worth noting, as part of the current state, is the legislative landscape which continues to languish regarding clear legislative direction and scalable authorities to oversee novel private sector space activities. This issue is further developed in Section 2.3 below, as are the ongoing issues the launch/reentry community continues to endure with the implementation of 14 Code of Federal Regulation Part 450 by the Federal Aviation Administration Office of Commercial Space Transportation (AST). Quite a few space relevant or adjacent bills have been introduced or made it out of committee, but other than S. 1648, the Launch Communications Act signed into law on 26 September 2024—which facilitates access to the electromagnetic spectrum for commercial space launches and reentries—no others have made it to the finish line.

The long-awaited space export control modernization process finalized two rules in 2024 but the largest portion of the work commenced that year has not yet made it past the 27 November 2024 grant of an extension for the public comment period to the Notices of Proposed Rulemaking from the DOS and DOC. The two rules that were successfully promulgated are:

- A Final Rule in which DOC's BIS removed license requirements for exports of certain items pertaining to remote sensing or space-based logistics, assembly, or servicing spacecraft destined for Australia, Canada, and the United Kingdom.
- An Interim Rule in which BIS removed certain license requirements to more than 40 allies and partners globally.

These steps were broadly welcomed by industry but were viewed as only a partial modernization. Without completion of the broader rulemaking, the United States risks losing global market share on space related products and services to jurisdictions seen as more predictable or less burdensome.

U.S. tariffs are higher than they have been, and this is impacting the global space industry. They affect the cost and availability of materials, components, and launch services, all of which leads to increased project/mission costs, supply chain disruptions, and shifts in international partnerships and sourcing decisions. There is pressure for companies to localize production and sourcing, both in the United States and internationally. Foreign companies launching satellites from U.S. sites may face tariffs. Further, rapid changes in position from the United States are creating a sense of instability. As a result, U.S. international partners are evaluating their reliance on U.S. space technology, perhaps making partnerships with other non-U.S. countries more attractive. This has the potential to reshape global space dynamics.

In August 2025, the Administration released Executive Order 14335, "Enabling Competition in the Commercial Space Industry," addressing novel activities, launch regulation streamlining, and spaceport infrastructure development. The EO directs DOC to "propose a process for individualized mission authorizations for articles that are covered by Article VI of the Outer Space Treaty of 1967, but not clearly or straightforwardly governed by existing regulatory frameworks." It explicitly carves human spaceflight out of the novel activities discussion. The EO also mandates FAA/DOT to streamline environmental reviews (NEPA) for launch and reentry, expedite Part 450 implementation, and directs an interagency MOU to eliminate duplicative spaceport development reviews. Organizationally, it elevates the Office of Space Commerce into the Office of the Secretary (DOC) and creates new senior positions for commercial space advocacy within DOT and FAA.

In December 2025, the Administration issued Executive Order 14369, "Ensuring American Space Superiority," which established concrete goals including returning Americans to the Moon by 2028, deploying a lunar surface nuclear reactor ready for launch by 2030, and attracting $50 billion in additional space investment by 2028. The EO mandates acquisition reform across DOD and NASA, establishing a "first preference" for commercial solutions and "general preference" for OTAs and Space Act Agreements. It directs review of major programs 30% or more behind schedule or over cost for potential cancellation and establishes a "National Initiative for American Space Nuclear Power."

Without new statutory authority from Congress, however, DOC's ability to enforce compliance with mission authorization processes remains limited. The EOs signal policy direction but do not resolve underlying statutory gaps, resource constraints, or interagency coordination challenges discussed throughout this chapter.

Efforts to streamline and implement regulations dating back to the first Trump Administration (Space Policy Directive2) have had mixed results. While DOC's Commercial Remote Sensing Regulatory Affairs (CRSRA) reboot of its regulations is seen as a win, AST's Part 450 has met with multiple challenges, chief among them regulatory bottlenecks that manifest as lack of consistency and transparency regarding licensing timelines. Some of the bottlenecks arise from civil service workforce shortages. Recently, several members of AST's senior leadership team took the early retirement offered by the Administration, leaving voids in expertise within the office. Chapter 3 (Launch Capacity, Spaceport Infrastructure, & NEPA Modernization) and Chapter 7 (Workforce) both examine these dynamics in more detail.

2.2.3 PROGRAMMATIC AND STRATEGIC DEVELOPMENTS

The appetite for integration of commercial capabilities into the national security enterprise was made further evident in 2024 through the release of DoD's Commercial Integration Strategy and the U.S. Space Force's Commercial Space Strategy.

The **DoD Commercial Integration Strategy** provided metrics to assist DoD and industry in determining appropriate levels of U.S. Government reliance on commercial solutions, breaking missions into three categories:

- **Government primary:** combat power protection, electronic warfare, and command and control (C2).
- **Hybrid:** satellite communications (SATCOM); intelligence, surveillance, and reconnaissance (ISR).
- **Commercial primary:** space access, mobility, and logistics (SML, including space servicing such as refueling).

The **USSF Commercial Space Strategy** articulated four principles to guide decision making whenever USSF considers using commercial space solutions:

1. **Balance.** Appropriately balance government and commercial solutions while avoiding overreliance on any single provider or solution.
2. **Interoperability.** Strengthen interoperability between government and commercial solutions through standards and interfaces, without stifling innovation, speed, or scale.
3. **Resilience.** Increase resilience by expanding the number and diversity of commercial providers, supply chains, and solutions, with emphasis on cyber resilience.
4. **Responsible Conduct.** Ensure that use of commercial solutions remains legally and ethically compliant and consistent with international norms and the DoD Tenets of Responsible Behavior in Space.

The USSF provided industry with a long sought demand signal by listing priority missions for commercial integration—tactical surveillance, reconnaissance, surveillance, and tracking (TacSRT); space based environmental monitoring (SBEM); positioning, navigation & timing (PNT); and SML (referred to as SAML and explained and distinguished in Annex C) — along with a commitment to continued integration into more mature missions such as SATCOM, launch, and space domain awareness. Whether this demand signal will be solidified with resources in upcoming budget cycles remains to be seen.

EXECUTIVE ORDER-DRIVEN ACQUISITION REFORM

Executive Order 14265 ("Modernizing Defense Acquisitions and Spurring Innovation in the Defense Industrial Base," April 2025) and EO 14369 ("Ensuring American Space Superiority," December 2025) mandate significant changes to DoD and NASA acquisition practices. Both orders establish a "first preference" for commercial solutions and "general preference" for OTAs, Rapid Capabilities Office policies, and Adaptive Acquisition Framework pathways. They direct elimination of unnecessary DFARS provisions, centralized decision-making, and workforce restructuring to reward use of commercial solutions and adaptive acquisition.

EO 14265 requires review of Major Defense Acquisition Programs (MDAPs) that are 15% or more behind schedule or over cost for potential cancellation. EO 14369 applies a similar 30% threshold to NASA and DOC programs. These aggressive accountability measures reflect frustration with slow acquisition timelines but also create uncertainty for long-lead space programs, particularly those requiring sustained multi-year investment such as nuclear propulsion (Chapter 6) and SML/ISAM infrastructure (Chapter 5).

Implementation of these orders will be critical. Past acquisition reform efforts have often foundered on institutional resistance, workforce capacity constraints, and the inherent tension between speed and oversight. Chapter 3 examines how these dynamics play out in launch and spaceport infrastructure; Chapter 5 discusses their implications for SML/ISAM; and Chapter 6 addresses their impact on advanced technology development.

The USSF made notable progress in the last year with its **Commercial Augmentation Space Reserve (CASR)**, a voluntary program that allows the Space Force to ensure access to commercial capabilities throughout the spectrum of conflict by identifying willing participants and facilitating interoperability ahead of time through training, wargames, and exercises. Contracts are pre-negotiated to provide surge capacity when needed. Surge capacity can be provided by leveraging capabilities already on-orbit, augmenting existing missions with additional capacity, increasing production, or denying service to adversaries over a region.

In March 2025, Space Systems Command (SSC) held its first CASR wargame in Washington, D.C., with participants from the SATCOM community, USSF, and other agencies, and awarded its first pilot contracts to four space domain awareness (SDA) companies. A second wargame followed in July at the Space Domain Awareness Tools, Applications and Processing Lab (SDA TAP Lab) in Colorado Springs. USSF is keeping the identities of the participating firms closely held to reduce adversary targeting risk.

In addition to CASR, the **USSF Front Door** web portal has refined its processes by automating entry and increasing industry engagements. The portal is evolving from a simple intake mechanism for new entrants into a fully trackable relationship management system connecting companies with relevant government stakeholders across the national security and civil communities.

In March 2025, Front Door launched **Orbital Watch**, a rapid communication platform to enhance unclassified threat information sharing with commercial space companies. USSF intelligence distributed an unclassified fact sheet to the 900+ companies in the Front Door catalog at launch. Orbital Watch is intended to communicate threats such as cyber intrusions, electronic warfare, and concerning on-orbit activities so that companies can build more resilient systems and mitigate threats more effectively.

On the acquisition and demonstration side, **Tactically Responsive Space (TacRS)** continues to showcase commercial contributions to national security space. The **Victus Nox** mission in 2023 demonstrated the ability to acquire, build, integrate, and launch a satellite with a modification for SDA in just over 24 hours from receipt of launch order. The next demonstration, **Victor Haze**, scheduled for Fall 2025 but moved to 2026, will demonstrate rapid rendezvous and proximity operations and on-orbit threat characterization. Rocket Lab and True Anomaly are building the spacecraft; Rocket Lab will launch its spacecraft and Firefly will launch True Anomaly's Jackal.

On the civil side, the **Commercial Lunar Payload Services (CLPS)** program recorded both major successes and setbacks. Intuitive Machines achieved the first successful landing in the CLPS program (Odysseus, February 2024) and later landed the Athena (NovaC) mission near the lunar South Pole, though both landers ultimately toppled. Firefly Aerospace's Blue Ghost Mission 1 delivered ten NASA payloads in March 2025, followed by a significant follow-on award. NASA and CLPS providers continue to learn from each mission, successful or otherwise. The program faces cost increases and schedule delays but enjoys bipartisan support; the House Appropriations Committee's draft FY 2025 bill fully funded CLPS, even as the President's Budget Request (PBR) proposed cuts to the Science Mission Directorate (SMD).

Other commercial milestones—**Polaris Dawn**, SpaceX's ongoing **Starship** development and Human Landing System (HLS) work, Amazon's **Project Kuiper/Amazon Leo**, and Blue Origin's **Blue Moon**—further illustrate both the dynamism and the fragility of the commercial space ecosystem. These examples are not merely technical anecdotes; they are indicators of how government acquisition decisions, regulatory clarity, and risk tolerance shape investment and innovation trajectories.

2.3 KEY ISSUES & CHALLENGES

A key challenge remains the need for greater alignment between government and industry. The collective growth of the space industry depends on sustained collaboration, where government investment plays a critical role in enabling private innovation that supports national interests and security. This symbiotic relationship is central to both the development of the industry and the advancement of national goals. Stakeholders emphasized that transparency, consistency, and continuity are essential to fostering innovation. Clear communication, well defined scopes of engagement, and predictable funding timelines help ensure that technological development aligns with American interests.

The SPRF working group identified several interrelated issue clusters.

2.3.1 REGULATORY ENVIRONMENT

Regulatory challenges ensue on both domestic and international fronts. As noted in the prior year's report, there remains a lack of regulatory clarity for novel space activities or those not currently directly regulated by a Congressionally authorized department or agency. Private space activities can require authorization from multiple departments and agencies (D/As). ISAM is a prominent example of a novel activity whose primary in-space operations fall outside direct regulation.

Most missions require spectrum use, necessitating a license from the FCC. The FCC opened its Notice of Proposed Rulemaking for Space Modernization in the 21st Century for public comment in December 2025. The Notice goes beyond a simple overhaul of spectrum licensing process for space activities and includes novel activities such as ISAM as well as cislunar activities. Launch providers require launch and, where applicable, reentry licenses from FAA/AST. Remote sensing operators need a license from DOC's CRSRA. Many emerging companies combine capabilities such as servicing, refueling, inspection, relocating, and assembly, blending technologies that are regulated (e.g., cameras and remote sensing) and not (e.g., refueling or relocating). Related spectrum, licensing, and interoperability issues for proliferated SATCOM and space-based networks are explored in Chapter 4 (Outernet).

The United States has not yet successfully addressed these gaps and overlaps. During the SPRF working group, some participants argued that this lack of regulatory certainty is not yet adversely impacting the private sector or U.S. international obligations. However, this is not the prevalent perspective expressed in broader listening sessions convened by the National Space Council in 2022, nor is it consistent with feedback from many SML/ISAM stakeholders.

As other nations modernize their regulatory frameworks—or create them where none existed previously—the absence of clarity in the United States can be perceived as instability and could challenge interoperable partnering across borders. The European Union, for example, has been vocal about prioritizing its domestic space industry and published its long-anticipated Space Act in June 2025.

EO 14335 attempts to address some of these gaps by directing DOC to propose mission authorization processes and mandating streamlined launch/reentry reviews. However, the order's effectiveness depends on Congressional action to grant DOC enforcement authority, adequate resourcing, and sustained interagency coordination—none of which are guaranteed. Human spaceflight is explicitly carved out of the EO, leaving a significant class of emerging commercial activities (e.g., commercial stations, tourism) reliant on existing patchwork authorities. The EU Space Act (June 2025) and other international regulatory developments continue to advance, potentially creating a first-mover advantage for frameworks developed outside the United States. This could result in duplicated or conflicting regulatory requirements for U.S. companies seeking to operate internationally.

2.3.2 ACQUISITION AND ANCHOR TENANCY

Last year's report highlighted the lack of a cohesive, overarching "North Star infrastructure vision" to guide long term investments in the space industrial base. Stakeholders in this year's working group observed that this remains true and may be worsening as policies shift across administrations. This is especially evident in NASA's proposed cutbacks for certain science and exploration programs and DoD's fluctuating emphasis on SML.

Acquisition cycles continue to lag behind innovation, and over classification often prevents new entrants from participating in requirements development. Prime contractors, with their resources and clearances, remain easier and lower-risk partners for government program offices. This dynamic can lock in legacy approaches and slow the integration of novel commercial capabilities.

The concept of anchor tenancy—originating with NASA and now used more broadly—remains poorly understood and inconsistently applied. Eligibility requirements in the Federal Acquisition Regulation (FAR) Supplement specify that anchor tenants should be part of a market with other existing or potential customers. This market development factor is sometimes overlooked. Some inherently governmental activities (such as DoD's "government primary" missions under its Commercial Space Strategy) will never be appropriate for anchor tenancy arrangements, whereas other mission areas could benefit significantly from disciplined anchor tenant use.

Despite new Executive Orders signaling a prioritization of improved procurement methods, acquisition practices remain a source of concern. Short-term contracts—for example, mouth-to-mouth arrangements for commercial space situational awareness services from DOC's OSC—undermine investor confidence and make it difficult for companies to scale. While mechanisms such as Space Act Agreements, OTAs, and Cooperative Research and Development Agreements offer flexibility, they are not yet being deployed systematically to support longer term, milestone-based engagements that could bridge the Valley of Death for emerging capabilities.

The December 2025 EO 14369 mandates a "first preference" for commercial solutions and directs aggressive review of programs behind schedule or over cost. While this policy direction aligns with industry calls for faster, more flexible acquisition, it also creates risks. Programs requiring patient, multi-year investment—such as nuclear propulsion (Chapter 6), SML/ISAM infrastructure (Chapter 5), and certain exploration architectures—may be vulnerable to cancellation if near-term milestones slip, even when the underlying technology and strategic rationale remain sound. Balancing speed with the realities of complex space system development will be a central implementation challenge.

2.3.3 FINANCIAL MARKETS AND MACROECONOMIC PRESSURES

The universe of firms investing in space is expanding, including early-stage venture capital, later stage private equity, and public markets. However, stakeholders expressed concern that, despite robust funding in early 2025, tariffs, international political reordering, public market volatility, advances in geospatial AI, and potential federal spending cuts may all contribute to a chilling effect.

Tariff policy is a particularly salient macroeconomic factor. Higher U.S. tariffs increase costs for imported materials and components, reduce flexibility in global supply chains, and can prompt reciprocal measures. Over time, this may encourage foreign partners to diversify away from U.S. space technology, undermining both U.S. industrial and diplomatic leverage.

2.4 KEY INFLECTION POINTS

The SPRF working group identified several classes of inflection points, building on prior years' taxonomy.

2.4.1 CONGRESSIONAL AND PRESIDENTIAL CYCLES.

Lack of consistency between administrations is adversely impacting long-term space missions and programs, particularly where budgetary commitments span multiple terms.

2.4.2 INSTITUTIONAL CAPACITY SHIFTS.

The creation of the Department of Government Efficiency (DOGE) and resulting restructuring have impacted institutional knowledge within the federal civil service, including in critical regulatory offices.

2.4.3 EMERGING TECHNOLOGIES.

Artificial intelligence and machine learning are being integrated into virtually every aspect of the space industrial base—from space domain awareness and autonomous navigation to manufacturing and logistics—creating both opportunities and cybersecurity and workforce challenges.

2.4.4 INTERNATIONAL DYNAMICS.

Proposed and actual NASA cuts are affecting international partners' perceptions of U.S. reliability, with potential spillover into Artemis Accords participation. U.S. arrearages in United Nations funding, including impacts on the UN Office of Outer Space Affairs, risk ceding influence to strategic competitors at a time when space issues are increasingly raised at the UN Security Council. Tariffs and the EU Space Act add further pressure.

Collectively, these inflection points will shape whether the United States solidifies or erodes its position as the partner and flag of choice for space activities.

2.5 KEY ACTIONS & RECOMMENDATIONS

Many themes in this section build on recommendations made in prior SSIB reports; Chapter 7 provides a consolidated recommendations table for the years 2020–2024. For the SPRF domain, the working group highlighted the following priority actions, organized by time frame.

2.5.1 SHORT-TERM (0–18 MONTHS)

- **Regulatory Reform.** U.S. space regulations should be assessed regularly to ensure a competitive environment. Assessments should measure regulatory intent against impacts, considering factors beyond financial cost, while recognizing the burden that frequent changes can impose on both industry and regulators.

- **Export Control Modernization.** Complete the export control initiative begun in 2024. Without this update, the United States risks losing market share to more agile competitors.
- **Mission Authorization and Supervision.** Advance legislative and regulatory efforts to establish a clear, enforceable mission authorization framework for novel space activities, building on the August 2025 EO but recognizing its limitations without new statutory authority.
- **14 Code of Federal Regulation Part 450 Implementation.** Continue refining Part 450 with a serious commitment to streamline launch and reentry approval processes and work toward interoperable license application systems across ranges and agencies.
- **Infrastructure Investment.** Improve environmental evaluations and analysis of extreme weather impacts on launch infrastructure; expand access to loan and credit lines for spaceport and transportation infrastructure, aligning with the Administration's EO on infrastructure reform.
- **RFI Process Review.** Reevaluate the U.S. Government Request for Information process to clarify high-level goals and program specific objectives and improve communication with industry.
- **Strategic Messaging.** Develop coordinated public-private messaging that connects the space industrial base story to a clear "North Star" vision. Joint engagements with the investment community—featuring both government and industry voices—can build confidence and trust.
- **Highlight Effective Organizations.** Expand awareness of and access to organizations such as DIU, Space Development Agency, SpaceWERX, and USSF Front Door, which are already experimenting with more agile acquisition and engagement models.
- **Accelerate Acquisition Flexibility.** Prioritize flexible procurement models and pilot programs (Space Act Agreements (SAAs), OTAs, milestone-based CRADAs) that enable faster adoption of emerging servicing, mobility, logistics, and sustainability technologies.
- **Leverage Unfunded Agreements.** Use unfunded agreements (e.g., NASA SAAs, DoD unfunded agreements) to provide commercial industry access to testing and facilities, reducing barriers for early-stage companies.
- **Implement EO 14335 and EO 14369 with Congressional Support and Adequate Resourcing.** Congress should provide the statutory authority, enforcement mechanisms, and funding necessary to implement the mission authorization, launch streamlining, and acquisition reform directives in EO 14335 and EO 14369. Without legislative action, these orders risk becoming aspirational statements rather than enforceable policy. Agencies should develop transparent implementation plans

with clear timelines, metrics, and stakeholder engagement processes. (*Owners*: Congress, DOC, DOD, NASA, FAA, OMB)

2.5.2 MID-TERM (3–5 YEARS)

- **Export Control Regularization.** Move away from decade-plus gaps between major export control updates; establish a regular cadence for review and adjustment.
- **Elevate AST within DOT.** From a public administration perspective, consider moving AST out of FAA and into DOT with proper resourcing and a dedicated space transportation funding line.
- **Resilient Contract Construction.** Structure contracts to incentivize resilience, with explicit assessment of and contingencies for worst-case scenarios.
- **Emerging Mission Understanding.** Invest in deeper understanding of mission lifecycles for emerging activities such as SML/ISAM, ensuring that acquisition strategies and regulatory frameworks reflect those lifecycles.
- **Technology Development Processes.** Develop portfolio-style acquisition roles or executives who can assist less mature companies in navigating procurement, improving organization and efficiency across stakeholders.

2.5.3 LONG-TERM (BEYOND 5 YEARS)

- **Space Commodities Exchange (SCX).** Pursue the establishment of a regulated market for in-space resources such as propellant, water, and building materials. A Space Commodities Exchange would both depend on and reinforce a North Star meta-view of in-space infrastructure and logistics.

The subsequent chapters—on launch capacity and NEPA, the Outernet, SML/ISAM, and workforce—provide more detailed analysis of how these policy, regulatory, and financial dynamics manifest in specific domains. Together, they underscore the need for an integrated approach to space industrial base strategy: one that aligns regulation, acquisition, infrastructure, architectures, and human capital around durable, bipartisan objectives.

The Gateway to Space terminal at Spaceport America, New Mexico, during sunset. ***[Credit: Spaceport America]***

CHAPTER 3: LAUNCH CAPACITY, SPACEPORT INFRASTRUCTURE, AND NEPA MODERNIZATION

Working Group Co-Leads:

- Dr. Annie Brett, University of Florida
- Dale Ketcham, Space Florida

"We are breaking records across the board. 100 launches is a complete game changer on the Space Coast. We're identifying efficiencies, getting additional mass to orbit — it couldn't be a more exciting time to be out here." - Col. Brian Chatman, commander of Space Launch Delta 45

3.1 BACKGROUND

The NewSpace Nexus SSIB partner workshop on Commercial Launch was hosted with Space Florida and convened government, industry, and academic stakeholders, including state spaceport authorities and ecosystem enablers, launch operators, utilities, and regulators, to examine how the United States can sustain rapid growth in launch activity while modernizing spaceport infrastructure and environmental/permitting processes.

Since 2021, the workshop's orienting "North Star" question has been: **What should we do that would most create anxiety and hesitation in President Xi?** That framing has consistently pushed participants to consider not only incremental improvements but also the strategic consequences of U.S. choices in space logistics, infrastructure, and regulation.

The 2024 discussions built on a post-2021 period of accelerated commercial launch activity and evolving regulatory frameworks, particularly around NEPA reform and spaceport modernization. Participants wrestled with how to reconcile U.S. environmental and community protection norms with the tempo, scale, and technological diversity of contemporary launch systems.

3.2 CURRENT STATE

3.2.1 SPACEPORT LAUNCH CADENCE, INFRASTRUCTURE, AND CONSTRAINTS

Launch cadence at U.S. spaceports has grown steadily and is now accelerating year over year. This growth is a positive indicator of national capability and commercial dynamism, but demand for modern infrastructure, commodities, and services is growing even faster.

The Eastern and Western Ranges—centered on Cape Canaveral and Vandenberg Space Force Base (VSFB)—are performing admirably under heavy load but are under considerable stress. Their operations tempo now far exceeds what their infrastructure was originally designed to support. Range operators are increasingly focused on managing risk and reliability in an environment characterized by:

- **Aging core infrastructure.** Roads, bridges, causeways, water and wastewater systems, harbor facilities, and entry control points are being used at rates far beyond original design assumptions.
- **Commodity generation and throughput constraints.** Liquid oxygen (LOX), liquified natural gas (LNG), and gaseous nitrogen (GN_2) production, storage, and distribution systems are struggling to keep pace with higher launch rates and larger vehicles.
- **Access, badging, and security bottlenecks.** Badging and clearance processes create significant friction, not only for highly skilled engineers but also for truck drivers, construction workers, roofers, HVAC technicians, and others essential to spaceport build-out and maintenance.
- **Limited workforce availability.** Critical skill shortages are acute. For example, on the Space Coast, the same electricians, welders, heavy equipment operators, and construction managers needed for launch infrastructure are also in high demand for other marquee regional projects (e.g., major theme park and resort expansions), tightening an already constrained local labor market.

Significant public investment has begun to mitigate some of these constraints. Approximately $1.3 billion in recent modernization projects at Cape Canaveral and VSFB—spanning roads, water and wastewater systems, harbor improvements, and entry control facilities—demonstrate that targeted capital can meaningfully improve throughput and safety. However, these efforts are still catching up to demand rather than getting ahead of it.

Spaceport growth is also reshaping surrounding communities, particularly in Brevard County and comparable regions. Rapid population growth, rising housing costs and affordability pressures, and service-sector labor shortages are altering local economic and social dynamics. At the same time, higher launch cadence and larger vehicles are creating new noise, vibration, and overflight impacts on ecosystems, neighborhoods, and regional infrastructure.

Stakeholders are actively studying previous periods of rapid regional development—such as the Apollo era on the Space Coast and the growth of major tourist and entertainment complexes—to better understand the mix of market forces, public investment, and targeted government intervention that may be needed to manage these stresses.

3.2.2 PUBLIC PRIVATE PARTNERSHIPS AND FUNDING

Participants emphasized that competitive pressure from China, coupled with likely tightening of the federal budget, will require unorthodox but appropriate approaches to spaceport funding and governance. Existing federal funding streams, including initiatives under the “Space Force of the Future” rubric, are not sized or structured to match multi-year, large-scale infrastructure needs. Needs are continuous and compounding; appropriations often are not.

In some areas, particularly for commodity generation and transport, the commercial marketplace could in principle mobilize substantial private capital. Long-term offtake agreements for LNG liquefaction facilities, LOX production, and pipelines are familiar instruments in other sectors. However, major commercial users such as SpaceX and Blue Origin have been reluctant to make the long-term, fixed volume commitments typically required to make these projects financeable.

Ongoing conversations among launch operators, local utilities, and state and local governments reflect this tension. Utilities, regulated largely at the state level, possess statutory tools to make bulk purchases “at risk” in order to aggregate demand and attract infrastructure investment. In practice, however, regulators and elected officials are understandably cautious about transforming utilities into commodity speculators or de facto spaceport developers. They are hesitant to expose rate payers or taxpayers to open-ended infrastructure risk, even where the national interest is clear.

These dynamics highlight a recurring theme of the workshop: the federalist structure of the United States, where states retain significant authority and financial tools, can be a source of strategic advantage if deliberately harnessed. State level bonding, tax, and procurement authorities could be more systematically aligned with national space infrastructure objectives.

3.2.3 DIGITAL MODERNIZATION — PROJECT ANDOR

Space Florida and the U.S. Space Force are collaborating on **Project Andor**, an enterprise level, cloud-based transportation and operations management system for spaceports. The vision is to provide real-time coordination, scheduling, accountability, and deconfliction across federal agencies and commercial operators.

Aspirational features include:

- Collaborative, shared workflows across government and industry.
- Measurable metrics on operational efficiency and delay drivers.
- Process optimization tools and transparent status dashboards for all stakeholders.
- An architecture designed from the outset to support future artificial intelligence (AI) integration.

Crucially, Andor is intended not merely to digitize existing paper-based processes, but to drive cultural change by critically reassessing and, where appropriate, eliminating legacy requirements. The success of Andor will depend as much on governance, change management, and leadership support as on software architecture.

3.2.4 NUCLEAR PAYLOAD INFRASTRUCTURE AND FUTURE NEEDS

The U.S. Space Force, NASA, and the commercial marketplace anticipate a significant increase in missions using nuclear power for propulsion and in space power systems, particularly in light of the mandates included in Executive Order 14369. See Chapter 6 for in-depth discussion of some of the impacts arising. NASA's investment in the Lunar Fission Surface Power Project and related initiatives signal a strategic shift toward nuclear technologies as enablers of sustained lunar and deep space operations. NASA has also emphasized that partners should "maximize external funding," underscoring the expectation of commercial and private capital participation.

At present, only a single payload processing facility at Cape Canaveral meets the stringent requirements for handling nuclear payloads. This single point of processing will quickly become a bottleneck as nuclear enabled missions scale. Participants expressed concern that the United States could face a structural capacity shortfall in nuclear payload handling, similar to historical constraints in other critical defense and energy infrastructure sectors.

There is no consensus on the appropriate business model for new nuclear capable facilities. Options range from fully government funded, dedicated facilities to modular, upgradable commercial facilities with government anchor tenancy and clear regulatory pathways. The technological diversity of potential nuclear payloads—spanning radioisotope power systems and higher power fission reactors—complicates matters further, as each class brings distinct safety, handling, security, and licensing requirements.

Participants underscored the need to:

- Streamline and clarify regulatory processes early, to provide predictable design and investment guidance.
- Leverage lessons learned from naval nuclear propulsion, commercial reactors, and small modular reactors (SMRs) for data centers and other non-traditional uses.
- Make deliberate use of financial instruments such as the Office of Strategic Capital and other federal incentives to crowd in private investment.

3.2.5 INLAND LAUNCH AND A NATIONAL SPACEPORT NETWORK

As coastal ranges approach both physical and political capacity—and as their vulnerability to hurricanes, sea-level rise, and potential adversary attack becomes more salient—the workshop explored inland launch as a strategy for resilience and redundancy.

Inland spaceports could:

- Provide alternative operational concepts, such as shared infrastructure, multi-use pads, and more flexible scheduling.
- Enhance national resilience by diversifying launch locations and reducing reliance on a small number of coastal sites.
- Potentially offer different community engagement models and economic development pathways.

However, the economic and policy viability of inland launch remains uncertain. Critical questions include:

- Whether the Department of Defense is prepared to commit to purchasing launches from inland sites at scale, providing an anchor demand signal.
- Whether the U.S. government is willing to make the kind of long-term policy and investment commitments that characterized the Interstate Highway System and Rural Electrification initiatives.
- Whether inland communities will support spaceport development in the face of noise, overflight, and safety concerns.

Safety and regulatory hurdles, including flight safety footprints and E_c (expected casualty) constraints, present additional complexity. The FAA and industry organizations such as the Commercial Space Federation are exploring a national spaceport network strategy, but key issues of infrastructure investment, workforce development, and public acceptance are far from resolved.

3.2.6 NEPA AND ENVIRONMENTAL REVIEW — POST-2021 CHANGES

NEPA implementation emerged as a central theme of the workshop. Major regulatory changes in the early 2020s reshaped the landscape in ways that are still playing out:

- Council on Environmental Quality (CEQ) regulations that had previously provided a measure of uniformity across agencies were rescinded or revised, leaving individual agencies to update their own NEPA procedures with only partial, high-level guidance.
- While the underlying environmental statutes have remained largely unchanged since the 1970s, the implementation environment is now more fragmented, with multiple overlapping legal regimes—including the Endangered Species Act (ESA), Section 4(f) protections for parks and historic sites, and historic preservation laws—converging on many coastal launch locations.

Agencies and operators—including NASA, the FAA, the Department of Defense, commercial spaceports, and launch providers—report that:

- Differing NEPA interpretations and procedures across agencies have increased complexity and inefficiency.
- Inconsistent requirements and documentation standards, coupled with duplicative reviews, contribute to slow permitting relative to launch growth.
- Risk-averse agency cultures, shaped in part by fear of litigation, encourage exhaustive analyses even when law and regulation would permit more streamlined approaches.

Some efforts to streamline and modernize are underway:

- Agencies are exploring Memoranda of Understanding (MOUs) to clarify roles and responsibilities for launch and reentry reviews.
- Categorical exclusions (CatEx) and programmatic environmental reviews—including pilots at sites such as Wallops—are being used to cover recurring activities and reduce the need for project-by-project reviews.
- Tools and models under consideration include “One Federal Decision” frameworks, NEPA–Clean Water Act Section 404 merger concepts, and FAST-41-style permitting dashboards and timelines.
- Legislative proposals such as the SPEED Act (H.R. 4776) aim to standardize and expedite environmental reviews for space activities.

Participants also discussed emerging technology solutions—AI, machine learning, and advanced visualization—to manage document volume, support impact analysis, and improve public engagement. However, they emphasized that technology is not a substitute for clear statutory and regulatory direction.

Executive Order 14335 (August 2025) directs FAA/DOT to streamline NEPA processes for launch and reentry, expedite Part 450 implementation, and establish an interagency MOU to eliminate duplicative reviews for spaceport infrastructure development. The order also mandates evaluation of state compliance with the Coastal Zone Management Act and directs DOC to assess how federal consistency reviews may be streamlined. These directives signal high-level policy intent to reduce permitting timelines, but their effectiveness will depend on agency implementation, resource allocation, and the degree to which they can navigate the statutory and procedural complexities discussed throughout this chapter.

For broader context on the policy and legislative environment surrounding NEPA and permitting reform, see Chapter 2: Space Policy, Regulation & Finance Landscape.

3.3 KEY ISSUES AND CHALLENGES

3.3.1 SPACEPORT CAPACITY AND FUNDING

The consensus view of workshop participants is that existing range and spaceport infrastructure is over capacity relative to original design assumptions and is not keeping pace with the trajectory of launch cadence.

Recent authorization for the U.S. Space Force to collect indirect cost fees from launch service providers is a step toward more sustainable funding, but these mechanisms are still constrained by statutory limits and appropriations rules. They do not yet provide a robust pathway for financing the largescale, multiyear infrastructure projects required for long-term competitiveness.

Infrastructure bottlenecks—commodity generation and transport, road congestion, access control, and workforce housing—pose a material threat to scalability. Without compromising security or safety, stakeholders are searching for ways to mitigate the negative impacts of current badging and access systems, which often delay critical maintenance, construction, and operational activities.

Private capital is available for infrastructure investment, but uptake is limited by:

- The absence of long-term, bankable commitments from major launch users.
- Constraints on how indirect fees and other charges may be collected and spent.

These funding and financing challenges sit within the broader acquisition and policy context outlined in Chapter 2: Space Policy, Regulation & Finance Landscape.

3.3.2 GOVERNANCE, POLICY, AND REGULATORY BARRIERS

Regulatory friction is a recurring barrier to timely infrastructure investment. Stakeholders cited delays related to:

- Lease terms and land use approvals on federal property.
- Environmental permits and consultations.

- Historic preservation and Section 4(f) reviews, which in some cases have expanded beyond their original scope.

Spaceport sponsors and operators often lack clear, unified “asks” when engaging Congress and federal agencies. Consequently, opportunities to secure:

- Longer-term leases,
- Flexible contracting authorities, and
- Revived or modernized grant programs tailored to spaceport infrastructure are frequently missed or pursued in a piecemeal fashion.

The vision of a national spaceport network, including inland launch sites, remains more aspirational than operational. Regulatory uncertainty, unclear DoD demand signals, and unresolved public acceptance issues all contribute to this gap.

EO 14335's directive for an interagency MOU on spaceport infrastructure and its mandate to streamline environmental reviews provide a potential pathway to address some of these barriers. However, MOUs are only as effective as the agencies' willingness and capacity to implement them. Without dedicated funding, clear accountability mechanisms, and sustained leadership attention, there is a risk that the EO's directives will produce process documents rather than operational improvements.

3.3.3 NEPA FRAGMENTATION AND PROCESS INEFFICIENCIES

Post-CEQ-rescission, NEPA application across agencies is non-uniform. Contractors and operators must navigate multiple, sometimes conflicting procedural regimes, with differing review timelines and documentation expectations. This complexity is particularly acute at environmentally sensitive coastal ranges where NEPA intersects with ESA, Section 4(f), and historic preservation requirements.

Agency NEPA offices are generally under resourced. Heavy workloads and personnel shortages slow reviews, while institutional risk aversion encourages expansive analyses that further tax staff capacity.

Industry participants emphasized the lack of clear, outward facing guidance and consistent opportunities to shape evolving MOUs and NEPA processes. Transparency, predictability, and meaningful input are seen as prerequisites for sustained private investment.

3.3.4 DIGITAL AND CULTURAL TRANSFORMATION

Project Andor illustrates both the promise and the peril of digital modernization. There is broad recognition that better data visibility, shared situational awareness, and automated workflows could materially reduce friction across the range. At the same time, participants cautioned that simply “putting bad processes on good software” risks entrenching outdated practices.

Cultural resistance to eliminating legacy requirements—whether due to habit, uncertainty about legal risk, or lack of clear decision ownership—remains a significant barrier. Digital tools alone cannot resolve this; leadership and governance changes are essential.

3.3.5 NUCLEAR PAYLOAD COMPLEXITY

Nuclear missions will place substantial additional stress on already limited facilities and regulatory processes. Without proactive planning, the single existing nuclear capable payload facility at Cape Canaveral will become a choke point.

Regulatory expectations across different nuclear technologies remain insufficiently clear or harmonized. Coordination among nuclear safety regulators, spaceport operators, and commercial stakeholders is nascent. Community concerns—including those of offshore commercial fishing interests and coastal communities—add another layer of complexity.

3.4 KEY INFLECTION POINTS

Several decision points emerging from the workshop will shape the trajectory of U.S. launch infrastructure and regulatory modernization over the next decade:

- **Range Capacity and Inland Launch.** Choices about whether, and how, to commit DoD support and federal funding to inland launch and a national spaceport network will determine whether launch growth can be sustained without over-reliance on a few coastal ranges.
- **NEPA Reform Trajectory.** The adoption—or failure—of legislative reforms such as the SPEED Act, broader use of programmatic reviews and categorical exclusions, and the application of FAST-41-style tools will either institutionalize more efficient, predictable environmental review for space or lock in fragmented, slow processes.
- **Digital Modernization (Project Andor).** If implemented as a genuine process optimization platform, Andor could reduce operational friction, improve transparency, and serve as a model for other ranges and transportation hubs such as airports and seaports. If it merely automates outdated workflows, it risks reinforcing skepticism about digital reforms and missing a rare window for cultural change.
- **Nuclear Payload Infrastructure.** Early decisions about funding models, regulatory frameworks, and facility designs for nuclear payload processing will either create a scalable path for nuclear enabled missions or lock in long-term bottlenecks and investor uncertainty and should be aligned with Executive Order 14369.

3.5 KEY ACTIONS AND RECOMMENDATIONS

1. Clarify and Unify Congressional “Asks” for Spaceport Infrastructure

Spaceport sponsors, state authorities, and industry should work together to develop a concise, unified set of requests to Congress and relevant federal agencies, including:

- Expanded and longer-term lease authorities on federal property, paired with more flexible contracting mechanisms.
- Revived and modernized grant programs explicitly tailored to spaceport infrastructure, including commodities, utilities, and access control facilities.
- Statutory recognition of spaceports and ranges as infrastructure eligible for FAST41 and Build America style support mechanisms.

2. Build a National Spaceport Coalition

A coalition of states, spaceport operators, and industry should be formed or strengthened to:

- Advocate for a coherent national spaceport network strategy that explicitly accounts for inland launch and resilience needs.
- Emphasize redundancy and geographic dispersion as national security imperatives, not merely commercial preferences.
- Explore innovative governance models, including interstate compacts and other non-federal authorities, to plan, finance, and operate segments of the national spaceport system.

3. Strengthen Public Private Infrastructure Financing

Stakeholders should pursue collaborative models that aggregate demand and de-risk investment in shared infrastructure, particularly for LOX, LNG, and GN_2 production and transport. States, which historically financed and operated much of the nation's infrastructure, possess bonding authority, procurement flexibility, and regulatory tools that could be deployed more fully.

Key steps include:

- Exploring group purchasing and commodity management structures that can support larger, more efficient production facilities while spreading risk.
- Designing long-term, flexible agreements that provide sufficient certainty to unlock private capital yet retain adaptability for operators in a rapidly evolving launch market.

4. Accelerate Digital Modernization with Process Reform

Project Andor should be treated as a flagship initiative for both digital and process transformation. Workshop participants recommended that:

- Deployment be tied explicitly to process simplification, including the deliberate removal of obsolete steps and duplicative reviews.
- Metrics be established to track reductions in cycle time, manual workload, and error rates, and these metrics be shared with stakeholders.

- The system be designed to provide shared situational awareness across DoD, FAA, the Coast Guard, NASA, and commercial operators, enabling faster, more transparent decision making.

5. Advance Planning for Nuclear Payload Processing

The United States should begin planning for additional nuclear capable payload processing facilities now, rather than waiting for capacity crises. Recommended actions include:

- Evaluating modular, upgradable facility designs that can evolve as nuclear technologies mature.
- Clarifying regulatory expectations early for safety, security, licensing, and emergency response, drawing on the experience of naval nuclear propulsion, SMRs, and other advanced reactor programs.
- Using tools such as the Office of Strategic Capital, credit support mechanisms, and other incentives to attract appropriately qualified commercial partners.
- Proactively engaging coastal communities, offshore fishing interests, and other stakeholders to address anxieties about launching nuclear materials through transparent risk communication and robust safety planning.

6. Modernize NEPA Processes for Space

To align environmental review with the pace of launch operations while preserving environmental protection, stakeholders should:

- Implement EO 14335 directives: FAA/DOT and DOC should expeditiously develop and execute the interagency MOU on spaceport infrastructure, streamline NEPA processes for launch/reentry, and clarify Coastal Zone Management Act compliance pathways as directed by the August 2025 Executive Order.
- Advocate legislative recognition of space as a transportation and infrastructure sector eligible for FAST-41 and related permitting reforms.
- Expand programmatic and regional NEPA reviews at major launch sites and develop cross-agency categorical exclusions for recurring, well-understood activities.
- Create formal mechanisms for industry participation in the development of interagency MOUs and NEPA procedures, and provide clear, outward-facing guidance to reduce uncertainty.
- Encourage agencies to adopt a more balanced risk posture—acknowledging that litigation is likely but focusing on building strong, legally defensible records rather than defaulting to excessive analysis.

7. Address Environmental and Historic Preservation Bottlenecks

Participants recommended targeted reforms to address recurring bottlenecks at the intersection of NEPA, ESA, Section 4(f), and historic preservation:

- Use programmatic agreements, waivers, or carefully scoped legislative changes to prevent the mission creep application of USDOT Section 4(f) to launch and landing where the underlying statutory purposes are not well aligned.
- Enable greater use of third-party contractor models or industry funded support—subject to conflict-of-interest safeguards—to augment constrained agency environmental staff.

8. Institutionalize Ongoing Dialogue and Best Practice Sharing

Finally, the workshop emphasized the importance of sustained dialogue beyond episodic meetings. Recommended steps include:

- Regular interagency and public private forums focused specifically on spaceport infrastructure, NEPA modernization, and permitting.
- Systematic sharing of best practices on programmatic reviews, categorical exclusions, mitigation strategies, and digital tools.
- Continuous monitoring and public reporting on the implementation of FAST-41-style tools, Project Andor, legislative reforms, and other key initiatives, so that lessons learned can be rapidly disseminated and incorporated into policy and practice.

Together, these actions would move the United States toward a more resilient, scalable, and strategically aligned launch infrastructure ecosystem—one capable of supporting both national security imperatives and a rapidly evolving commercial space economy.

An infrared photograph of the Optical Communications Telescope Laboratory at JPL's Table Mountain Facility beaming an eight-laser beacon to the Psyche spacecraft. [Credit: NASA/JPL-Caltech]

CHAPTER 4: OUTERNET: HYBRID SPACE COMMUNICATIONS ARCHITECTURE

Working Group Co-Leads:

- Steve Nixon, Outernet Council
- Michael Cheng, Outernet Council

"DIU's ability to rapidly integrate and deliver a hybrid space network architecture is testament to its process of allowing commercial innovators to solve complex problems at speed and scale by applying their solutions to DoD's problems." - Maj. Gen. Steven Butow, director of the Defense Innovation Unit's space portfolio

4.1 BACKGROUND

Following the creation of the Outernet Council and developments in hybrid space architecture communications over the past year, the Outernet Working Group continues to advance its mission: discussing challenges, opportunities, and risks associated with building a diversified network of operators and intersatellite links (ISLs). The Outernet Council describes the Outernet as "a connected, secure, resilient network of communications satellites"—the internet extended to space.

The Outernet has the potential to fundamentally transform how network traffic is handled globally. With hundreds of thousands of miles of undersea cables representing vulnerabilities to attack by an increasing number of global actors, the Outernet can serve as both backup and primary communications infrastructure during times of crisis. The strategic importance of non-terrestrial communications was underscored throughout 2025 by continued undersea cable incidents, regional conflicts, and growing competition from state-backed constellations.

The Department of Defense has embraced the Outernet concept. As Colonel Eric Felt, Director of Architecture and Integration at the U.S. Space Force (USSF), stated: "The outernet is the internet in space… That's very important because it gives us real-time command and control and access to our data… which we don't always have today." The Space Warfighting Analysis Center (SWAC) force design envisions concentric circles of linked SATCOM networks—highly encrypted military constellations, allied partner networks, and commercial constellations—all interconnected to provide resilience through path diversity.

This chapter describes the current state of space-based communications and identifies key issues and challenges, highlights upcoming inflection points, and proposes actions and recommendations. Acquisition and regulatory dynamics that shape Outernet adoption are closely related to those discussed in Chapter 2 (Space Policy, Regulation & Finance).

4.2 CURRENT STATE

4.2.1 CONSTELLATION LANDSCAPE AND GOVERNMENT PROGRAMS

SDA Transport Layer Reaches Operational Status.
The Space Development Agency (SDevA) launched its first operational Tranche 1 Transport Layer satellites on 10 September 2025, beginning a campaign to deploy over 150 satellites. By year's end, 42 satellites were on orbit providing regional Link-16 and Ka-band connectivity targeted toward Indo-Pacific Command. In December 2025, SDevA awarded an additional $3.5 billion for 72 Tracking Layer Tranche 3 satellites. However, Transport Layer Tranche 3 has been paused pending a DoD analysis of alternatives considering commercial proliferated LEO options.

Commercial Constellation Competition Intensifies.
SpaceX's Starlink continues to dominate with approximately 9,400 operational satellites as of early 2026, representing a majority share of operational spacecraft in LEO. Estimated 2025 revenue projections reached $11.8 billion. DoD's Proliferated LEO (PLEO) contract ceiling expanded from $900 million to $13 billion based on military demand, with SpaceX securing approximately 97 percent of awarded task orders.

Amazon rebranded Project Kuiper as "Amazon Leo" in November 2025 and began launching production satellites, announcing commercial service in the U.S., UK, France, Germany, and Canada beginning in Q1 2026. The FCC deadline requires half of its

3,236-satellite constellation to be operational by July 2026, creating strong near-term incentives to deploy at scale.

OneWeb, Telesat Lightspeed, and other operators continue to build out their systems, but none currently match Starlink's scale or vertical integration.

China's MegaConstellations Accelerate.
China's dual constellation strategy made significant progress. The state backed Guowang constellation deployed over 100 satellites by December 2025 through an intensive launch cadence, while the commercially oriented Qianfan ("Thousand Sails") constellation reached a similar scale. Combined announced targets—including the planned Honghu3 constellation—total nearly 40,000 satellites, though deployment timelines remain uncertain. Industry analysts estimate that Chinese manufacturing capacity has expanded significantly, with state media citing production rates exceeding 300 satellites per month.

These constellations are tightly integrated into China's Military Civil Fusion framework and are expected to support both commercial services and military command, control, and sensing.

European IRIS² Program Launches.
The European Union signed the IRIS² (Infrastructure for Resilience, Interconnectivity and Security by Satellite) concession contract in December 2024 with the SpaceRISE consortium. The ~€10.6 billion program will deploy approximately 290 satellites in LEO and MEO by 2029–2030, providing secure governmental connectivity and commercial broadband. IRIS² is explicitly framed as a strategic capability to reduce dependence on non-European providers and to anchor a European space industrial base.

On-Orbit Edge Computing Emerges.
Axiom Space and Kepler Communications announced initial Orbital Data Center (ODC) nodes and on-orbit compute services tied to Kepler's optical relay network, with intent to align with SDevA standards for eventual interoperability. This marks a significant step toward operational in-space computing infrastructure for AI/ML processing, data fusion, and low latency decision support.

4.2.2 ENTERPRISE SATCOM CHALLENGES

A March 2025 Government Accountability Office report (GAO-25-107034) found that while DoD is increasing coordination on enterprise SATCOM, significant challenges remain. The historically slow speed of system acquisitions—averaging approximately 10 years—poses problems for fielding hybrid terminals and interoperable systems in an environment where commercial constellations iterate rapidly. The report recommended annual Congressional reporting on implementation progress.

As Mike Dean of the DoD CIO's SATCOM division put it, user terminals remain "the tail that wags the dog." It currently takes 7–15 years to integrate new terminals into ships, submarines, or aircraft "until we get to software defined." While all three military services are developing hybrid terminals—an "unprecedented" development—the Navy and Air Force still describe their approach as "crawling, walking, running." The Air Force's Global Lightning hybrid terminal may deploy in 2026, but comprehensive fielding remains years away.

Ground segment modernization is also lagging. As Dean emphasized, "We think about the space segment, we think about the terminals, but we always forget the ground." DoD's enterprise SATCOM vision requires virtualization and digitization of ground infrastructure to move data at machine speeds across hybrid architectures. The DoD CIO has joined industry consortia including the Digital Intermediate Frequency Interoperability (DIFI) consortium and the Waveform Architecture for Virtualized Ecosystems (WAVE) to address standardization, but implementation trails constellation deployments.

Executive Order 14369 (December 2025) mandates acquisition reform across DoD and NASA, establishing a "first preference" for commercial solutions and "general preference" for OTAs and Space Act Agreements. This policy direction could accelerate hybrid terminal development and commercial SATCOM integration if implemented effectively. However, the order's aggressive program review thresholds (cancellation consideration for programs 15–30% behind schedule or over cost) may create risk aversion that slows, rather than accelerates, adoption of novel architectures.

Environmental permitting constraints and range capacity issues affecting ground modernization at launch sites and ranges are analyzed in Chapter 3 (Launch Capacity, Spaceport Infrastructure & NEPA Modernization).

4.3 KEY ISSUES & CHALLENGES

4.3.1 PROLIFERATION OF WALLED GARDENS

Major commercial constellations—Starlink, Amazon Leo, OneWeb, Telesat Lightspeed and others—continue to operate as "walled gardens," unable to exchange data in space due to proprietary interfaces and a lack of cross-operator roaming agreements. While operators (Starlink and Amazon Leo) have reported communications about possible conjunctions, they do not yet communicate machine-to-machine.

As one industry official noted at the 2024 Space Symposium: "My guess right now is that Starlink is not gonna talk to OneWeb, is not gonna talk to Kuiper, is not gonna talk to Lightspeed."

Commercial entities are disincentivized from interoperability for several reasons:

- Proprietary terminal ecosystems are significant revenue streams and lock-in mechanisms.
- There is no widely accepted, neutral standards body defining interoperable optical intersatellite links (OISLs) and associated protocols.

- Government customers have not yet provided sufficiently strong or consistent demand signals for cross constellation interoperability.

The longer proprietary interfaces proliferate without common standards, the harder integration becomes. Retrofitting interoperability into thousands of deployed satellites and millions of terminals would be technically and economically challenging.

4.3.2 GOVERNMENT VS. COMMERCIAL ISL PERFORMANCE GAP

SDevA optical ISL standards are being adopted for government use, but commercial ISLs—such as those deployed on Starlink—often operate at significantly higher throughput. Industry estimates suggest that commercial links may exceed government standard bandwidth by an order of magnitude or more, depending on the specific comparison.

Government dominance of current standards development risks biasing specifications toward government needs at the expense of commercial capabilities. There is a danger of locking in sub-optimal performance profiles and discouraging commercial innovation that could otherwise benefit government users. As Paul Van Slett, DoD CIO SATCOM division chief, warned: a satellite "that is not interoperable with the ground segment or user terminal is effectively an orbiting paperweight."

4.3.3 SINGLE VENDOR DEPENDENCY RISK

DoD's heavy reliance on Starlink—securing approximately 97 percent of PLEO task orders—creates strategic vulnerabilities. Technical, cyber, or business disruptions affecting SpaceX would cascade across military operations. A 24-hour Starlink disruption would degrade communications for deployed forces across multiple theaters, with potential impact on both routine and crisis operations.

International allies are increasingly concerned about relying on U.S. controlled systems. Europe is accelerating IRIS² and regional alternatives; Germany has been paying to provide Ukraine with Eutelsat OneWeb terminals as an alternative to Starlink. These acquisition and regulatory dynamics are closely related to the broader commercial integration and procurement issues discussed in Chapter 2.

4.3.4 TERMINAL INTEGRATION TIMELINES AND GROUND SEGMENT LAG

As noted above, terminal integration timelines remain measured in years to decades. Legacy platforms—ships, aircraft, ground vehicles—are difficult and costly to retrofit with new terminals. Hybrid terminals that can roam across multiple constellations are under development but not yet widely fielded.

On the ground side, virtualization and digitization efforts are still in early stages. Without a modern, software-defined ground segment, the potential benefits of orbital diversity and flexible routing cannot be fully realized. The result is an architecture in which the space segment advances rapidly while terrestrial infrastructure acts as a brake.

4.3.5 CHINESE STANDARDS INFLUENCE

China holds leadership positions in key standards bodies, including chairing ITU-R Study Group 4 (satellite services) and holding vice-chair positions in relevant 3GPP committees. The China Spatio-Temporal Information Group, formed in 2024, combines state telecommunications, satellite, and defense entities under Military-Civil Fusion to shape specifications favoring Chinese systems while creating regulatory barriers for Western competitors.

Without proactive U.S. and allied engagement, international standards for non-terrestrial networking could evolve in ways that disadvantage Western constellations or embed technical and regulatory preferences aligned with Chinese interests.

4.4 KEY INFLECTION POINTS

The Outernet working group identified several inflection points over the next five years.

4.4.1 AMAZON LEO COMMERCIAL LAUNCH (Q1 2026)

Amazon's market entry could recalibrate competitive conditions in LEO. With deep financial resources, Amazon Web Services (AWS) integration capabilities, and potential bundling with Prime memberships and enterprise services, Amazon represents the first credible challenger to Starlink's dominance. DoD officials hope that Amazon Leo's success will diversify the supplier base, though significant price competition against SpaceX's vertically integrated cost structure remains challenging.

4.4.2 ON-ORBIT EDGE COMPUTING BECOMES OPERATIONAL

The Kepler Axiom ODC deployment marks the beginning of a new computational frontier. As on orbit edge computing becomes a mission imperative for constellation operators—beyond just Starlink or Amazon Leo—it could fundamentally change data handling, reduce latency, and enable real time AI/ML processing in space. This is particularly significant for Earth observation, autonomous systems, and defense applications requiring rapid processing and decision support.

4.4.3 CHINESE CONSTELLATIONS REACH OPERATIONAL SCALE

As Qianfan and Guowang achieve regional operational coverage, they will offer alternatives to Western systems for nations along the Belt and Road Initiative and beyond. This could fragment global space communications into competing spheres, with standards and governance implications extending beyond technical interoperability. Nations may find themselves choosing between Western-aligned and China-aligned communications ecosystems.

4.4.4 GOLDEN DOME INTEGRATION REQUIREMENTS

The Golden Dome missile defense initiative creates urgent requirements for resilient, high-bandwidth space communications. Congress provided $24.4 billion through the FY

2025 reconciliation law (P.L. 119-21) as an initial investment, with cost estimates ranging from $175 billion (White House) to over $500 billion (CBO) over 20 years. The communications architecture required to integrate thousands of space-based sensors with ground-based shooters may accelerate demand for Outernet capabilities and create powerful incentives for interoperability, redundancy, and multi-vendor participation.

4.4.5 SATELLITE SERVICING ENABLES RETROFIT

Four DoD funded satellite servicing demonstrations are planned for 2026. If on-orbit servicing and retrofit become routine, older but operational vehicles could be fitted with optical terminals and improved communications technology, enabling more actors to participate in the Outernet without full constellation replacement. Chapter 5 (SML/ISAM) provides a broader assessment of the in-space servicing and logistics architectures that enable these retrofit concepts.

4.4.6 GEOPOLITICAL SHIFTS IN PROVIDER RELIANCE

European backlash against U.S. provider concentration is accelerating IRIS² and regional alternatives. Germany's support for Eutelsat OneWeb terminals in Ukraine is one example. A broader diversification from U.S.-controlled systems by allies would increase demand for interoperable, multi-vendor architectures, and would make it harder for any single provider to dictate standards de facto.

4.5 KEY ACTIONS & RECOMMENDATIONS

Interoperability spans multiple layers. The working group organized recommendations around four layers: (1) Physical/link layer (optical terminals, RF waveforms); (2) Data link/network (routing, QoS, time synchronization, identity); (3) Service orchestration (NOC APIs, provisioning, management); and (4) Terminal abstraction (software-defined radios and networks, modem applications, security enclaves). A "minimum viable roaming" path prioritizes ground-based roaming first, cross network data exchange via gateways second, and in-space crosslinks last.

Several recommendations align with broader SSIB proposals on regulatory reform, export control, and coordinated investment; see Chapter 8 for a consolidated recommendations table.

4.5.1 SHORT-TERM (0–18 MONTHS)

USG Should Fund Industry Led Outernet Standards Development.
In the absence of strong signals from major customers, space communications will continue to fragment. DoD CIO and USSF should provide funding and government participation in an industry led standards initiative. A model akin to the WiFi Alliance or Bluetooth SIG is appropriate, with defined specifications, certification test plans, and "Outernet Certified" marks. Government participation should focus on defining interoperability requirements and security baselines, not on over specifying

implementation details.
Owners: DoD CIO, USSF, Space Systems Command (SSC).

Score Interoperability in Source Selection.
Rather than simply mandating interoperability, acquisition organizations should award evaluation points in source selection for demonstrated roaming and cross-constellation links. Contracts should require published interface control documents (ICDs) for interoperability boundaries, even if internal system details remain proprietary. This approach allows industry to retain differentiation while ensuring that systems can interconnect where it matters.
Owners: SSC, DISA, DoD CIO.

Outernet Council to Provide Neutral Advocacy and Standards Coordination.
The Outernet Council should survey constituents and provide thought leadership across industry, following models such as the Linux Foundation. Initial priorities should include network operations center (NOC) orchestration APIs and next-generation ISL standards identified by USSF SWAC and DARPA's Space-BACN program.
Owners: Outernet Council, industry partners.

Accelerate Hybrid Terminal Development.
Air Force Global Lightning and Navy efforts such as STtNG (if maintained) should be prioritized and coordinated to avoid duplication. The goal should be initial hybrid terminal deployment by ~2026 with as much cross service commonality as feasible. These terminals should be software defined and capable of supporting multiple waveforms and constellation interfaces through software updates.
Owners: USSF, Navy, Air Force.

4.5.2 MID-TERM (3–5 YEARS)

Develop NextGeneration ISL Standards Beyond SDevA Tranche 1.
DARPA's SpaceBACN program should inform higher bandwidth standards that bridge government and commercial capabilities, closing the performance gap between government standard and commercial ISLs. These standards should support flexible, vendor agnostic optical terminals and allow for incremental upgrades.
Owners: DARPA, SDevA, AFRL.

Implement Enterprise SATCOM Management and Control (ESC-MC).
Complete ESC-MC implementation to enable automated resource allocation across military, commercial, and allied satellite networks. Ground segment infrastructure should be virtualized to enable machine-speed data routing across heterogeneous networks.
Owners: DoD CIO, USSF, USSPACECOM.

Establish Commercial Diversity Requirements.
Develop policies to ensure that no single commercial provider exceeds a defined threshold percentage of DoD's PLEO capacity in any theater under normal operations, while

preserving surge clauses for contingencies. Acquisition strategies should explicitly support emerging providers such as Amazon Leo, Telesat Lightspeed, and others to foster a competitive ecosystem.
Owners: SSC, DISA, DoD CIO.

Integrate Allied Constellations.
Coordinate with IRIS² and allied national constellations to ensure interoperability at key interfaces. NATO SATCOM Services 6th Generation (NSS6G) activities should explicitly incorporate Outernet principles and standards.
Owners: DoD CIO, USSF, Department of State.

4.5.3 LONG-TERM (BEYOND 5 YEARS)

Achieve the "3GPP Moment" for SATCOM.
Develop comprehensive global standards enabling seamless roaming across satellite networks, analogous to mobile telecommunications. Software-defined terminals should be able to connect to any compliant constellation without hardware changes. This will require sustained engagement with international standards bodies and alignment of commercial and government interests.
Owners: DoD CIO, USSF, industry, international standards bodies.

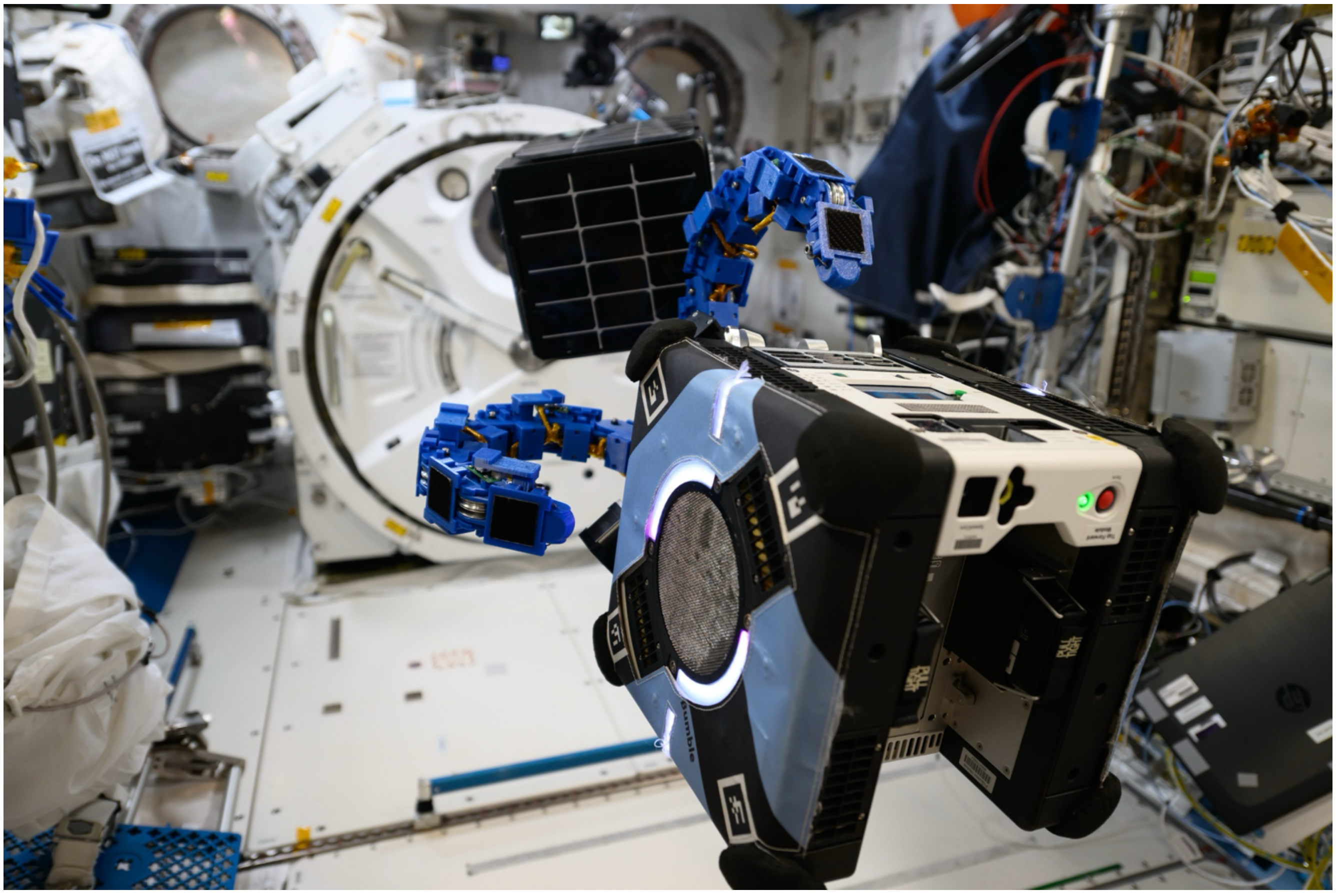
Counter Chinese Standards Influence.
Pursue active U.S. and allied engagement in ITU and 3GPP to ensure that Outernet standards reflect Western technical preferences and avoid regulatory barriers to non-Chinese systems. This includes funding technical contributions, increasing participation in relevant ITU-R Study Groups and 3GPP Technical Specification Groups, and coordinating positions with allies.
Owners: Department of State, FCC, NTIA, DoD CIO.

Develop International Space Traffic Management and Spectrum Coordination Protocols.
With tens of thousands of satellites planned across multiple national constellations, collision avoidance, spectrum deconfliction, and interference mitigation require international cooperation—even with adversaries. Outernet coordination should be linked to Outer Space Treaty discussions, Artemis Accords frameworks, and emerging space traffic management initiatives.
Owners: Department of State, DOC/Office of Space Commerce, USSPACECOM.

Integrate Outernet Architecture with Golden Dome.
Ensure that the communications backbone for missile defense leverages a resilient, multi-path Outernet architecture consistent with PACE (Primary, Alternate, Contingency, Emergency) principles. Commercial augmentation should provide redundancy for government transport layers, and Golden Dome requirements should drive investment in interoperable, multi-vendor architectures rather than reinforce single-provider

dependence.
Owners: SDevA, Missile Defense Agency (MDA), USSF, DoD CIO.

Taken together, these actions aim to move the Outernet from concept to operational reality: a secure, resilient, interoperable network of space-based and terrestrial communications systems that supports national security, civil, and commercial needs, while preserving strategic flexibility and mitigating single-point vulnerabilities. The 2025 Working Group focused on the Outernet as defined in the first paragraph of this section. Integration with space traffic and spectrum coordination support the concept that Outernet, as described and evaluated for this report, are part of something bigger. This will be addressed in the Epilogue.



The NOCTRL KMI REACCH payload performing a robotic capture of a target satellite aboard the International Space Station (ISS). ***[Credit: Kall Morris Inc. (KMI)]***

CHAPTER 5: SPACE MOBILITY & LOGISTICS / IN-SPACE SERVICING, ASSEMBLY & MANUFACTURING

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"Our entire U.S. commercial space industry has fundamentally changed. The Chinese have produced hundreds of satellites that are on orbit, and they produce weapons that are on orbit, and then you look at our on-orbit capabilities, they're basically the same as they were 10 years ago … I think we have to start giving military leadership—and I'm a military person, so I'm biased—authority and responsibility to go buy things and give them a

flexible budget in order to do that." - Retired Gen. John Hyten, former Vice-Chairman of the Joint Chiefs of Staff

5.1 BACKGROUND

The SML/ISAM Working Group examined mobility and logistics capabilities and emerging technologies for ISAM. The group focused on how the United States and its allies should advance development of modular, serviceable, and reusable systems and sustainable in-space logistics infrastructure (both physical and digital) to support operations by leveraging commercial, civil, and national security space systems.

The working group decomposed SML/ISAM into three functional areas:

- **Space Servicing:** Repairing, refueling, reloading, repurposing, upgrading, and maintaining satellites and other space assets.
- **Space Mobility:** Moving assets in space, including transporting people, cargo, and equipment.
- **Space Logistics:** The broader planning, coordination, and execution of resupply, support, and maintenance across space operations.

Another useful decomposition is into core SML/ISAM capabilities:

- Rendezvous and Proximity Operations (RPO);
- Orbital servicing (dexterous robotics and autonomous systems: refueling, resupply, upgrade/modernization, repositioning);
- In-space construction, assembly, augmentation, and reconfiguration;
- In-space manufacturing;
- SML/ISAM infrastructure, architecture, and logistics;
- Orbital disassembly, debris capture, relocation, and remediation.

The group's central question was whether the SML/ISAM community is making the progress needed to make these capabilities a routine part of space operations, and if not, why not. This chapter summarizes significant developments since the 2021 SSIB workshop, assesses key issues and challenges, identifies inflection points, and offers a set of actions and recommendations.

5.2 CURRENT STATE

This section provides a high-level snapshot of activity across the SML/ISAM capability taxonomy.

5.2.1 RENDEZVOUS AND PROXIMITY OPERATIONS (RPO)

RPO capabilities—autonomous target acquisition, inspection, and docking—are foundational for SML/ISAM.

Recent developments include:

- **Starfish Space** awarded a NASA SBIR Phase III for the Small Spacecraft Propulsion & Inspection Capability Mission (SSPICY) for debris inspection of defunct spacecraft, and a SpaceWERX STRATFI contract for qualification of its Otter vehicle for station-keeping, orbital transfer, and orbital disposal. Starfish successfully demonstrated an RPO between its Otter Pup and a partner satellite with ~1 km approaches and imagery capture.
- **True Anomaly** awarded a SpaceWERX STRATFI contract for highly maneuverable, multi-orbit, autonomous tactically responsive JACKAL development.
- **Turion Space** awarded a SpaceWERX TACFI for biometric-enabled autonomous on-orbit capture.
- **Mosaic ATM** awarded a NASA Phase II STTR for advanced, transparent, trusted AI for increased autonomy in ISAM operations.
- **APECH Labs** received a Phase II SBIR for a launch-hardened deploy and docking mechanism.
- **Arkisys** demonstrated spacecraft assembly, add-on propulsion, and RPO sensing on a robotic testbed, collaborating with multiple ISAM partners.
- **WBGlobalSemi** commercialized new materials and calibration systems enabling higher-value information from high-frequency optical sensors.
- The **NRO's BALISTA** program awarded contracts to Cognitive Space, Impulse Space, and Starfish Space to assess in-space mobility, on-orbit logistics, sustainability, and mission acceleration.

RPO investments are crucial for enabling autonomous, precise satellite servicing and inspection, driving efficiencies in future SML/ISAM missions and enhancing space operations safety.

5.2.2 ROBOTIC SERVICING, DEXTEROUS ROBOTICS, AND AUTONOMOUS SYSTEMS

Robotic systems provide the "hands" for servicing, upgrade, and repair operations.

Key developments:

- **Scout Inc** awarded a SpaceWERX TACFI for leveraging on-board perception data products for tactically responsive counterspace autonomy and intelligence.
- **Lunar Outpost** awarded a SpaceWERX STRATFI for mobile autonomous robotic swarms.
- **Katalyst Space Technologies** awarded a DIU M4SS contract to develop a retrofit attachment system for spacecraft capture; separately funded to upgrade a U.S. government satellite with sensing capability in 2026.
- **SpaceLogistics** (Northrop Grumman) completed its first MEV life extension mission for Intelsat901 and is preparing for additional customers. Intelsat extended the MEV2 contract for four more years.
- **Enduralock** designed OneLink™, a mechanical docking and data/power/fuel connection interface and has a letter of intent with Space Ocean for standardization.

- **iBOSS** developed the intelligent Space System Interface (iSSI), an androgynous multifunctional connector that can serve as docking interface, robotic end effector or foot, or universal ground test port. iSSI was demonstrated in space in 2022 (Skycorp/DIU/NASA/ISSNL) and is now deployed with multiple integrators in the U.S., Europe, and elsewhere.
- **HEBI Robotics** received a 2025 Phase I NASA SBIR to create space-rated hardware compatible with its robot development ecosystem and signed a Space Act Agreement with NASA Ames for the ARMADAS project.
- **Rogue Space Systems** awarded a SpaceWERX Phase II SBIR for development of its Orbot extensible platform with thruster systems and edge-computing (OTP-2 mission, March 2025).
- The **European Commission** launched the In-Space Operations and Servicing (ISOS) project in April 2025 to prepare a multi-element demo mission by 2030, including servicing, assembly, manufacturing, recycling, and logistics.
- **SpaceWERX** solicited and is awarding contracts for its Sustained Space Maneuverability (SSM) challenge (~$20M for Phase II SBIRs with USSPACECOM sponsorship).
- **DARPA** delivered the RSGS servicing payload from the Naval Research Lab to SpaceLogistics for integration with the Mission Robotic Vehicle (MRV).

5.2.3 REFUELING – PROPELLANT/PRESSURANT/CRYOGENIC HANDLING AND TRANSFER

Refueling is central to the SML vision of "maneuver without regret."

Recent progress:

- **Astroscale** and USSF established a public-private partnership for the Prototype Servicer–Refueling (APS-R) program, targeting refueling for small, prepared clients.
- **L3Harris/Aerojet Rocketdyne** is advancing cryogenic fluid transfer technologies with testing in 2025.
- **SpaceX** performed an in-flight propellant transfer demonstration on a Starship test flight under a NASA Tipping Point award.
- **Orion Space** completed CDR on Tetra-5 (USSF/AFRL) and was awarded follow-on work for Tetra-6.
- **Orbit Fab** completed testing of its RAFTI refueling interface at Kirtland AFB under DIU/AFRL; USSF selected Orbit Fab's GRIP and SpaceLogistics' Active Refueling Module under the ROOSTER initiative.
- **iBOSS** developed IFEX (intelligent Fuel EXchanger), an androgynous refueling interface technology for all propellant types unveiled during SSIB 2024.
- DIU issued Multiple Orbit Logistics contracts to Space Logistics and others for refueling capability development.
- NASA continues Tipping Point efforts for on-orbit storage and transfer of cryogenic fluids, as well as the AXCIS Early Career Initiative.

Note: NASA cancelled the OSAM-1 mission (which would have demonstrated robotic servicing of an unprepared client and the SPIDER in-space assembly experiment) but issued an RFI on hardware reuse and potential partnerships.

5.2.4 IN-SPACE CONSTRUCTION, ASSEMBLY, AUGMENTATION, AND RECONFIGURATION

Representative developments:

- **Momentus** secured a DARPA NOM4D contract to support design and in-space demonstration of large-scale structures.
- **Enduralock** awarded a SpaceWERX TACFI for robotic arm installation of space-qualified fasteners.
- **NovaWurks** demonstrated SLEGO ISAM interfaces with Arkisys' Spaceport robotic arms.
- NASA Early Career Initiative projects such as MARVL (Modular Assembled Radiators for NEP Vehicles) are exploring modular assemblies for nuclear electric propulsion.

Again, NASA's cancellation of OSAM-1/SPIDER removed a flagship demonstration, but the technology base continues to advance through other efforts.

5.2.5 IN-SPACE MANUFACTURING

Several commercial and public initiatives are exploring manufacturing in microgravity:

- **Varda Space Industries** is developing in-space manufacturing of high-value pharmaceuticals with orbital production and Earth return capability.
- **Ecoatoms** conducted a privately funded thin-layer deposition demonstration producing 500 samples in space.
- **Astral Materials** awarded NASA SBIR Ignite Phase II to develop a microgravity semiconductor crystal growth furnace.
- **Outward Technologies** completed a Zero-G flight campaign, successfully welding titanium in vacuum and microgravity.
- **ThinkOrbital** launched and recovered the first autonomous welder in space (May 2024), but has since pivoted away from ISAM, citing concerns about architecture and demand timing.
- **Space Forge** built an in space semiconductor manufacturing tool to create materials that are impossible to make terrestrially.
- **Flawless Photonics** conducted optical glass manufacturing experiments on ISS through ISS National Labs.
- **DARPA NOM4D** funds eight commercial and academic teams for ISM solutions, including potential lunar sourced materials.
- **NASA JOINS (JOining demonstrations IN Space)**, a Tipping Point program with Lockheed Martin, will demonstrate in space welding and inspection methods external to ISS (planned flight March 2026).

5.2.6 SML/ISAM INFRASTRUCTURE, ARCHITECTURE, AND LOGISTICS

Several efforts are aimed at SML/ISAM infrastructure and logistics concepts:

- **LMI Consulting** developed a quantitative modeling and simulation framework for SML/ISAM movement and maneuver trade studies.
- **Sedaro** completed an Orbital Prime Phase II STTR to develop ISAM/RPO digital twin capabilities.
- **EXAIL** offers compact, high accuracy space qualified IMUs supporting the lunar economy.
- SpaceWERX awarded TACFIs to:
    - **Exploration Laboratories** (autonomous capture/acquisition mechanisms for superheavy launch vehicles);
    - **Impulse Space** (two space vehicles demonstrating how highly maneuverable on-orbit assets can complement responsive launch approaches);
    - **Antaris** (self-healing satellite concepts);
    - **Apex Technology** (satellite bus modular interfaces).
- DIU's Novel Responsive Space Delivery initiative awarded contracts to **The Spaceport Company** (sea-based launch platforms), **Stoke Space** and **Astra** (responsive point-to-point cargo), and **Firefly** (reduced time cislunar delivery via Sinequone).
- DIU awarded multi-orbit logistics contracts to **Blue Origin** (Heavy Logistics Vehicle) and **Spacebilt** (medium-class Orbital Logistics Vehicle).
- SpaceWERX Orbital Prime awarded 26 Phase II contracts focused on ISAM mission capabilities.

5.2.7 ORBITAL DISASSEMBLY, DEBRIS CAPTURE, RELOCATION, AND REMEDIATION

Orbital debris is both a sustainability challenge and a potential SML/ISAM demand driver.

Recent activities:

- **Kall Morris Inc (KMI)** and **geCKo Materials** demonstrated a debris capture concept on ISS.
- **TransAstra** won a NASA contract for an orbital debris capture bag.
- **Astroscale Japan** launched the ADRASJ mission, with a follow-on capture and deorbit mission planned for a rocket body.
- SDevA funded six feasibility studies for commercial deorbit-as-a-service for the Proliferated Warfighter Space Architecture.
- NASA awarded SpaceX a contract for an ISS deorbit vehicle, an important precedent for end-of-life disposal.

5.2.8 INSTITUTIONAL AND ECOSYSTEM DEVELOPMENTS

Two key institutions are helping to shape the ISAM ecosystem:

- **CONFERS -** the independent not-for-profit global trade association for satellite servicing, developing recommendations for industry-led voluntary consensus standards and guiding international policies that contribute to a sustainable, safe, and diverse space economy.
- **COSMIC** – a U.S. not-for-profit consortium integrating domestic industry, academia, and government to foster U.S. leadership in making ISAM a routine part of space mission lifecycles.

COSMIC and CONFERS are collaborating on frameworks to enable SML/ISAM cooperation between states, and have co-organized events (e.g., circular space economy webinars). COSMIC's Capstone Challenge (C3) engaged 33 student teams in SML/ISAM conceptual designs. COSMIC also convened a National Security Space Senior Leader roundtable to probe barriers to SML/ISAM adoption; a key conclusion was that DoD prefers the term SML and sees immediate relevance primarily in servicing and logistics.

Despite technical progress, some firms—such as ThinkOrbital—have pivoted away from SML/ISAM, citing lack of near-term architecture and demand.

Near term outlook highlights:

- 2025: USSF/AFRL **Tetra5** refuellable experiment; Astroscale **LEXI™** servicer launch.
- 2026: APS-R (USSF/Astroscale), USSF/Starfish Otter™ GEO RPO and electrostatic docking, DIU/Orbit Fab/Kamino depot demo, DARPA/NGC MRV & RSGS, USSF/Impulse OTVs, NASA/Starfish SSPICY RPO/inspection.
- 2027: USSF **ROOSTER5** propulsive ESPA refueling mission and ESA ADRIOS-RISE for satellite life extension in GEO.
- 2029: ESA **ClearSpace-1** active debris removal for PROBA-1.

However, funding trajectories beyond near term demos remain uncertain, and—as discussed below—the absence of an overarching SML architecture limits the ability to scale.

Executive Order 14369 (December 2025) establishes a policy preference for commercial solutions and directs DoD and NASA to prioritize OTAs and Space Act Agreements in acquisition. This could provide a more favorable policy environment for SML/ISAM demonstrations and early operational services. However, risk is created by the order's mandate to review programs 15–30% behind schedule or over cost for cancellation in conflict with long-lead SML/ISAM technology development, which often requires patient, multi-year investment to mature capabilities from TRL 6 to operational readiness.

5.3 KEY ISSUES & CHALLENGES

5.3.1 OVERARCHING ISSUE: MISSING ARCHITECTURE AND NORTH STAR

Despite years of discussion, there is still no coherent North Star vision for SML/ISAM across the U.S. government. Nearly all current and planned technology demonstrations are one-off missions or, at most, small systems of systems. There is no overarching architecture into which they can be incorporated. Without such an architecture, the capabilities cannot scale into routine operations. ISAM must be accepted as operationally necessary.

Dr. Andy Williams (AFRL) summarized DoD's current stance: for national security applications, the priority is servicing and logistics—refueling, reprovisioning, technology upgrades—not near-term in-space assembly or manufacturing. From his perspective, broader ISAM discourse creates "noise" that distracts from pressing servicing needs. He called for an "Amazon Prime for space," emphasizing responsive logistics chains that can deliver new capabilities every few years.

From the National Security Space perspective, there is also frustration that Space Futures Command (SFC) has not yet been formally established within USSF. SFC is seen as the natural home for objective force design and long-term space infrastructure architectures, including SML.

Operationally, USSF has not yet fully internalized how SML/ISAM could change the nature of space operations. Today's conversations often focus on how to do existing missions at lower cost, rather than exploring qualitatively new operations enabled by routine refueling and servicing, analogous to how aerial refueling and precision-guided munitions transformed airpower.

5.3.2 GOVERNMENT ISSUES

- **Limited and uncertain investment.** Meaningful SML/ISAM investments are currently concentrated in national security programs and are not clearly sustained over time. The December 2025 EO 14369 mandates acquisition reform and commercial preference, which could improve access to funding mechanisms such as OTAs. However, the same order's aggressive program review thresholds create risk that SML/ISAM demonstrations experiencing technical delays or cost growth, common in novel technology development, could be cancelled before reaching operational viability. Absent a whole-of-government commitment with stable, multi-year funding protected from short-term performance metrics, SML/ISAM will struggle to move beyond demonstrations.
- **Lack of standards adoption.** Government has not yet fully embraced the role of driving adoption of interface standards and norms of behavior (e.g., refueling ports, RPO fiducials, docking interfaces).

- **No professional space logistics corps.** Unlike other domains, national security space lacks a professional logistics community. This limits the ability to develop strategy, doctrine, operational plans, and architectures for sustainment in space. (Chapter 7 on Workforce discusses broader workforce gaps, including logistics roles).
- **NASA's mixed signals.** NASA's flagship observatories after Hubble have generally not been designed for servicing. The Habitable Worlds Observatory represents an opportunity to reverse this pattern. Some in the working group argued that NASA, as an "agency of one-offs," will not be the primary ISAM driver; others argued that NASA must lead by example.
- **Limited cost analysis transparency.** There is no widely accessible, government endorsed cost analysis comparing SML/ISAM to traditional replacement models. Aerospace Corporation has conducted analyses showing benefits in both cost and capability, but most are not public. RAND's Dynamic Space Operations study, commissioned by USSF, is expected to address costs and value.
- **Launch costs and capacity.** High launch costs and constrained capacity drive mission designs toward hyper-optimization, limiting flexibility for servicing and upgrade. Launch capacity and spaceport infrastructure constraints are examined in Chapter 3.

5.3.3 INDUSTRY ISSUES AND PERCEPTIONS

- **Nascent markets and investor timelines.** SML/ISAM is still a nascent industry. Private investors often expect rapid returns and may not fully understand development timelines. Some are exiting the sector. Government strategic investment and acquisition commitments are critical to bridge this gap, issues developed in Chapter 2.
- **Demand vs. supply ambiguity.** Some participants stressed a lack of clients; others argued demand exists, but customers require flight heritage and the right price. For GEO servicing, potential customers want proven services on favorable terms.
- **Temporal gap between servicing and manufacturing.** Servicing appears achievable and scalable in the near term; assembly and manufacturing are less mature technically and commercially. Some customers with older assets prefer new programs to servicing; debris mitigation is often cheaper to address through insurance than active removal under current economics.
- **Government not structured for sustainment in space.** Many government programs have neither requirements nor funding for on-orbit maintenance and support. Sustainment tails often exceed initial acquisition costs in other domains; space needs to adopt similar thinking.

- **Debris as a future but not current driver.** Orbital debris is a major long-term challenge, particularly in GEO where lifetimes are millennia. However, there are few paying customers today for debris remediation. Space Force considers debris part of SML but has no dedicated funding. SDevA is exploring deorbit services for LEO constellations.

5.3.4 POLICY AND REGULATORY ISSUES

(For broader U.S. regulatory reform, export control, and mission authorization, see Chapter 2.)

Key SML/ISAM-specific concerns:

- **Debris and graveyard orbit policy.** Some participants suggested a "tax" or fee for using graveyard orbits to fund debris mitigation—raising concerns about cost and uneven international application.

- **FCC servicing approvals.** Proposed FCC rules could require servicers to obtain approval for each servicing event, an untenable model for high cadence operations. The FCC December NPRM directly includes ISAM. While EO 14335 may mitigate some concerns, implementation remains unclear and conflicts or duplication between the FCC and OSC Commerce are possible.

- **International servicing.** Servicing clients from other countries often requires complex international agreements. CONFERS and COSMIC are working on generic models, but current timelines (12–18 months for multi-agency approvals) are unsustainable at commercial cadence.

- **Spectrum access.** SML/ISAM missions rely on spectrum bands (including X-band) that are under pressure from other uses. The community is concerned about both access and authorization models (e.g., temporary non-interference authorizations with no guaranteed access "when needed").

- **Single agency licensing.** There is broad support—at least within the working group—for a single, properly resourced agency to serve as a "one stop shop" for SML/ISAM authorizations. Other countries are moving toward such models, potentially making them more attractive regulatory homes for ISAM businesses. The OSC Commerce proposal presented in December 2025 may be a step toward resolution of this issue.

- **Export control ambiguity.** RPO related capabilities employed between international entities blur lines in ITAR and EAR; it is not always clear when a servicing asset becomes an RPO asset subject to stricter controls. Companies worry that assembly and manufacturing activities could also trigger unexpected restrictions.

5.4 KEY INFLECTION POINTS

The SML/ISAM mission area is at a critical juncture.

- **Demonstration outcomes (2026–2027).** Success or failure of planned AFRL, DARPA, SpaceWERX, DIU, and SDevA demonstrations in 2026–2027 will significantly influence perceptions of viability. Successful demos could unlock funding and accelerate adoption; failures could reinforce skepticism and slow progress.
- **Licensing evolution.** Shifts in licensing and mission authorization approaches—particularly around multi-mission, multi-client servicing—will determine whether SML/ISAM remains a series of one-off demos or transitions to routine operations.
- **Leadership and messaging.** NASA's cancellation of OSAM-1/2 and mixed messages from National Security Space (USSPACECOM enthusiasm vs. USSF caution) have created uncertainty. Emerging programs like the Space Rapid Capabilities Office's serviceable spacecraft and the GSSAP replacement (commercially sourced with potential for serviceability) could become positive exemplars.
- **Space Futures Command decision.** Formal establishment (or not) of SFC will shape where long horizon space infrastructure and logistics architectures are developed within DoD.
- **In-space manufacturing pilots.** Demonstrations by companies such as Varda (pharmaceuticals), EcoAtoms ARES (precision coatings), and Space Forge could validate business cases and accelerate industrialization, particularly if they show clear terrestrial value.
- **Human exploration architectures.** If a human mission to Mars retains political and budgetary support, in space assembly becomes nonoptional, potentially pulling ISAM capabilities forward.

As Joerg Kreisel (CONFERS President, iBOSS Chairman) noted:

"Future space infrastructure and logistics will be based on modular architectures and inspace servicing, assembly and manufacturing (ISAM) to increase mission flexibility and overall space sustainability. Enabling factors will be cooperative design, building block approaches and interfaces with standards for both technology and operations to pave the way for a circular space economy. This will lead to entirely new mission architectures, system designs, operational concepts and business models, and the involvement of new players across the entire spectrum of space industrialization."

5.5 KEY ACTIONS & RECOMMENDATIONS

There was broad consensus that SML/ISAM can create multilevel synergies that benefit future space activities and space sustainability. Realizing this potential requires coordinated steps across government, industry, and regulators. Recommendations are grouped by time frame.

5.5.1 SHORT-TERM (0–18 MONTHS)

Government Actions – Fast-Track Impact

- **Articulate the military value of servicing.** USSPACECOM and USSF should clearly articulate the operational advantages of space servicing and logistics—beyond life extension—to gain buy in from senior leaders, investors, and appropriators. This includes developing an SML/ISAM-related cost analyses to help the broader community gain a realistic appreciation of what SML/ISAM capabilities should cost.
- **USSF embrace its anchor-tenant role.** USSF should accept and formalize its role as an anchor tenant for SML/servicing capabilities, and develop an in-space servicing architecture focused on refueling, reprovisioning, and upgrades. This aligns with the commercial-first acquisition policy mandated by EO 14369 (December 2025) and should be structured to provide multi-year demand signals that enable industry investment while protecting critical early-stage programs from the order's aggressive cancellation review thresholds. *Owners:* USSF, USSPACECOM
- **Incorporate sustainment into space acquisitions.** Future USSF acquisitions should treat support and sustainment of space assets as core elements—not afterthoughts—and advocate for dedicated maintenance and sustainment budget lines.
- **Build a space logistics profession.** USSF should begin creating professional development pathways analogous to other military logistics specialties, including doctrine for "classes of supply" in space and planning for sustainment. (See the Workforce chapter for broader pipeline recommendations.)
- **Protect and execute planned demos.** DARPA, AFRL, DIU, SpaceWERX, SDevA, and SpRCO should maintain planned SML/ISAM demonstrations for 2026–2027; these are critical to proving viability.
- **Establish dedicated ISAM R&D funding lines.** National Security Space should establish and POM for 6.2, 6.3, and 6.4 funding lines specifically for SML/ISAM.
- **Regulatory sandbox.** Create limited policy "sandboxes" where ISAM companies can test capabilities with reduced bureaucratic hurdles and more flexible licensing, while regulators work toward longer-term frameworks.
- **Convene standards workshops.** Government space agencies should convene workshops to accelerate consensus on interface standards (e.g., refueling ports, RPO fiducials, modular connectors).

Industry Actions – Proving Concepts Now

- **Demonstrate value of capabilities.** Prove the key capabilities for in-space refueling, resupply and upgrading to demonstrate their viability for National Security Space interests and ultimately attract investor interest.

- **Design for modularity and serviceability.** Satellite and spacecraft manufacturers should begin incorporating modular designs, standardized interfaces, and replacement-friendly architectures into at least some new builds.
- **Pilot "service-as-a-product" models.** Companies should launch pilot programs offering ongoing maintenance, relocation, or upgrade services—creating recurring revenue and flight heritage.
- **Pursue joint ventures.** ISAM startups should partner with larger providers (launch, bus manufacturers, sensor makers) to share resources and de-risk missions.

Joint Government–Industry Actions

- **"Space Olympics" for ISAM.** Create competitive challenges with tangible rewards (contracts, test range access) for ISAM technology demonstrations.
- **Skills training initiatives.** Jointly fund targeted training in robotics, autonomous systems, spacecraft mechanics, and space logistics.
- **Data transparency.** Share lessons—successes and failures—across the ecosystem to avoid repeated reinvention.

Metrics for success in this timeframe include: number of grants/awards, public commitments to modular designs, pilot servicing programs launched, participation in challenges, and graduates from ISAM relevant training programs.

5.5.2 MID-TERM (3—5 YEARS)

- **NASA to define ISAM's role in exploration.** NASA should articulate and begin implementing a clear vision for ISAM in human and robotic exploration, including serviceable flagship missions (e.g., Habitable Worlds Observatory) and use of Commercial LEO Destinations as testbeds.
- **NSS architecture for SML.** National Security Space (USSPACECOM, USSF, NRO) should establish an overarching in-space servicing and logistics architecture, with a roadmap and demand signal for industry.
- **CONFERS and international bodies to advance standards.** CONFERS, COSMIC, AIAA, IEEE, and others should continue standards work for servicing interfaces, RPO safety, and operational norms.
- **Government/industry cost analysis.** Expand and publicize cost and value analyses (Aerospace Corp, MITRE, RAND, COSMIC workshops) to help decisionmakers and investors understand when SML/ISAM is cost effective.

5.5.3 LONG-TERM (BEYOND 5 YEARS)

- **Build out articulated visions.** NASA, USSF, and USSPACECOM should implement the SML/ISAM visions and architectures they establish, enabling industry to adapt and extend them as foundational infrastructure models.

- **Mature a professional space logistics workforce.** USSF and industry partners should grow a cadre of logistics professionals specializing in in space sustainment and operations.
- **Increase international cooperation.** Expand SML/ISAM cooperation among allies and partners to share expertise, resources, and best practices, and to give friendly nations attractive alternatives to potential adversary frameworks.
- **Create regulatory clarity for novel activities.** Implement a clear mission authorization regime and ISAM appropriate spectrum allocations, reducing investment and insurance uncertainty.
- **Improve launch licensing for ISAM.** Continue refining Part 450 and related processes to support high cadence SML/ISAM missions, including interoperable license application systems.
- **Develop on orbit test infrastructure.** NASA and USSF should cooperate on robust onorbit testbeds (possibly in very low Earth orbit or via CLDs) for repeated SML/ISAM demonstrations.

Many of these recommendations build directly on earlier SSIB proposals in policy, finance, and workforce and are cross-referenced in the consolidated recommendations table. The central message is that SML/ISAM is no longer a speculative future concept; the technology base is emerging now. The question is whether the United States will provide the architectures, standards, acquisition strategies, and regulatory clarity needed to make servicing, mobility, and logistics a routine, scalable part of space operations.

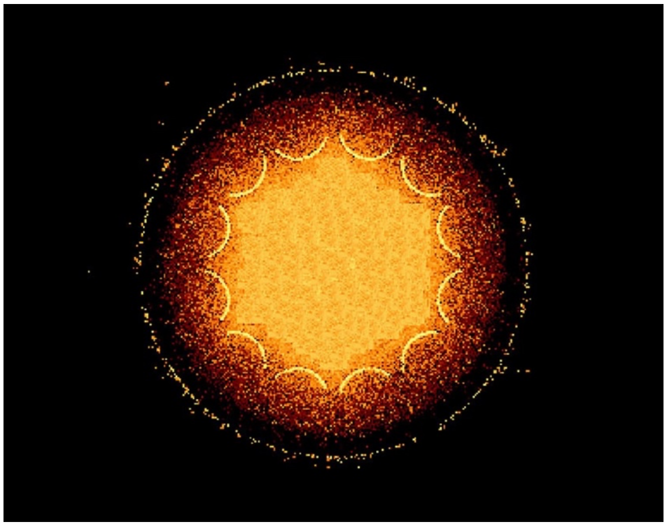

Photo 1: Computational simulation of the Antares R1 microreactor core, highlighting the prismatic graphite blocks and reactivity control drums. ***[Credit: Antares];*** *Photo 2: NASA and NNSA engineers lower the vacuum chamber wall around the Kilowatt Reactor Using Stirling Technology (KRUSTY) to simulate space conditions.* ***[Credit: Los Alamos National Laboratory]***

CHAPTER 6: NOVEL SPACE TECHNOLOGIES

Working Group Co-leads:

- Rob Antypas, AFRP
- Lee Steinke, CisLunar Industries

"Nuclear propulsion is the key that unlocks the solar system. Without it, we're stuck in Earth's orbit watching others explore."
– Dr. Bhavya Lal, former NASA Associate Administrator for Technology, Policy, and Strategy

6.1 BACKGROUND

Novel technologies are central to enabling the next generation of space capabilities across national security, civil, and commercial domains. These include advanced propulsion systems (electric and nuclear), space-based power generation and transmission, in-space resource utilization (ISRU), and emerging cislunar infrastructure such as positioning, navigation, and timing (PNT), communications, and logistics.

These technologies enable the transition from episodic space missions to persistent, scalable operations across multiple orbital regimes, including cislunar space. As the space domain becomes increasingly contested and commercially active, the development and integration of these capabilities will be critical to sustaining U.S. leadership and ensuring long-term operational advantage.

6.2 CURRENT STATE

Since the earlier SSIB workshops, the development of advanced and novel space technologies has progressed unevenly, characterized by significant technical advancements alongside persistent programmatic and funding disruptions.

Internationally, China continues to demonstrate sustained and coordinated progress across cislunar and lunar mission sets. The China National Space Administration (CNSA) has achieved a series of high-profile milestones, including the successful Chang'e-6 lunar sample return mission and continued progress toward the Chang'e-7 mission. These efforts are part of a broader, long-term strategy focused on establishing a sustained presence on the lunar surface. In parallel, China is advancing plans for a joint lunar surface fission power capability with Russia targeted for deployment by approximately 2035. Additionally, China's ability to recover and successfully deploy its distant retrograde orbit (DRO) communications satellite constellation after initial challenges in low Earth orbit demonstrates increasing operational resilience and technical maturity in complex space architectures.

Within the United States and allied ecosystems, momentum is building in the space nuclear domain. Nuclear electric propulsion (NEP) and nuclear thermal propulsion (NTP) are gaining traction as enabling technologies for cislunar and deep space missions, offering significant advantages in transit time, maneuverability, and mission endurance. At the same time, a broader suite of supporting technologies—including compact "nuclear batteries," advanced fuel forms such as novel fuel kernels, and high-efficiency power conversion systems—are under active development. However, progress in this area remains inconsistent. Key programs have experienced setbacks, most notably the cancellation of Demonstration Rocket for Agile Cislunar Operations (DRACO) and financial challenges within the commercial sector, which have slowed the maturation of nuclear thermal propulsion capabilities.

Efforts to enhance resilience in positioning, navigation, and timing (PNT) systems are also advancing. The U.S. Space Force has awarded contracts to multiple companies like, Astranis, Axient, L3Harris, and Sierra Space to develop design concepts for the Lite Evolving Augmented Proliferation (LEAP) architecture, representing an initial step toward a more distributed and resilient GPS framework. These efforts reflect growing recognition of the need to modernize legacy systems to operate effectively in contested and congested space environments.

Despite these areas of progress, the overall trajectory of novel space technologies is constrained by persistent budgetary instability. The cancellation or delay of key programs including DRACO, the freezing of ARACHNE funding, and the stagnation of the Kilowatt Reactor Utilizing Stirling Technology (KRUSTY) initiative has disrupted technology development pipelines and reduced continuity across research efforts. These disruptions not only slow technical advancement but also create uncertainty for industry stakeholders, undermining investment and long-term planning.

Executive Order 14369 ("Ensuring American Space Superiority," December 2025) attempts to address some of these challenges by establishing concrete goals, including deployment of a lunar surface nuclear reactor ready for launch by 2030, and creating a "National Initiative for American Space Nuclear Power" with implementation guidance due within 60 days. This has potential impacts upon infrastructure as described in Chapter 3. Additionally, the order mandates acquisition reform prioritizing commercial solutions and OTAs, which could accelerate technology maturation if implemented effectively. However, the same order directs review of programs 30% or more behind schedule or over cost for potential cancellation. Given the technical complexity and long development timelines inherent in nuclear propulsion and power systems, this aggressive accountability threshold creates risk that programs experiencing predictable technical challenges could be terminated before reaching operational capability.

6.3 KEY ISSUES AND CHALLENGES

6.3.1 SUPPLY CHAIN CONSTRAINTS

Supply chains for advanced and emerging technologies, particularly those required for cislunar operations, are underdeveloped. These missions require specialized components, including advanced communications systems, radiation-hardened electronics, and novel materials, many of which face sourcing challenges or limited production capacity.

6.3.2 FRAGMENTED GOVERNMENT EFFORTS

U.S. government initiatives across advanced power and propulsion remain highly fragmented. Agencies including AFRL, DARPA, NASA, and others are pursuing parallel efforts with limited coordination. This results in duplicated efforts, inefficient allocation of resources, and a lack of unified strategic direction.

6.3.3 BUDGETARY INSTABILITY

Inconsistent funding remains a critical barrier. Program cancellations and shifting budget priorities disrupt long-term technology development and erode industry confidence. Political sensitivities surrounding nuclear technologies further complicate sustained investment.

6.3.4 TENSION BETWEEN POLICY AMBITION AND IMPLEMENTATION REALITY

The December 2025 EO 14369 sets ambitious goals—lunar surface nuclear reactor by 2030, permanent lunar outpost by 2030, $50 billion in additional space investment by 2028—while simultaneously mandating aggressive program accountability (30% schedule/cost threshold for cancellation review). This creates a fundamental tension: advanced nuclear and propulsion technologies require patient, sustained investment over 10–15-year timelines, yet the policy environment increasingly emphasizes rapid results and low tolerance for delays. Without careful implementation that distinguishes between programmatic mismanagement and inherent technical risk, the EO's accountability measures could paradoxically undermine its ambitious goals by discouraging the very long-term investments required to achieve them.

6.3.5 LACK OF POLICY AND LEGISLATIVE UNDERSTANDING

There is a gap in awareness among policymakers regarding the strategic importance of cislunar operations and enabling technologies. This lack of understanding contributes to insufficient funding, unclear priorities, and delayed decision-making.

6.3.6 STRATEGIC COMPETITION

China’s continued investment and progress in cislunar and nuclear-enabled capabilities highlight the risk of the United States falling behind in key technology areas if current trends persist.

6.4 KEY INFLECTION POINTS

Several developments over the next decade could significantly alter the trajectory of advanced power and propulsion technologies:

6.4.1 OPERATIONAL IN-SPACE NUCLEAR SYSTEMS

The successful deployment and operation of a nuclear reactor in space, whether for propulsion or power, would represent a transformative milestone. Such a capability would enable faster transit, greater maneuverability, and sustained operations in cislunar and deep space environments.

6.4.2 LUNAR IN-SITU RESOURCE UTILIZATION (ISRU)

The first medium- to large-scale ISRU demonstration on the lunar surface would mark a shift toward sustainable space operations. Applications could include fuel production, material processing, or energy generation.

6.4.3 SHIFTS IN U.S. BUDGET PRIORITIES

Significant reductions in NASA science and exploration funding, combined with broader political shifts, could delay or cancel key programs. Such outcomes would risk ceding a strategic advantage to international competitors.

6.5 KEY ACTIONS AND RECOMMENDATIONS

6.5.1 SHORT-TERM (0–18 MONTHS)

Implement EO 14369 Space Nuclear Initiative with Sustained, Multi-Year Commitment. OSTP, DOE, NASA, and DoD should develop and resource the "National Initiative for American Space Nuclear Power" mandated by EO 14369 with realistic timelines, adequate funding, and protection from short-term performance metrics that do not account for inherent technical complexity. The initiative should coordinate fragmented efforts across agencies, establish clear milestones tied to the 2030 lunar reactor goal, and provide industry with predictable demand signals. Congress should provide multi-year appropriations authority to enable sustained investment. *Owners: OSTP, DOE, NASA, DoD, Congress.*

Expand Investment in Testing Infrastructure
Increase funding for both terrestrial and on-orbit testing capabilities, including facilities for advanced propulsion and nuclear technologies. On-orbit demonstrations may provide cost-effective and scalable validation pathways.
Owners: DoD, NASA, AFRL, DARPA

Diversify Electric Propulsion Supply Chains
Reduce reliance on limited and geopolitically sensitive propellants such as xenon by investing in alternatives including krypton, argon, and iodine.
Owners: DoD, DOE, industry

6.5.2 MID-TERM (3–5 YEARS)

Develop Cislunar PNT Architecture
Establish robust positioning, navigation, and timing systems for the cislunar domain to support increasing mission complexity and traffic.
Owners: USSF, NASA, SDA

Enable In-Space Power Markets
Demonstrate early commercial transactions for power generated in space to establish demand signals and support future infrastructure development.
Owners: NASA, DoD, DOC, industry

6.5.3 LONG-TERM (BEYOND 5 YEARS)

Establish a Unified National Strategy for Advanced Space Technologies
Develop and implement a coordinated national strategy that aligns policy, funding, and technical development across agencies for advanced power, propulsion, and cislunar infrastructure. This strategy should build on the "National Initiative for American Space

Nuclear Power" mandated by EO 14369 but extend beyond nuclear systems to encompass electric propulsion, ISRU, cislunar PNT, and related enabling technologies. It should include realistic timelines that account for technical complexity, mechanisms to sustain programs through inevitable setbacks, and clear criteria for distinguishing programmatic failure from inherent technical risk.
Owners: OSTP, DoD, NASA, Congress

Build Integrated Cislunar Infrastructure
Invest in a comprehensive architecture that integrates propulsion, power, communications, and logistics systems to enable sustained operations beyond Earth orbit.
Owners: NASA, USSF, industry partners

Celebrating a successful deployment: A student at NewSpace Nexus Intern Day showcases a winning 'Orbital Persistence' entry following a 20-foot drop challenge. ***[Credit: NewSpace Nexus]***

CHAPTER 7: SPACE EDUCATION, WORKFORCE & STEM

Working Group Co-Leads:

- Dr. Shery Welsh, University of Texas at El Paso (UTEP)
- Kathy Steen, NewSpace Nexus
- Dr. Monica Sandoval-Johnson, STEM Boomerang

"We need to widen the door, not lower the bar in space education to create high quality, visible and accessible entries to the industry."
– Melanie Stricklan, Executive Director of Space Workforce for Tomorrow, Space Symposium 2025

"We must maintain a decisive science and technology advantage." - Dr. Stacie Williams, Chief Science Officer, U.S. Space Force

"We have to invest in the science and technology, continue to develop things that we don't completely understand." - Gen. Chance Saltzman, Chief of Space Operations

7.1 BACKGROUND

The strength of the U.S. space industrial base is inseparable from the strength of its education and workforce pipelines. Space systems today demand not only engineers and scientists, but also technicians, tradespeople, data analysts, cybersecurity professionals, manufacturing operators, business developers, and mission support staff. Emerging communications architectures such as the Outernet (Chapter 4) and in-space logistics and servicing capabilities (Chapter 5) further amplify demand for software, networking, data, and operations skills.

Participants in the Space Education, Workforce & STEM Working Group emphasized that successful workforce systems are community-connected systems. Effective models, such as those emerging at the University of Texas at El Paso and the NewSpace Nexus Pathways to the Stars, demonstrate the value of "boots-on-the-ground" engagement: regular meetings with local officials, county leaders, nonprofits, schools, and employers to codesign pathways that reflect real regional needs. These efforts extend beyond classrooms into school demonstrations, exhibits, grassroots outreach, and sustained relationship building through informal convenings such as recurring coffee meetings for brainstorming and collaborative planning.

Recent labor market analyses such as Space Foundation's Space Report 2025 reinforce what employers already report: domestic production of qualified space talent is not keeping pace with demand. In response, states such as New Mexico have begun investing in connective infrastructure, including the legislatively funded New Mexico STEM Innovation Network (2025) and NewSpace Nexus' Pathways to the Stars, designed to better align education providers, workforce organizations, and industry partners.

Working group discussions stressed the importance of building clear, stackable pipelines modeled after mature electrical and plumbing trades that blend federal and state funding with direct employer engagement. These pipelines must intentionally value the full product lifecycle, from molecules to manufacturing, not just early-stage research. Participants noted persistent gaps between product development and scalable, profitable manufacturing, driven by underinvestment in applied technical skills such as CAD, precision measurement, lathe operation, lab support functions, and data analytics. These gaps are particularly consequential for emerging in-space servicing, logistics, and manufacturing roles discussed in Chapter 5 (SML/ISAM).

Finally, employers underscored that adaptability and work ethic remain as critical as technical credentials. Preparing students to understand business development, production realities, and team-based work environments is essential to long-term workforce resilience.

7.2 CURRENT STATE

The U.S. space workforce continues to expand rapidly but unevenly. According to Space Foundation data, employment in the U.S. space sector grew by roughly 18 percent over the past five years, outpacing overall private sector growth (14.3 percent). Average private sector space salaries reached approximately $135,000 in 2023, nearly double the national private sector average. Demand is strongest for computer science, data analytics, and information security skills, with cybersecurity roles projected to grow 30+ percent over the 2022–2032 period.

At the same time, the workforce is undergoing significant restructuring. Across government, unconfirmed reductions in force at the Department of Defense (estimated 5–8 percent), an 8 percent U.S. Space Force budget reduction, and planned staff cuts at NASA (5–10 percent), along with impacts at NOAA and NGA, are reshaping career expectations. Industry players such as Blue Origin and Boeing have also announced workforce adjustments, contributing to uncertainty among early- and mid-career professionals.

These workforce disruptions occur against a backdrop of ambitious policy goals and acquisition reform mandates. Executive Order 14369 ("Ensuring American Space Superiority," December 2025) establishes targets including returning Americans to the Moon by 2028, deploying a lunar surface nuclear reactor by 2030, and attracting $50 billion in additional space investment by 2028. Simultaneously, EO 14265 ("Modernizing Defense Acquisitions," April 2025) and EO 14369 mandate restructuring of acquisition workforces to reward commercial solutions and adaptive acquisition, with 120-day plans required to analyze staffing levels and establish new performance metrics. The tension between ambitious mission goals, aggressive acquisition timelines, and simultaneous workforce reductions creates significant risk. Advanced space capabilities—particularly nuclear propulsion (Chapter 6), SML/ISAM (Chapter 5), and space communications, Outernet, infrastructure (Chapter 4)—require sustained technical expertise that cannot be rapidly reconstituted if lost through reductions in force or attrition.

Education and workforce initiatives continue to advance, but scale remains a persistent challenge. Discussions at the 2025 Space Symposium "Space Workforce for Tomorrow" luncheon highlighted that hands on programs such as FIRST Robotics demonstrate strong workforce readiness outcomes yet remain under resourced relative to student demand. Participants emphasized the growing importance of community colleges, vocational training, and apprenticeship models, particularly for space adjacent roles that do not require four-year degrees.

Promising, but still fragmented, public private partnerships are emerging, including internships, capstone projects, and mentorship programs supported by companies such as Firefly, Blue Origin and Rocket Lab. However, these efforts have not yet scaled into a consistent, systemwide talent pipeline.

Importantly, SSIB participants noted that future workforce needs extend well beyond engineers. Trades, technicians, and operational roles are critical. While traditional software engineering demand may soften in coming years, adjacent skills such as data science and applied analytics offer transition pathways if supported intentionally. Overall, progress is evident, but misalignment between education outputs and employer needs persists.

Chapter 5 (SML/ISAM) provides concrete examples of how such roles are essential to sustaining in space logistics and servicing operations. Chapter 3 (Launch Capacity, Spaceport Infrastructure & NEPA Modernization) describes how these workforce and housing constraints are manifesting in key launch regions such as Brevard County.

7.3 KEY ISSUES & CHALLENGES

Working group discussions identified several interconnected challenges that threaten the sustainability of the space workforce pipeline.

7.3.1 SUPPORT STRUCTURE GAPS

Rapid growth in states like New Mexico, Florida, Colorado, and Texas is constrained by shortages in healthcare, housing, and benefits, particularly in rural or rapidly developing areas. “Healthcare deserts” and limited mental health services directly impact recruitment and retention, especially for families considering moves to space hubs. Rising housing costs and long commute times further erode the attractiveness of some regions despite high nominal wages.

These community level constraints intersect directly with spaceport capacity and infrastructure issues (Chapter 3). Without deliberate planning for housing, transportation, and social infrastructure, workforce shortages will remain a binding constraint on launch, manufacturing, and operations.

7.3.2 HIGHLY COMPETITIVE LABOR MARKETS

The space sector competes with other technology sectors—often with higher pay, more flexible work arrangements, or clearer career mobility—for the same talent pools in software, AI/ML, cybersecurity, and advanced manufacturing. In some regions, energy, automotive, and semiconductor industries draw from the same engineering and technician pipelines as space.

Employers expressed concern that the narrative of “space as elite and exclusive” can be a double-edged sword: attractive for some, but off-putting for others who perceive the sector as inaccessible or risky.

The acquisition reform mandates in EO 14265 and EO 14369—which prioritize commercial solutions, OTAs, and streamlined processes—may intensify competition for acquisition professionals with expertise in non-traditional contracting mechanisms. These specialists are in high demand across DoD, NASA, and the intelligence community, yet the same orders mandate workforce restructuring and performance metric changes that create uncertainty about career stability and advancement pathways. Without deliberate retention strategies, the government risks losing precisely the acquisition expertise needed to implement the reforms the orders mandate.

7.3.3 MISALIGNED TRAINING AND “UNICORN” JOB DESCRIPTIONS

Employers questioned whether current training programs, particularly at four-year institutions, align with real operational needs. Academic curricula can be slow to update, and some programs remain heavily oriented toward research rather than applied engineering, manufacturing, operations, or data analytics.

Job descriptions frequently exacerbate the problem by seeking “unicorn” candidates—early career professionals expected to possess deep expertise across multiple disciplines, extensive hands-on experience, and security clearances. This discourages applicants and obscures the fact that many skills can be learned on the job if organizations have structured onramp training.

7.3.4 MESSAGING, PERCEPTION, AND ACCESS

Many students and mid-career professionals lack a clear understanding of:

- Why space careers matter beyond exploration;
- What roles exist beyond engineering; and
- How those careers connect to personal and financial stability.

The working group emphasized the need to “widen the door, not lower the bar”: to provide high quality, visible, and accessible entry points for a broad range of learners while maintaining rigorous standards. That requires better storytelling, more relatable role models, and clear, stepwise pathways from education into employment.

7.3.5 VOLUNTEER AND ENGAGEMENT FATIGUE

K–12 outreach and extracurricular programs—robotics, rocketry, coding clubs—depend heavily on professionals volunteering their time. While passion is high, the structure to sustain and scale this engagement is often weak. There are limited incentives for employers to systematically support outreach, and burnout among dedicated volunteers is a recurring concern.

7.3.6 FACULTY AND GENERATIONAL GAPS

Rapid technological change in space and adjacent sectors has outpaced curriculum updates at many institutions. Faculty may not have recent experience with contemporary tools (e.g., cloud native development, AI/ML pipelines, modern manufacturing processes). Universities and community colleges are experimenting with short-term or modular training as stopgaps, but these efforts are uneven.

Generational expectations also diverge. Younger workers may prioritize flexibility, mission alignment, and work-life balance, while some legacy organizational cultures remain oriented toward long hours, rigid hierarchies, and opaque career paths.

7.3.7 EXPECTATION MISMATCH AND RETENTION

Some workers leave the space sector due to mismatches between expectations and reality regarding:

- Compensation relative to cost of living in space hubs;
- Inclusion, psychological safety, and pathways for advancement; and
- The degree to which their day-to-day work aligns with the inspirational narratives often used in recruitment.

Participants stressed that passion for space is not a substitute for fair pay, clear progression, and supportive environments. Without attention to retention, investments in education and recruitment yield limited long-term benefit.

Policy volatility compounds retention challenges. Executive orders establishing ambitious goals (e.g., EO 14369's 2028 lunar return and 2030 nuclear reactor targets) create excitement and urgency, but when coupled with aggressive program review thresholds (15–30% schedule/cost overruns triggering cancellation consideration), they generate uncertainty about program longevity. Early- and mid-career professionals are increasingly reluctant to commit to programs that may be cancelled before reaching fruition, particularly when private sector alternatives offer greater stability and comparable or superior compensation. This dynamic is particularly acute in advanced technology domains such as nuclear propulsion (Chapter 6), where program cancellations (DRACO, KRUSTY stagnation) have already disrupted career pathways.

7.4 KEY INFLECTION POINTS

The space workforce sits at a convergence of demographic, economic, and geopolitical inflection points.

7.4.1 UNDERGRADUATE PARTICIPATION TRENDS. Continued decline in undergraduate participation in some demographics—particularly among young men in certain fields—threatens long-term capacity and diversity.

7.4.2 LABOR FORCE PARTICIPATION. Workforce participation rates remain below pre-pandemic levels. It is not yet clear how many potential workers are permanently disengaged or could be reengaged through targeted reskilling.

7.4.3 FEDERAL BUDGET UNCERTAINTY AND RESTRUCTURING. Administration changes, defense budget adjustments, and agency level reductions in force introduce volatility into talent planning and deter some candidates from entering government service.

7.4.4 COST-OF-LIVING AND HOUSING PRESSURES. Rising costs in key hubs (e.g., along the Space Coast, Front Range, and certain Texas corridors) challenge younger workers' ability to sustain careers without multiple jobs, despite relatively high space sector wages.

7.4.5 INTENSIFYING GLOBAL COMPETITION AND REAL-WORLD CONFLICT. Demonstrations of space enabled conflict and competition (e.g., in Ukraine, the Middle East, and IndoPacific) underscore the urgency of faster, more scalable workforce preparation, including for national security roles requiring clearances and specialized training.

7.4.6 ACQUISITION WORKFORCE RESTRUCTURING AND RETENTION. Executive Orders 14265 and 14369 mandate significant restructuring of DoD and NASA acquisition workforces, including new performance metrics rewarding commercial solutions and adaptive acquisition, analysis of staffing levels, and establishment of field training teams. If implemented thoughtfully, these reforms could build a more agile, commercially savvy acquisition workforce. However, if implemented without adequate transition support, training resources, or retention incentives, they risk accelerating attrition of experienced acquisition professionals—particularly those with expertise in space-unique requirements, OTAs, and non-traditional contracting mechanisms. The outcome of this restructuring will significantly affect the government's ability to execute the commercial-first acquisition strategy the orders mandate.

The policy, budget, and acquisition drivers behind this volatility are explored in greater detail in Chapter 2.

7.5 KEY ACTIONS & RECOMMENDATIONS

Working group recommendations coalesced around building pathways—between school and work, between sectors, and between aspiration and reality. Actions are grouped by timeframe.

7.5.1 SHORT-TERM (0–18 MONTHS)

Expand Paid, Inclusive Work-Based Learning Across Roles.

- Normalize paid internships, co-ops, and pre-apprenticeships not only for engineering roles but also for technicians, trades, operations, manufacturing, and data/AI positions, using New Mexico's Pathways to the Stars as possible model.
- Use these programs to broaden access for underserved populations and to relieve immediate hiring bottlenecks, particularly in launch regions and manufacturing hubs.
  Owners: USSF, AFRL, NASA, major primes and commercial providers.

Deploy Modular Space Career Awareness Content in Middle and High Schools.

- Leverage existing high-impact programs to develop and disseminate modular, plug-and-play career awareness content that:
    - Explains the breadth of space roles (from welders and machinists to coders and mission planners);
    - Connects those roles to tangible local opportunities; and
    - Highlights a diversity of role models.
- Integrate this content into existing STEM initiatives rather than creating entirely new programs.
  Owners: USSF, NASA, state education agencies, industry associations.

Support Existing High Impact Programs.

- Identify and stabilize funding for high leverage programs such as FIRST Robotics, high school rocketry leagues, and community college aerospace pathways that already have demonstrated workforce outcomes.
- Encourage employers to provide structured support (mentors, in-kind resources, modest funding) leveraging support programs, in addition to ad hoc volunteerism.
  Owners: DoD STEM offices, NASA STEM, state agencies, industry.

Protect and Invest in Acquisition Workforce During Restructuring.

As DoD and NASA implement the acquisition workforce restructuring mandated by EO 14265 and EO 14369, agencies should:

- Provide robust transition support, training, and career counseling for acquisition professionals adapting to new performance metrics and processes;
- Establish retention incentives (e.g., bonuses, student loan repayment, flexible work arrangements) for personnel with expertise in OTAs, Space Act Agreements, and commercial space acquisition;
- Create clear career pathways and advancement opportunities for acquisition professionals specializing in commercial solutions and adaptive acquisition;
- Ensure that workforce reductions do not disproportionately affect space-unique technical expertise that cannot be rapidly reconstituted.

The goal should build a more agile acquisition workforce without losing the institutional knowledge and technical expertise required to execute complex space programs. *Owners: DoD, NASA, OPM, OMB.*

7.5.2 MID-TERM (3–5 YEARS)

Build Regional Space Workforce Consortia.

- Establish regional consortia in key space hubs (e.g., Space Coast, Front Range, Albuquerque, El Paso, Las Cruces, Houston, Seattle) that align:

  - Employers (primes, new entrants, government);
  - Community colleges and universities;
  - Workforce boards and economic development agencies.

- These consortia should agree on shared skill standards, coordinate applied learning projects, pool resources for equipment and labs, and jointly pursue federal and state funding.
  Owners: USSF, AFRL, NASA centers, state governments, industry councils.

Create Structured Reskilling Pathways from Adjacent Industries.

- Develop accelerated, stackable credential programs that enable mid-career professionals from adjacent sectors—automotive, energy, manufacturing, IT—to transition into space roles without requiring full degree reentry.
- Emphasize applied skills that are directly transferable to SML/ISAM operations, spaceport infrastructure, and Outernet ground systems (e.g., robotics technicians, network engineers, welders, machinists, cybersecurity analysts).
  Owners: Community colleges, workforce boards, DoL apprenticeships, industry

Align Curriculum with Future Demand.

- Use 5- to 10-year demand forecasting from agencies and major employers (e.g., for SML/ISAM logistics, cyber/AI for SPACECOM, space domain awareness) to inform curriculum updates "with the end in mind."
- Encourage joint curriculum development teams that include faculty, practitioners, and acquisition professionals, particularly those with expertise in OTAs, Space Act Agreements, and commercial space acquisition mechanisms emphasized in EO 14265 and EO 14369.
- Prioritize interdisciplinary programs that integrate nuclear engineering, aerospace engineering, materials science, and systems engineering to support advanced propulsion and cislunar infrastructure development (Chapter 6).
- Develop specialized training programs in commercial space acquisition, adaptive acquisition frameworks, and rapid capabilities development to support the acquisition reform mandates in EO 14265 and EO 14369.

Owners: USSF, AFRL, NASA, DOE, Defense Acquisition University, higher education accrediting bodies.

Establish Space Acquisition Professional Development Pipeline.

- Create a dedicated professional development pipeline for space acquisition specialists, modeled on successful programs such as the Defense Acquisition Workforce Improvement Act (DAWIA) framework but tailored to space-unique requirements. This pipeline should include:

- Specialized training in OTAs, Space Act Agreements, and other flexible acquisition mechanisms prioritized by EO 14265 and EO 14369;
- Rotational assignments between government acquisition offices, commercial space companies, and venture capital firms to build commercial fluency;
- Mentorship programs pairing experienced space acquisition professionals with early-career personnel;
- Clear certification pathways and career progression tied to demonstrated expertise in commercial space acquisition.

This initiative would help ensure that the acquisition workforce can effectively implement the commercial-first, adaptive acquisition strategy mandated by recent Executive Orders. *Owners: DoD, NASA, Defense Acquisition University, OPM.*

7.5.3 LONG-TERM (BEYOND 5 YEARS)

Institutionalize a National, Interconnected Space Workforce Pipeline.

- Build a national framework that connects K–12 outreach, community colleges, universities, apprenticeships, reskilling programs, and mid-career development into a coherent pipeline, modeled from the NewSpace Nexus Pathways to the Stars with:
    - Recognized stackable credentials;
    - Portability across states and employers; and
    - Incentives for educators and employers to participate.
- Treat key space education and training institutions as strategic national assets, with funding mechanisms that recognize their role in national security and economic competitiveness.
- Ensure that this pipeline explicitly supports the full range of space workforce needs, from launch operations (Chapter 3) and Outernet infrastructure (Chapter 4) to SML/ISAM (Chapter 5) and advanced propulsion and power systems (Chapter 6), as well as the acquisition professionals required to procure and integrate these capabilities under the commercial-first framework mandated by EO 14265 and EO 14369.
  Owners: USSF, DoD, NASA, Department of Education, state governments.

Align Cost-of-Living, Benefits, and Retention Strategies.

- Integrate workforce considerations into broader housing, transportation, and healthcare planning in key space regions, recognizing that community infrastructure is a critical enabler of industrial-base resilience.
- Encourage employers and regional partnerships to address retention through competitive pay, clear progression paths, and cultures that support inclusion and professional growth.
  Owners: State and local governments, economic development agencies, employers, federal installations.

Many of these workforce recommendations intersect directly with the acquisition, infrastructure, and architectural decisions described in earlier chapters. For example, decisions to adopt modular, serviceable spacecraft designs (Chapter 5), deploy advanced nuclear propulsion systems (Chapter 6), or pursue inland launch and a national spaceport network (Chapter 3) will only be executable if the United States can recruit, train, and retain the necessary workforce. Similarly, the acquisition reform mandates in EO 14265 and EO 14369—prioritizing commercial solutions, OTAs, and adaptive acquisition—require a workforce with fundamentally different skills and mindsets than traditional government acquisition. Conversely, clear, stable demand signals from those architectures and programs, protected from short-term performance metrics that do not account for inherent technical complexity, will help education and workforce systems plan and invest with confidence.

In that sense, the workforce is not a downstream consideration; it is a co-equal pillar of space industrial base strategy.

CHAPTER 8: STATE OF SPACE INDUSTRIAL REPORT (2020–2024)

This table consolidates key recommendations from SSIB reports 2020–2024. Several 2025 chapters examine how these themes are manifesting today—for example, Chapter 2: Space Policy, Regulation & Finance Landscape (regulatory reform, export control, and mission authorization), Chapter 5: SML/ISAM (application to space servicing and logistics), Chapter 4: Outernet (implications for proliferated SATCOM and standards), and Chapter 6: Workforce (workforce and critical-infrastructure issues). Future reports will carry this table forward, updating as appropriate, to facilitate implementation of recommendations and assessment of outcomes.

Space Policy and Finance Key Actions & Recommendations				
Short-Term Pay-Off				
Year	**Category**	**Title**	**Description**	**Status**
2024	Regulatory Reform & Improvement	**Accelerate Regulatory Approvals**	The current approach lacks clear timelines and risk management, potentially draining resources from small to medium-sized enterprises, causing burnout among technical teams, and delaying important innovations. Interagency approval processes need to be streamlined, coordinated, and evaluated to ensure they are effective in supporting space services. The existing regulatory framework falls behind technological advancements and new business models in the space industry. Proactive coordination between agencies, industry associations, and innovations like a Space Commodities Exchange could help identify dependencies, synchronize efforts, and uncover bottlenecks.	Ongoing
2024	Regulatory Reform & Improvement	**Interagency Approval**	Interagency approval processes must be better aligned and coordinated, as current regulations often lag behind technological advancements and new space business models. Pre-agency coordination through industry associations could help synchronize government and private sector efforts and identify bottlenecks.	Ongoing
2024	Regulatory Reform & Improvement	**Space Activities and Investments Processes Journey Map**	Develop a journey map for space activities and investments, using data-driven statistics to benchmark space activities, procurement or investment commitments, the regulatory approval process, and changing conditions for companies and governments. Identify pain points linked to incentives at each approval stage and evaluate regulatory decision authority based on the novelty, routine nature, and risk of the activity. Assess where risks of	Not Begun

			failure or interference exist and address them holistically. Shift the accountability threshold for risk so that commercial space activities are presumed approved unless a justification for rejection is provided. Focus on speed and resilience, aligning the pace of regulation with technological advancements, while considering commercial strategies and asymmetric advantages.	
2024	Acquisition Reform & Market Access	**Support Nascent Space Companies via an Ombudsperson / Coach / Sherpa for procurement and regulatory navigation.**	Assist these companies in advancing their business cases and aligning with U.S. government customer needs. Establish a "Good Lawyers Corps" to guide both government and commercial parties through regulations like FAR and DFAR, promoting creative solutions to overcome bureaucratic inertia. This initiative would help level the playing field for new space companies competing with established vendors for USG contracts.	Ongoing
2024	Export Control & International Coordination	**Revise ITAR, MTCR**	If industry is restricted from hiring foreign-born individuals, providing guidance on which countries to avoid is helpful, but alternative solutions must be available. Restricting access to top talent harms commercial viability and strengthens adversarial advantages.	Ongoing
2024	Investment & Finance	**Space Financing bill**	Consider creating Space Infrastructure Bonds, similar to those used for terrestrial critical infrastructures, and establishing a Space Commodities Exchange.	Not Begun
2023	Workforce & Infrastructure	**Designate the Space Sector as a Critical Infrastructure Sector**	The U.S. government has officially designated 16 critical infrastructure sectors, including communications, defense industrial base, information technology, and transportation, which directly impact the space sector. By adding space to this list, it will receive the same support and recognition as other critical sectors, aiding its development. Space can be designated as a critical infrastructure sector through a Presidential Policy Directive or Homeland Security Presidential Directive.	Not Begun
2023	Acquisition Reform & Market Access	**Allocate Larger Amounts of Capital to Fewer Companies**	The U.S. Government should allocate more capital to fewer space companies to create a strong demand signal and quickly scale up production of space products, with contracts awarded in line with government timeline commitments.	Ongoing
2023	Workforce & Infrastructure	**Examine and Expand the Professional Opportunities for Public and Private Sectors' Workforce Cross-Pollination**	The U.S. public and private sectors suffer from a lack of mutual understanding. The government is unaware of industry capabilities, while industry doesn't grasp government demand signals. To bridge this gap, government personnel in acquisition and program offices should be given opportunities to work in the private	Ongoing

			sector, such as in financial institutions, tech companies, and startups. Similarly, private sector personnel should be allowed to serve in government acquisition and program roles. These exchange opportunities should be expanded wherever possible.	
2022	Government Coordination & Planning	**Develop a Commercial Space Roadmap that Executes a National Space Investment Policy**	Establish a central office with a "policy planning" mandate to develop a commercial space roadmap. This roadmap would identify key technologies needing funding, the resources required to support future industries, and the government offices that must coordinate to allocate resources and enable these industries. The office should be located within the OSC at the DOC, elevated from NOAA, and directly report to the Secretary of Commerce. It should be provided with additional resources and a mandate to lead efforts across the government. (Owners: NSpC, DoC)	Not Begun
2022	Government Coordination & Planning	**Elevate the Office of Space Commerce**	Elevate the OSC beyond NOAA to a higher influence role, enabling it to develop a commercial space roadmap and implement a national space investment policy. This office could also serve as the central space licensing agency. (Owners: DOC, NSpC)	Ongoing
2022	Investment & Finance	**Optimize SBIC programs to target capital-intensive space technologies**	The SBIC program, once key in jumpstarting the semiconductor industry, has lost influence as private equity has shifted to software-based technologies. However, the SBIC could regain significance in encouraging private investment in "deep-tech" companies, especially in the space sector. (Owners: SBA, DoD/SBIR, OMB, DoC)	Not Begun
2022	Regulatory Reform & Improvement	**Increase Transparency and Communication in Regulatory Application Process**	Many companies find the U.S. regulatory system slow, cumbersome, and opaque. While some agencies use metrics and portals for tracking approvals, deviations from the standard process often make these tools ineffective, causing frustration and a lack of transparency. This can lead to delays, with simple questions or clarifications remaining unresolved for days. (Owners: DOC/BIS, DOD/DTSA, DOS/DDTC, DOT/FAA, FCC)	Ongoing
2022	Export Control & International Coordination	**Constantly review ITAR lists and Remove Technologies Available in the International Marketplace and Treat Space as a Priority Export Activity**	The list of restricted exports needs to be constantly reviewed and updated on a one-to-three-year cadence to ensure that the technology does require controls. If a company believes their technology is dual use, or commercially available, a two-page white paper should be adequate to force an expedient export review. (Owners: DOC/BIS, DOD/DTSA, DOS/DDTC)	Ongoing

2021	Workforce & Infrastructure	**Recognize space or key space capabilities as U.S. 'Critical Infrastructure'**	Designate space and key space capabilities as U.S. "Critical Infrastructure" and provide funding and incentives that reflect their significance to national security and prosperity. Key enablers include a Space Commodities Exchange and attractive financial incentives for space investment. (Owners: NSpC, NEC, OSTP, DHS)	Not Begun
2021	Investment & Finance	**Establish a U.S.-based Space Commodities Exchange**	The NSpC or its successor and National Economic Council (NEC) should direct the Secretary of Commerce and the Chair of the CFTC to identify the steps needed to establish a Space Commodities Exchange. This would provide a detailed view of pricing and market demand, supporting planning and valuations by the private sector. (Owners: NSpC, NEC, OTMP, DOC, SBA, CFTC)	Not Begun
2021	Investment & Finance	**Adopt a holistic readiness level framework**	Adopt a holistic readiness level framework, such as the System Readiness Level Metric, to integrate TRL, MRL, IRL, and business readiness into a commercialization metric that is clear and actionable for capital markets. (Owners: NIST, SEC, NA)	Not Begun
2021	Acquisition Reform & Market Access	**Adopt a scheduled National Security Space Launch strategy**	Adopt a scheduled National Security Space Launch (NSSL) strategy, replacing the current "charter" scheduling method, to more clearly define future requirements for vehicles, propellants, and other critical long-lead items. (Owners: OSTP, NSC, OMB)	Ongoing
2021	Investment & Finance	**Create a Chief Economist within the Department of Defense**	Establish a Chief Economist within the DOD to advise OMB and the Department of the Treasury on defense technology budgeting and financing. This expert would assess the economic benefits of defense technology and the potential economic impact of lost capabilities, providing recommendations on funding and financing instruments. (Owners: DOD)	Not Begun
2020	Government Coordination & Planning	**Stand up a National Space Enterprise Task Force**	The Executive Branch should establish a National Space Enterprise Task Force, with the potential to evolve into a permanent National Space Enterprise Center. The Task Force would develop a top-level "North Star" vision and strategy to maintain U.S. space superiority, integrating and coordinating actions across the entire government and utilizing all necessary national power instruments. The National Space Enterprise Center, modeled after the National Counterterrorism Center, would function as an interagency coordinating body, synthesizing diverse perspectives and swiftly addressing space-related issues across participating departments and agencies. (Owners: OSTP, NSC, NEC, OTMP)	Not Begun

2020	Export Controls & International Coordination	**Establish interagency export information sharing**	The U.S. should establish a unified export information system between DOC and DOC to enhance national security and global economic competitiveness. The NSC and NSpC should direct all federal departments and agencies to expand domestic information-sharing and streamline the export control review process, accelerating efforts to move technologies from the U.S. Munitions List (USML) to the Commerce Control List (CCL). (Owners: NSC, NSpC successor)	Partially Complet e
2020	Export Controls & International Coordination	**Formalize information sharing with Five Eyes partners**	Pursue a Five Eyes-like collaborative agreement with allies and partners to establish a common standard for information sharing on space supply chain providers and to support counterintelligence activities and training. (Owners: DOC, DOS, DoD, ODNI, NASA, FBI)	Partially Complet e
2020	Investment & Finance	**Establish new financial tools to increase transparency, liquidity, and investment capital in the new space commercial market**	Develop a range of short-term and long-term financial tools to support the rapidly evolving U.S. space industrial base. These tools should include investment capital for companies, patient capital such as bond offerings for large-scale infrastructure, and exchange mechanisms to stabilize future demand and supply. (Owners: Treasury, DOC, DFC, SBA)	Not Begun
2020	Investment & Finance	**Create a US-based Space Commodities Exchange**	NSpC's successor and NEC should instruct the Secretary of Commerce, the Chair of the CFTC, and other relevant experts to determine the necessary steps for the USG to establish a Space Commodities Exchange and report back to the NSpC with a recommended course of action. (Owners: NSpC's successor, NEC, OTMP, DOC, SBA, CFTC)	Not Begun
2020	Government Coordination & Planning	**Aggregate current and future US government market demand**	The OSTP should fund a FFRDC to conduct a federal inventory of current and future USG demand for space-related goods, services, and space-based commodities in the near, mid, and long-term. The USG should identify common purchases and establish a centralized process for procuring space-related products and services. (Owners: NSC, OSTP, OTMP, DoD, OMB, DOC, NASA)	Not Begun
Mid-Term Pay-off				
2024	Investment & Finance	**Financial markets**	Establish a Center for Space Finance, Insurance, and Market Formation to research funding mechanisms for space companies. The center would help companies align their readiness levels (technology, manufacturing, business model) with coherent funding strategies to overcome development risks. It would also innovate and match appropriate finance	Not Begun

			mechanisms to each project's phase, while promoting supply chain diversification and breaking up monopolies, such as in early-stage launch services.	
2023	Export Control & International Coordination	**Streamline and Align Export Regulatory Regime to International Market Conditions**	The current ITAR regime fails to keep up with the rapid availability of space products and services globally. To boost U.S. exports, strengthen supply chain resilience, and enhance international collaborations, the export regulatory framework must be aligned, streamlined, and adaptable to market conditions and technological progress. Stakeholders have expressed frustration that U.S. companies cannot export space products already available in international markets from allied nations. Updating export controls would enable U.S. companies to generate more revenue, compete globally, and improve products by gaining access to global talent and supply chains.	Ongoing
2023	Acquisition Reform & Market Access	**Accelerate the Pace and Alignment of Government Procurement and Acquisition**	As the anchor customer for space-related products, USG's acquisition timelines set the pace for the commercial sector, often leading to delays, especially for space platforms due to supply chain issues and dominance by defense contractor primes. To accelerate procurement, the DOD's acquisition system should address the root causes of these delays. Increased use of the OTA and better coordination between entities like DIU, SpaceWERX, USSF Commercial Services, USSPACECOM, NSIC, and OSC is essential to meet the demands of rapidly evolving technologies.	Ongoing
2023	Investment & Finance	**Implement a Coordinated National Investment Strategy**	The U.S. currently has an uncoordinated investment approach, relying on small grants across various agencies. While the OSTP plays a key role in providing strategic guidance for federal R&D funds, the investment system remains highly fragmented. Agencies like Treasury, OMB, Commerce, NSF, DOD, DOE, and NASA all contribute financially without coordination or a unified roadmap. To better support the domestic space economy, the U.S. Government needs to implement a coordinated national investment strategy that integrates grants, debt, equity, insurance markets, and commodities exchanges, minimizing duplication of efforts.	Not Begun
2022	Investment & Finance	**Inventory and Coordinate USG Investment Tools and Interventions**	Identify the various sources of non-dilutive capital, procurement, advance-market commitments, and debt instruments the USG can provide and align them to the taxonomy of challenges different elements of the space-industry encounter. Make	Not Begun

			concentrated interventions in these sectors, designed to solve the unique nature of the funding challenges. (Owners: SBA, DOD/NSIC, DOD/DPA Title III, DOD/SBIR/STTR, DOE, ExIm, DFC)	
2022	Investment & Finance	**Develop and Apply Economic Models and Financial Engineering to Incubate and Mature the Space Economy**	Conceptualize new economic models and future technologies that will require financial engineering and financial resources to incubate and mature. (Owners: OSTP, DOC, DoD/A&S, DoD/USSF, U.S. Ex-Im Bank, Treasury, SBA, NSF)	Not Begun
2022	Regulatory Reform & Improvement	**Establish Single Licensing Agency or Single Face to the Customer**	The U.S. regulatory process is exceedingly slow and opaque, stifling innovation domestically and between the US and international partners. In general, there is currently not a single point of approval or denial, and it is often difficult to achieve consensus between the necessary regulatory agencies (e.g., FAA, FCC, DOS, DOC). Any agency can delay or deny approvals. This process lacks transparency and takes a "red light" approach to approvals. Establishing a single licensing agency will enable a "single point of contact" for industry, concentrate government regulatory expertise, and accelerate the process and transparency. (Owners: DOC, FAA, FCC)	Not Begun
2022	Workforce & Infrastructure	**USG needs to identify space infrastructure as critical infrastructure**	Space infrastructure should be considered critical infrastructure per the USG. The USG should lead investment in space and technology infrastructure to drive the future economy and growth. Companies locate in areas where infrastructure exists, for example, semiconductor facilities. (Owners: DHS, NSC, NEC, DPC)	Not Begun
2022	Workforce & Infrastructure	**Space Stakeholders Must Engage and Shape Federal Resources Disbursed for Infrastructure and Technological Competitiveness**	Various departments and agencies across the USG will be charged with executing over $1 trillion in federal funding for infrastructure and the proposed $200+ billion in funding for critical and emerging technologies. Stakeholders across the space ecosystem have an opportunity to shape how these monies are spent and should make every effort to ensure that relevant space infrastructure is prioritized for federal funds and technical resources. (Owners: National Security, Civil, Commercial Space Stakeholders)	Complet ed
2022	Workforce & Infrastructure	**Supply Chain Development and Understanding**	Consistent with the Administration's focus on building more resilient supply chains in microelectronics, pharmaceuticals and advanced batteries, the space industry needs greater clarity on the health, strengths and vulnerabilities of critical components in its supply chain. The supply chain for satellites, launch infrastructure, advanced communications and other	Ongoing

			critical space-enabling technologies should also be considered critical as part of space infrastructure. It is critical that supply chains are understood, supported, and trusted between public and private partnerships. (Owners: DOC, DOD, DOE)	
2022	Export Controls & International Coordination	**Target International Engagement Around Specific Topic Areas: U.S. international engagement in space remains vague**	The U.S. should specify areas for collaboration, develop roadmaps and measure progress. For example, the U.S. could identify space traffic management or space situational awareness as specific topic areas, where each partner can focus technical, financial, and diplomatic resources to improve collective capability and interoperability. (Owners: OSTP, DoS, DOC/OSC, DoD/Office of Space Policy, USSF)	Ongoing
2021	Acquisition Reform	**Address structural barriers to new entrant competition**	Address structural barriers to new entrant competition by modifying contract selection criteria to enable small firms with limited financial resources to compete. Additionally, create a mechanism for firms without security clearances to address critical government challenges while safeguarding national security. (Owners: USSF, NASA, SBA)	Ongoing
2021	Supply Chain & Industrial Base	**Establish a Strategic Propellent Reserve**	Establish a Strategic Propellant Reserve, similar to the Strategic Petroleum Reserve (SPR), to provide an initial demand signal to industry and ensure the future availability of this essential and critical resource. (Owners: DOE, USSF, NASA)	Not Begun
2021	Investment & Finance	**Incorporate financial incentives for investors**	Incorporate financial incentives to encourage investors to provide “patient capital” for the space sector. This could include favorable tax treatment for long-term capital gains, such as expanding or extending Qualified Small Business (QSB) Stock Tax Benefits, as well as corporate tax deductions for space-related projects or capital expenditures. (Owners: Treasury)	Not Begun
Long-Term Pay-off				
2024	Government Coordination & Planning	**Funding Mechanisms**	The government should create funding mechanisms to support the growth and resilience of space technology, similar to other critical infrastructure industries, and diversify supply chains to strengthen the U.S. space economy. Strategies must be in place to address potential business failures among space companies, preserving talent, technology, and customers. Collaboration with private equity to establish "Space Company Reorganization" Funds could help protect human capital and intellectual property. National space policy should provide financial structures for space companies to mature, pivot, and succeed, both domestically and with	Not Begun

			international partners. Additionally, a coordinated, interagency space policy and regulatory approach is essential to support a unified "Moon to Mars" program and establish a "North Star Vision" for space.	
2023	Government Coordination & Planning	**Develop a Coordinated Space Policy and Regulatory Approach**	Stakeholders have suggested creating a coordinating body, such as a Department of Space or an interagency body like CFIUS, to manage civilian space policy and regulations. This approach could better regulate the space sector and support the space commercial economy, without the internal challenges faced by entities like DHS. A Department of Space could provide a comprehensive space strategy, similar to the DOE, or an interagency body could coordinate space regulations and policy, with one department leading, as Treasury does with CFIUS, while involving representatives from other agencies.	Not Begun
2022	Acquisition Reform & Market Access	**Simplify DFARs to Lower Barriers to Entry and Accelerate Acquisitions to Speed of Relevance**	The DFARS to the FAR was written in the 20th century and has become more complex, burdensome over time. The DFARS requires a review to determine the intent of the requirement, what risk does removing the regulation pose, and is the requirement applicable. Ideally, this review would reduce and simplify the DFARS significantly, making it easier for commercial companies to do business with the USG/DOD. (Owners: Congress, DOD)	Ongoing
2022	Investment & Finance	**USG should designate space as an economic opportunity zone to encourage growth and investment**	The U.S. can designate Space as an economic opportunity zone in order to improve the economic prospects for critical space-technologies or infrastructure. Historically, U.S. economic zones offered a range of benefits, including favorable tax treatment for investors and companies, improved trade opportunities, or the ability to leverage federal infrastructure. In order to advance U.S. space competitiveness, policy makers need to consider such a designation in order to incent stakeholders across the space community to actively invest in space. (Owners: Treasury, OMB, DOC, Congress)	Not Begun
2022	Government Coordination & Planning	**Follow the airport model for space infrastructure**	Similar to how the federal government defers the planning and permitting of airports to the local level, the USG should work with state and local officials to ensure that states/regions determine the best use of funds, with light-touch direction from the federal government. The local regions are responsible for future planning and growth and are therefore the appropriate agency to plan space infrastructure. (Owners: DOT, DOC, State and Local Governments)	Ongoing

2021	Workforce & Infrastructure	**Establish a STEM ROTC**	Establish a “STEM ROTC” or similar scholarship program for undergraduate students in technical majors, with a commitment to placement in relevant positions after graduation. This initiative will highlight the importance of technical disciplines to the future economy and bridge the cultural gap between government, industry, and academia. (Owners: DOD, DOEd, DOE, NSF)	Not Begun

Taken together with the 2025 sections of this report, these recommendations highlight the continuity and evolution of priorities across policy, finance, technology, and workforce in the U.S. space industrial base.

Earthset: The Artemis II crew captured this view of Earth setting on April 6, 2026, as they flew around the moon. ***[Credit: NASA]***

EPILOGUE

As we finalize the drafting of this year's report, the United States has, once again, accomplished an inspiring and incredible milestone for humankind. The Artemis II crew has visited deeper space than humans prior, flying 252,756 miles from Earth. Looking back over epilogues from reports in years past, we have marked the return of human spaceflight to U.S. soil, Voyager I leaving the solar system, and images from the James Webb Space Telescope. But this new accomplishment is made more notable today because it is a triumph of a long-term exploration goal realized during a time when commitment to projects requiring more than an election cycle is a challenge. This issue, timeline to execution for some projects in times of disruption, is addressed within this year's report.

Marking the accomplishment here in the epilogue, and entering it into the annals of reports past, illustrates one of the more profound values of this report. This is our record. The report represents a snapshot in time but one that builds upon reports from years past. And, more importantly, the report is the result of collaboration. It is crafted from inputs from multiple working groups populated by stakeholders representing all aspects of our space community.

The release of this year's report was delayed by the government shutdown in the fall of 2025. The shutdown postponed one of our workshops necessary to this report. Funding and resource impacts are noted throughout this year's report. In our case, we used the additional time to look back over the reports from 2019 to the present and to evaluate and contextualize. We saw the evolution of topics over time. We discovered the need to do a better job of cross referencing for our readers. We made some decisions.

We will make some changes for the 2026 report. We will bring back the International Partnerships chapter, rather than simply threading it through the other chapters, and we will continue to cross-reference. The Outernet chapter will be expanded to include all forms of communication and connectivity and renamed Space Communications and Sensingm Architecture which will include the Outernet as defined in this report.

This year we also provided a table of recommended actions from 2020-2024 (the year of our last report). We will continue to provide an updated table going forward. That exercise revealed the fact that we have identified supply chain issues since 2020. We realized that we need data points to better quantify supply chain impacts to our space industrial base. The team is crafting an instrument and process to capture this information and present it to you, our community, in an actionable format.

We are committed to our stakeholders and will continue to work to bring you a report that builds upon our past reports, notes our present-day accomplishments, and looks to the future as we move forward together in our rapidly changing and increasingly dynamic world.

APPENDIX A: PROGRAM AND INITIATIVE TABLE (CROSS-CUTTING, CHAPTERS 1–7)

Program / Initiative	Chapter(s)	Lead / Key Actors	Purpose / Scope	Relevance Across the Report
Commercial Launch Workshop	Intro, Ch. 1, Ch. 3	Workshop organizers, government, industry, academia	Multi-stakeholder forum to assess U.S. commercial launch, space policy, finance, infrastructure, and workforce issues.	Provides the empirical and deliberative foundation for all chapters and recommendations.
Space Florida & State Spaceport Authorities	Ch. 2, Ch. 3, Ch. 4	State governments, spaceport operators, industry	Plan, finance, and operate state-level spaceports; structure PPPs and incentives.	Central to spaceport modernization (Ch. 3), Outernet infrastructure siting (Ch. 4), and regional workforce strategies (Ch. 6).
New Space Nexus (and similar regional accelerators)	Ch. 1, Ch. 2, Ch. 3, Ch. 5	State/Regional orgs, industry	Support regional space innovation ecosystems via incubation, matchmaking, and policy engagement.	Bridges national policy and local implementation for ISAM/servicing (Ch. 5) and workforce pipelines (Ch. 6).
Space Force of the Future	Ch. 2, Ch. 3	USSF, DoD, Congress	Modernize Space Force capabilities, installations, and acquisition practices.	Source of some range/spaceport funding (Ch. 3) and part of broader acquisition reforms (Ch. 2).
U.S. Space Force (ranges and operations)	All, esp. Ch. 2, Ch. 3, Ch. 5	USSF	Operate Eastern and Western Ranges, manage range safety, scheduling, and infrastructure.	Foundation for launch capacity (Ch. 3), enabling Outernet deployment (Ch. 4) and on-orbit servicing mission support (Ch. 5).
NASA Exploration & Technology Programs (e.g., Artemis, CLPS, Tipping Point)	Ch. 2, Ch. 4, Ch. 5	NASA, industry	Develop capabilities for lunar exploration, cislunar operations, and space infrastructure.	Anchor demand for Outernet infrastructure (Ch. 4) and SML/ISAM services (Ch. 5); key NEPA actor (Ch. 3).

Program / Initiative	Chapter(s)	Lead / Key Actors	Purpose / Scope	Relevance Across the Report
Lunar Fission Surface Power Project	Ch. 3, Ch. 4	NASA, industry	Design and demonstrate fission-based power systems for the lunar surface; encourage cost-sharing via external funding.	Signals coming wave of nuclear missions (Ch. 3), enabling persistent lunar Outernet nodes (Ch. 4).
Project Andor	Ch. 3	Space Florida, USSF, range operators	Cloud-based operations and transportation management system for spaceports.	Flagship digital modernization project for range coordination and deconfliction (Ch. 3), a reference model for orbital traffic management (Ch. 4) and logistics for ISAM missions (Ch. 5).
Office of Strategic Capital (DoD - OSC)	Ch. 2, Ch. 3, Ch. 5	DoD	Provide credit and financial tools to attract private capital into critical dual-use technologies and infrastructure.	Potentially supports spaceport/nuclear facilities (Ch. 3), Outernet backbone infrastructure (Ch. 4), and ISAM servicing platforms (Ch. 5).
DARPA & DIU Space Programs	Ch. 2, Ch. 4, Ch. 5	DARPA, DIU, DoD, industry	Prototype advanced space capabilities (e.g., servicing, logistics, resilient comms).	Shape the technology base for Outernet and ISAM (Ch. 4–5) and illustrate alternative acquisition pathways (Ch. 2).
FCC Licensing and Spectrum Management	Ch. 2, Ch. 4	FCC, space operators	License satellite communications and manage spectrum assignments.	Central to Outernet architectures and competition for spectrum, and part of the broader regulatory mosaic (Ch. 2).
FAA Office of Commercial Space Transportation (AST)	Ch. 2, Ch. 3, Ch. 4, Ch. 5	FAA AST	License commercial launches and reentries; oversee safety and some environmental requirements.	Cross-cutting regulator for launch cadence (Ch. 3), gateway to orbital infrastructure (Ch. 4) and on-orbit servicing missions (Ch. 5).
National Spaceport	Ch. 3	FAA, USSF, Commercial Spaceflight	Conceptual framework for coordinated coastal and inland spaceports.	Addresses resilience and capacity limits of existing ranges, with implications for

Program / Initiative	Chapter(s)	Lead / Key Actors	Purpose / Scope	Relevance Across the Report
Network Concepts		Federation, states		all downstream space economies.
Programmatic Environmental Reviews & Categorical Exclusions	Ch. 3	NASA, FAA, USSF, CEQ	NEPA tools that cover classes of actions and routine activities.	Critical for aligning permitting timelines with launch cadence (Ch. 3) and enabling rapid infrastructure deployment (Ch. 4–5).
Third-Party NEPA Contractors	Ch. 2, Ch. 3	Federal agencies, private environmental firms	Applicant-funded preparation of NEPA documents under agency direction.	Mechanism to augment agency capacity for spaceport, Outernet, and ISAM project reviews.
ISAM / SML Demonstration Programs	Ch. 5	NASA, USSF, DARPA, industry	Demonstrate on-orbit servicing, manufacturing, and logistics capabilities.	Anchor early-stage demand and de-risk business models for in-space servicing and depots.
Regional Workforce Initiatives & Apprenticeships	Ch. 1, Ch. 2, Ch. 6	States, community colleges, universities, industry	Build talent pipelines for technical and skilled-trade roles in the space economy.	Ensure adequate workforce for launch operations (Ch. 3), Outernet infrastructure (Ch. 4), ISAM services (Ch. 5), and long-term competitiveness (Ch. 6).
DRACO – Demonstration Rocket for Agile Cislunar Operations	Ch. 6	DARPA, industry (cancelled 2024–2025)	Demonstrate nuclear thermal propulsion for rapid cislunar transit and deep space missions.	Exemplifies budgetary instability and program cancellations that disrupt advanced technology development (Ch. 2, 6); would have enabled faster SML/ISAM missions (Ch. 5) and supported cislunar infrastructure (Ch. 4).
KRUSTY – Kilowatt Reactor Using Stirling Technology	Ch. 3, Ch. 6	NASA, DOE, LANL	Demonstrate compact fission power system (1–10 kW) for lunar surface and in-space applications using Stirling engine power conversion.	Technology base for lunar surface power and potential orbital depot power (Ch. 5); funding stagnation illustrates interagency coordination challenges (Ch. 2, 6); relevant to nuclear payload infrastructure planning (Ch. 3).

Program / Initiative	Chapter(s)	Lead / Key Actors	Purpose / Scope	Relevance Across the Report
ARACHNE	Ch. 6	DARPA (funding frozen)	Advanced nuclear electric propulsion research and development program.	Another example of disrupted nuclear technology development pipeline; illustrates fragmentation and budgetary instability (Ch. 2, 6).
Lunar Fission Surface Power Project	Ch. 3, Ch. 6	NASA, DOE, industry	Design and demonstrate fission-based power systems for sustained lunar surface operations; NASA emphasizes external cost-sharing and commercial participation.	Signals coming wave of nuclear missions requiring specialized ground infrastructure (Ch. 3); foundational for sustained cislunar operations (Ch. 6); creates workforce demand for nuclear engineering skills (Ch. 7).
R-GPS / Resilient GPS (formerly LEAP)	Ch. 4, Ch. 6	USSF, Astranis, Axient, L3Harris, Sierra Space	Develop design concepts for distributed, resilient GPS architecture to operate in contested environments.	Addresses PNT resilience for terrestrial and near-Earth operations (Ch. 4); precursor to cislunar PNT architecture development (Ch. 6).
Cislunar PNT Architecture Development	Ch. 4, Ch. 6	USSF, NASA, SDA, industry	Establish positioning, navigation, and timing infrastructure for cislunar domain to support increasing mission complexity and traffic.	Enables Outernet extension to cislunar space (Ch. 4); critical infrastructure for SML/ISAM operations beyond GEO (Ch. 5); requires advanced propulsion for economical deployment and station-keeping (Ch. 6).
Nuclear Electric Propulsion (NEP) Programs	Ch. 5, Ch. 6	NASA, AFRL, DOE, industry	Develop high-efficiency electric propulsion systems powered by space nuclear reactors for cislunar and deep space missions.	Enables efficient SML/ISAM transit and multi-mission servicing vehicles (Ch. 5); part of broader advanced propulsion portfolio (Ch. 6); requires nuclear payload processing infrastructure (Ch. 3) and specialized workforce (Ch. 7).
Nuclear Thermal Propulsion (NTP) Programs	Ch. 6	NASA, DARPA (post-DRACO), industry	Develop high-thrust propulsion using nuclear reactors to heat propellant, enabling faster transit to Moon, Mars, and beyond.	Complements NEP for different mission profiles (Ch. 6); faces regulatory and infrastructure challenges (Ch. 2, 3); commercial sector financial challenges have slowed maturation.
In-Situ Resource Utilization (ISRU) Demonstrations	Ch. 5, Ch. 6	NASA, AFRL, commercial partners	Demonstrate extraction, processing, and utilization of lunar or asteroid resources (water,	Foundational for sustainable cislunar logistics (Ch. 5, 6); reduces launch mass requirements; creates new

Program / Initiative	Chapter(s)	Lead / Key Actors	Purpose / Scope	Relevance Across the Report
			regolith, metals) for propellant, construction, or life support.	workforce skill demands (Ch. 7); regulatory frameworks unclear (Ch. 2).
Chang'e Lunar Program (China)	Ch. 6	CNSA, Chinese government	Series of lunar exploration missions including sample return (Chang'e-6) and planned sustained surface presence; joint lunar fission power development with Russia targeted ~2035.	Demonstrates sustained Chinese progress in cislunar domain; competitive benchmark for U.S. advanced technology development (Ch. 6); influences strategic urgency across policy (Ch. 2) and technology domains.
Chinese DRO Communications Constellation	Ch. 4, Ch. 6	CNSA, Chinese commercial entities	Distant retrograde orbit communications relay constellation recovered and deployed after initial LEO challenges.	Demonstrates Chinese operational resilience and technical maturity in complex space architectures (Ch. 4, 6); part of broader cislunar infrastructure strategy.
New Mexico's Pathway to the Stars	Ch. 7	New Mexico stakeholders	Grow the space talent pipeline through programming, mentoring, experiential learning and career connection services spanning K-12 to early career.	

APPENDIX B. LEGISLATIVE AND POLICY INSTRUMENTS TABLE (CROSS-CUTTING)

Instrument	Type	Chapter(s)	Core Content / Function	Relevance Across the Report
Executive Order 14335 “Enabling Competition in the Commercial Space Industry”	Policy	Executive Summary, Ch. 1, Ch. 2, Ch. 3, Ch. 5	Streamlines commercial space licensing, launch, and spaceport regulation.	Central to launch licensing, spaceport infrastructure, nuclear payloads, and ISAM infrastructure approvals.
Executive Order 14369 “Ensuring American Space Superiority”	Policy	Executive Summary, Ch. 1, Ch. 2, Ch. 3, Ch. 4, Ch. 5, Ch. 6, Ch. 7	Sets integrated civil, commercial, and national security space strategy.	Central to launch licensing, spaceport infrastructure, nuclear payloads, and Outernet/ISAM infrastructure approvals.
Executive Order 14265 “Modernizing Defense Acquisitions and Spurring Innovation in the Defense Industrial Base”	Policy	Ch. 2, Ch. 7	Overhauls defense procurement to favor faster, commercial-first acquisitions.	Central to alignment of timelines between government and industry.
National Environmental Policy Act (NEPA)	Statute	Ch. 2, Ch. 3	Requires federal agencies to assess environmental impacts and consider alternatives.	Central to launch licensing, spaceport infrastructure, nuclear payloads, and Outernet/ISAM infrastructure approvals.
CEQ NEPA Regulations & Guidance	Regulation / Policy	Ch. 2, Ch. 3	Provide framework for NEPA implementation; recent changes shifted responsibility to agencies.	Their evolution drives process fragmentation and reform efforts discussed in Ch. 3.

Instrument	Type	Chapter(s)	Core Content / Function	Relevance Across the Report
Endangered Species Act (ESA)	Statute	Ch. 2, Ch. 3	Protects listed species and critical habitat.	A key overlay on launch and infrastructure activities at coastal ranges and future inland sites.
Department of Transportation Act §4(f)	Statute	Ch. 3	Protects parks, refuges, and historic sites from transportation project impacts without stringent justification.	A recurring bottleneck around launch and landing infrastructure near protected lands.
National Historic Preservation Act (NHPA), esp. §106	Statute	Ch. 2, Ch. 3	Requires consideration of effects on historic properties and consultation with stakeholders.	Particularly relevant at historic launch complexes and spaceports.
FAST-41 (Federal Permitting Improvement for "Covered Projects")	Statute	Ch. 2, Ch. 3	Establishes coordinated schedules and dashboards for major infrastructure project reviews.	Proposed as a model and vehicle for spaceport/Outernet infrastructure permitting.
Federal Permitting Improvement Steering Council (FPISC)	Interagency body	Ch. 2, Ch. 3	Oversees FAST-41 implementation and maintains the permitting dashboard.	Potential home for space-related infrastructure projects if designated as "covered."
One Federal Decision (OFD)	Policy framework	Ch. 2, Ch. 3	Coordinates multi-agency NEPA reviews and decisions on a defined timeline.	Offers a template for multi-agency launch, reentry, and spaceport permitting.

Instrument	Type	Chapter(s)	Core Content / Function	Relevance Across the Report
NEPA–CWA §404 Merger Concepts	Policy practice	Ch. 3	Integrate NEPA review with Clean Water Act §404 permitting.	Illustrates how space-related NEPA processes could be better integrated with other permitting regimes.
SPEED Act (as referenced)	Proposed statute	Ch. 2, Ch. 3	Aims to streamline environmental reviews for space activities.	Part of the legislative trajectory that will decide whether NEPA processes become more predictable for launch and Outernet projects.
H.R. 4776 (as referenced)	Proposed statute	Ch. 2, Ch. 3	Another legislative effort to update or expedite environmental review for space.	Indicator of congressional interest in space permitting reform.
Commercial Space Launch Act (as amended)	Statute	Ch. 2, Ch. 3, Ch. 4, Ch. 5	Governs commercial launch and reentry licensing.	Core legal authority for FAA AST oversight of launch/ISAM missions and some environmental requirements.
National Space Policy / National Space Strategy	Policy	Intro, Ch. 2	High-level guidance on U.S. civil, commercial, and national security space goals.	Provides the strategic frame adopted in Ch. 2 and underpins later chapters on Outernet, ISAM, and workforce.
National Cislunar Strategy / Space Priorities Framework (where referenced)	Policy	Ch. 2, Ch. 4	Articulate U.S. objectives in cislunar space and long-term exploration.	Justifies early investment in Outernet and SML/ISAM capabilities.

Instrument	Type	Chapter(s)	Core Content / Function	Relevance Across the Report
Build America-style Federal Infrastructure Programs	Statutes & programs	Ch. 2, Ch. 3	Provide loans, grants, and credit assistance for transportation and other infrastructure.	Potential vehicles if spaceports and space infrastructure are formally recognized as eligible.
State-Level Incentive and Bonding Authorities	State law	Ch. 2, Ch. 3, Ch. 6	Include tax incentives, industrial revenue bonds, and "at-risk" utility purchasing.	Enable states to co-finance launch infrastructure, industrial facilities, and workforce training.
Interstate Compacts	Constitutional/Statutory mechanism	Ch. 2, Ch. 3	Allow states, with Congress's consent, to jointly exercise powers.	Possible governance model for a multi-state spaceport authority or national spaceport coalition.
Workforce Innovation and Opportunity Act (WIOA) and Related Workforce Programs	Statutes & programs	Ch. 2, Ch. 6	Fund job training, apprenticeships, and workforce development.	Underpin recommendations on building sustainable pipelines for space technicians and skilled trades.

APPENDIX C. ACRONYM EXPANSION AND GLOSSARY (CHAPTERS 1–7)

Below are acronyms and key terms that figure prominently across the report, noting where a term is highly chapter specific.

AFRL – Air Force Research Laboratory

AI – Artificial Intelligence

Computer systems that perform tasks normally requiring human intelligence. In the report, AI is a future enhancement for operational tools (e.g., Project Andor) and for managing Outernet/ISAM data.

AST – Office of Commercial Space Transportation

The FAA office responsible for regulating commercial launch and reentry. Central to Chapters 2, 3, 4, and 5.

BEA – Bureau of Economic Analysis, Department of Commerce

BIS – Bureau of Industry and Security

CASR—Commercial Augmentation Space Reserve (Chapter 2)

CatEx – Categorical Exclusion

A class of actions an agency has determined normally has no significant environmental effect and thus does not require an EA or EIS. Key NEPA streamlining tool in Chapter 3.

CEQ – Council on Environmental Quality

Executive Office entity that oversees NEPA policy. Its regulations and revisions are central to the permitting context in Chapters 2 and 3.

Ch. – Chapter

Used in this annex to reference report chapters (Ch. 1–7).

CISA – Cybersecurity and Infrastructure Security Agency

CLD/CLDs—Commercial LEO Destinations

Commercial LEO Destinations (CLDs) are privately owned and operated space stations or platforms in low Earth orbit (typically ~400 km up) supported by NASA to replace the International Space Station (ISS) after 2030. (Exec Summary, Ch. 2, 5).

CLPS – Commercial Lunar Payload Services

NASA program buying lunar delivery services from commercial providers. Relevant to Outernet (Ch. 4) and ISAM (Ch. 5).

CRSRA – Commercial Remote Sensing Regulatory Affairs

CWA – Clean Water Act

Federal law regulating discharges into U.S. waters. §404 (wetlands permits) often overlaps with NEPA for infrastructure projects.

DARPA – Defense Advanced Research Projects Agency

DoD agency that funds high risk, high reward research, including space technologies and ISAM concepts (Ch. 5).

DHS – Department of Homeland Security

DIFI – Digital Intermediate Frequency Interoperability

DIU – Defense Innovation Unit

DoD organization that accelerates adoption of commercial technologies. Relevant to acquisition experiments in space (Ch. 2) and ISAM/Outernet prototypes (Ch. 4–5).

DoC – **Department of Commerce**

DoD – Department of Defense

Federal department responsible for national defense, including USSF. A central stakeholder throughout the report.

DoT – Department of Transportation

DOGE—Department of Government Efficiency (Ch. 2)

DRACO – Demonstration Rocket for Agile Operations

EA – Environmental Assessment

NEPA document prepared to determine whether an EIS is required; used for many spaceport and launch related projects.

EIS – Environmental Impact Statement
Comprehensive NEPA document for major federal actions significantly affecting the environment, including new spaceports or nuclear facilities (Ch. 3).
ESA – Endangered Species Act
Federal statute protecting listed species and habitats. A constraint on some coastal range development (Ch. 3).
FAA – Federal Aviation Administration
Civil aviation regulator; through AST, oversees commercial space transportation. Cross-cutting role in launch regulation (Ch. 2–3) and Outernet operations (Ch. 4).
FAST-41 – Fixing America's Surface Transportation Act, Title 41
Statutory framework for enhanced federal permitting coordination and dashboards for major projects. Proposed model for spaceport and Outernet infrastructure in Ch. 3.
FCC – Federal Communications Commission
FOCI – Foreign Ownership, Control or Influence
FPISC – Federal Permitting Improvement Steering Council
Body that manages FAST-41 implementation and the federal permitting dashboard.
GAO – General Accounting Office
GN_2 – Gaseous Nitrogen
Nitrogen gas used for purging and pressurization in launch operations; a commodities bottleneck in Ch. 3.
HR / H.R. – House of Representatives bill
Used (e.g., H.R. 4776) to refer to specific legislative proposals relevant to space permitting.
HVAC – Heating, Ventilation, and Air Conditioning
Building systems essential to spaceport facilities; the trades that maintain them face clearance and supply constraints (Ch. 3, Ch. 6).
IRIS² - Infrastructure for Resilience, Interconnectivity and Security by Satellite
ISAM – In-Space Servicing, Assembly, and Manufacturing
Suite of capabilities to refuel, repair, assemble, or manufacture structures in space. Core focus of Chapter 5.
LEO – Low Earth Orbit
LNG – Liquefied Natural Gas
Cryogenic fuel used in some launch systems; requires large-scale liquefaction/storage infrastructure (Ch. 3).
LOX – Liquid Oxygen
Cryogenic oxidizer widely used in rocket propulsion (Ch. 3).
MOA / MOU – Memorandum of Agreement / Understanding
Instruments used by agencies to clarify roles, responsibilities, and procedures, including for NEPA and launch/reentry coordination (Ch. 2–3).
NASA – National Aeronautics and Space Administration
U.S. civil space agency; prime driver of lunar, science, and technology missions. Featured throughout the report.
NEP – Nuclear Electric Propulsion
NEPA – National Environmental Policy Act
Cornerstone statute governing environmental review of federal actions. Central in Chapters 2 and 3, with implications across all infrastructure-related recommendations.
NHPA – National Historic Preservation Act
Law requiring agencies to consider impacts on historic properties, especially under §106 (Ch. 3).
NRO – National Reconnaissance Office
NTP – Nuclear Thermal Propulsion
NTIA – National Telecommunications and Information Administration
O&M – Operations and Maintenance
Budget accounts that fund recurring expenses, contrasted with MILCON (military construction). Relevant to how ranges are funded (Ch. 3).
OFD – One Federal Decision
Policy initiative to coordinate environmental reviews and decision-making across agencies. Referenced in Ch. 3.

OMB – Office of Management and Budget
Executive Office entity that coordinates the federal budget and reviews regulations; influences permitting timelines and agency resources (Ch. 2–3).
OPR – Office of Professional Responsibility
OSC (Commerce) – Office of Space Commerce
DOC office that coordinates space policy, advocates for industry in the Executive Branch, licenses private remote sensing activities, operates a civil space situational awareness system, and is building out a mission authorization and supervision framework (Ch. 2, 4, 7).
OSC (DoD) – Office of Strategic Capital
DoD office that uses financial tools to attract private capital into critical capabilities; a possible vehicle for spaceport and ISAM infrastructure financing (Ch. 2, 3, 5).
OSTP – Office of Science and Technology Policy
Outernet In this report, the integrated physical and digital infrastructure extending networking and data services through LEO, MEO, GEO, and cislunar space. Core focus of Chapter 4.
PER – Programmatic Environmental Review
Broad NEPA review (often an EIS or EA) covering a class of actions or an entire site, so that project-specific reviews can "tier" off of it (Ch. 3).
PLEO – Proliferated Low Earth Orbit (Exec Summary, Ch. 4)
Constellations of large numbers of small, relatively inexpensive satellites operating in low Earth orbit (typically 160–2,000 km).
PNT – Positioning, Navigation and Timing
PPP / P3 – Public-Private Partnership
Cooperative arrangement between public and private sectors for financing, building, and operating infrastructure. Cross-cutting funding mechanism in Ch. 2, 3, 4, 5.
RPOD - Rendezvous Proximity Operations and Docking
SBIR/STTR – Small Business Innovation Research/Small Business Technology Transfer
SATCOM – Satellite Communications
SDA—Space Domain Awareness
The identification, characterization, and understanding of any factor—including space objects, debris, and environmental phenomena—that affects space operations. It focuses on assessing the intent and capabilities of artificial objects, moving beyond simple tracking to ensure safe, secure, and sustainable space operations. (Ch. 2)
SDevA—Space Development Agency
The Space Development Agency (SDA) is a U.S. Department of Defense (DoD) organization established in 2019, now part of the Space Force, focused on rapidly developing and deploying the Proliferated Warfighter Space Architecture. (Ch. 4, 5)
SMR – Small Modular Reactor
Smaller, factory-built nuclear reactor; used as an analog for space nuclear systems and regulatory approaches (Ch. 3, Ch. 4).
SML –Space Mobility and Logistics
Variant framing around ISAM that emphasizes end-to-end supply chains and support services in space (Ch. 5). Initially, SAML was used to denote space access mobility and logistics but the "A" has since been dropped as this aspect is covered via "launch".
Space RCO – Space Rapid Capabilities Office
SPEED Act Short-hand for proposed space permitting legislation aimed at "Speeding" environmental decisions (Ch. 2, 3).
SSC – Space Systems Command
SSIB – State of the Space Industrial Base
STRATFI, TACFI—Strategic/Tactical Funding Increase (Ch. 2, 5)
SWAC—Space Warfighting Analysis Center (Ch. 4)

USG – United States Government
Collective term for federal entities, used across the report.
USSF – United States Space Force
Military service responsible for space operations, including ranges at Cape Canaveral and VSFB.
VSFB – Vandenberg Space Force Base Western Range launch site in California, critical for polar and sun-synchronous launches (Ch. 3).
WAVE - Waveform Architecture for Virtualized Ecosystems
WIOA – Workforce Innovation and Opportunity Act
Federal statute authorizing workforce and job-training programs relevant to space workforce development (Ch. 2, 6).

SSIB 2025 Participants at the NewSpace Nexus Launchpad enjoying the conference reception and Tech Demonstrations [Credit: NewSpace Nexus].

APPENDIX D. SSIB 2025 PARTICIPANTS

2025 SSIB Participants, Albuquerque, New Mexico

Name (Last), Name (First), Company/Organization

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Phipps, Marja, Davidson
Piovesan, Jorge, IDEAS-TEK
Pullen, George, MilkyWay Economy
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Schwenke, Jim, BlueTek
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Smith, Eric, X-Bow Systems
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Verska, Steve, Connectivity Toolbox
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Welsch, Carol, CRC Consulting
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Wiatr, Patryk, Turion Space
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Williams, Dr. Andy, Air Force Research Lab (AFRL)
Williams, Dr. Stacie, US Spaceforce
Wingo, Dennis, Spacebilt
Winter, Laura, The DownLink
Wisnosky, Sydney, George Washington University
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Woodbury, Drew, Aerospace Corp.

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Bogdan-Jarvis, Staci, Astrion
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Walker, Robert, Lockheed Martin Spade
Wessel, Brook, Elliseaum International LLC
Zingler, Scott, Tecolote Research

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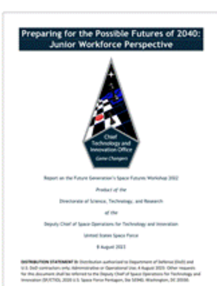

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Lee D. Steinke
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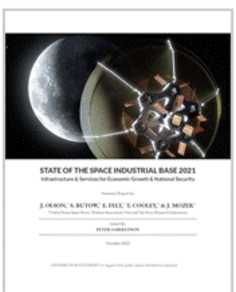

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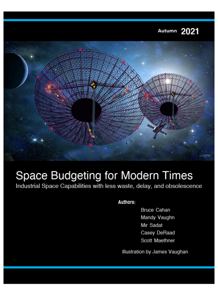

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