TEXAS A&M SEMICONDUCTOR INSTITUTE

CHIPS IN SPACE

Contents

Introduction

In June 2025, the TechConnect World Innovations Conference & Expo convened in Austin, Texas, followed by the International Space Industry and Government Summit & Expo in August in National Harbor, Maryland. These venues enabled direct engagement between dual-use technology providers and government/commercial space stakeholders focused on in-space manufacturing, national security applications, and routes to public- and private-sector funding.

The Texas A&M Semiconductor Institute (TSI) partnered with expo organizers to host *CHIPS in Space* sessions at each event. These sessions included panels and briefings to accelerate in-space semiconductor manufacturing and identify practical obstacles in this emerging ecosystem.

This report focuses on semiconductors – examining the constraints of traditional silicon, highlighting advanced semiconductor materials, and explaining how microgravity can unlock higher-quality crystals that translate into terrestrial performance gains for AI, quantum technologies, secure communications, and other advanced computing applications.

Background and Key Facts

Background

The U.S. is strategically behind in several segments of semiconductor materials manufacturing, including single-crystal substrates and wafers produced from polycrystalline silicon. Over 95% of the crystals used in semiconductor manufacturing are made from this polycrystalline material.[1] East Asia accounts for more than 80% of global silicon production, with China by far the leading supplier. U.S. crystalline capacity is minimal, creating dependencies that carry national-security risk.[2]

Key Facts

Limits of traditional silicon: Transistor scaling now faces physical barriers (quantum tunneling, leakage, heat density), escalating fabrication costs, and diminishing performance returns at advanced nodes. Consequently, the industry is complementing node scaling with new architectures and packaging, while also looking beyond polycrystalline silicon to advanced materials.

Material imperatives: Next-generation performance increasingly depends on materials such as gallium nitride (GaN), silicon carbide (SiC), III-V compounds, diamond, and 2D materials [graphene, molybdenum disulfide (MoS2)]. These enable higher mobility, wider bandgaps, superior thermal characteristics, and radiation hardness, but they are also far more sensitive to crystalline defects at advanced technology nodes (7nm, 5nm, 3nm, 2nm, and below).

Shifting compute paradigms: To sustain performance growth, the ecosystem is increasingly adopting heterogeneous and specialized accelerators and advanced system integration and packaging techniques — including 3D stacking and chiplet architectures — supported by parallel advances in software and algorithms.

Why Crystal Quality Matters (Defects and Device Outcomes)

Crystalline quality directly governs mobility, leakage current, device lifetime, radiation response, thermal transport, and manufacturing yield. Both atomic-scale and macroscopic defects degrade device performance and manufacturability.

- *Electrical performance:* Lattice defects reduce carrier mobility and increase leakage currents, destabilizing threshold voltages and shortening effective device lifetimes.
- *Device reliability:* Native and extrinsic defects including vacancies, interstitials, oxygen-related complexes, and seed-related stacking faults contribute to parameter drift, premature failure, and long-term instability.
- *Yield and scalability:* Process-induced microdefects, oxygen precipitation, and dislocation densities limit very-large-scale integration (VLSI) feasibility and die yield. Grown-in defects from Czochralski (CZ) crystal growth reduce electrical uniformity and wafer quality.
- *Thermal/high-power behavior:* Crystalline imperfection increase phonon scattering and reduce thermal conductivity, effects that are especially consequential for wide-bandgap (WBG) and ultra-wide-bandgap (UWBG) materials such as SiC and GaN.
- *Radiation hardness:* Pre-existing defects function as nucleation sites for radiation-induced damage, amplifying leakage, and parameter drift; precise control of intrinsic point defects is essential in space and defense applications.

Microgravity as an Enabler for Crystal Quality

Gravity induces buoyancy, sedimentation, hydrostatic pressure, and thermal convection. Each is a driver of defects during crystal growth. Low Earth Orbit (LEO) suppresses these mechanisms, enabling detached growth and diffusion-dominated heat/mass transport, which lowers defect densities and improves compositional uniformity.

- *Buoyancy (flotation/sedimentation):* In LEO, the absence of buoyant forces reduces bubble migration and entrapment, mitigating dislocation clustering and micropipe formation.
- *Hydrostatic pressure and container interactions:* Microgravity favors surface-tension-driven, detached growth, minimizing mechanical stress and container-induced lattice mismatch.
- *Thermal convection:* With convection suppressed, diffusion dominates, stabilizing the growth interface and reducing point-defect formation.

A meta-analysis of 160 semiconductor crystal experiments conducted in microgravity reported that 86% showed gains in size, structural quality, uniformity, or performance compared with Earth-grown crystals.[3] NASA has explicitly identified AI chip manufacturing as a terrestrial beneficiary of improved space-grown materials.[4]

Mechanism to impact: Microgravity → better crystals → better chips → higher-performance AI/quantum/secure-comms systems.

Applications and Use Cases

Artificial Intelligence (AI)

AI accelerators demand ultra-low leakage, high thermal conductivity, high-current, high-frequency devices, and advanced integration (e.g., 3D stacking). Defects in substrates and epitaxial layers raise leakage, limit switching speed, and constrain heat removal — all of which are direct bottlenecks for AI compute density and efficiency. Space-grown materials can materially reduce these constraints by improving crystal uniformity, purity and defect control.

- *2D materials:* Ultra-dense logic and low-power accelerators mean fewer defects and more uniform monolayers to preserve carrier mobility and suppress leakage.
- *III–V semiconductors:* High-speed logic and photonics mean improved composition and interfacial uniformity for low-loss interconnects and stable laser performance.
- *SiC:* Robust high-voltage power delivery for AI racks requires tight parametric distributions and minimal defect-driven variability.
- *GaN:* Efficient high-frequency power conversion demands low dislocation densities to enable higher yields, reliability, and operating margins.
- *Diamond:* Extreme heat spreading and radiation hardness require uniform chemical vapor deposition (CVD) layers with minimal microcracks and impurity incorporation.

Quantum Technologies

Quantum computing, sensing, networks, materials research, and simulation rely on exquisitely controlled materials systems to achieve long coherence times, low error rates, and scalable architectures capable of supporting fault tolerant operation. Across solid state, photonic, and hybrid quantum modalities, performance is fundamentally constrained by crystalline defects, interface disorder, charge noise, strain, and thermal dissipation.

Microgravity manufacturing improves crystal uniformity, reduces defect formation, and stabilizes compositional and strain profiles, enabling materials with the purity and structural coherence required for next generation quantum processors. These improvements position space manufactured materials as enabling substrates for scalable, high fidelity quantum compute platforms operating across terrestrial and space-based environments.

- *2D Materials*: Spin and valley qubits, superconducting hybrid structures, and quantum interconnects benefit from atomically uniform layers with minimal charge traps and substrate induced disorder. Microgravity growth improves thickness uniformity and reduces grain boundaries and impurities, suppressing charge noise and extending qubit coherence times.
- *III–V Semiconductors (GaAs, InAs, InP):* Quantum dot and spin qubit platforms depend on precise alloy composition, low background doping, and defect controlled heterostructures. LEO growth reduces buoyancy driven segregation and phase separation, improving interface quality, spectral uniformity, and qubit reproducibility across large arrays.
- *SiC:* Solid state defect qubits (e.g., divacancies) and integrated quantum classical control electronics leverage SiC's wide bandgap and radiation hardness. Space grown SiC

exhibits reduced dislocation densities and improved defect uniformity, enabling tighter control of color center properties, longer coherence times, and higher device yield.
- *Diamond:* Diamond is a leading platform for quantum sensing, networking, and computation based on nitrogen vacancy and other color centers. Microgravity enabled growth reduces microcracks, strain gradients, and parasitic defect populations, stabilizing color center formation and enabling more uniform, scalable qubit arrays with improved thermal management.

Secure Communications
Secure communications across government, industry, and academia depend on resilient, encrypted, zero-trust architectures. Next-generation optical and quantum links require materials with exceptional purity, low defect density, high optical coherence, radiation tolerance, and stable electronic and photonic behavior. Space manufacturing enhances these properties across 2D, III–V, SiC/GaN, and diamond, positioning these materials as foundational for ultra-secure terrestrial and space-based networks.

- *2D Materials:* Deterministic single-photon sources and tunable quantum emitters; microgravity improves layer uniformity and emitter coherence, reducing quantum bit-error rates.
- *III–Semiconductors (GaAs, InP, etc.):* Quantum-dot emitters, entangled-photon sources, and high-speed lasers; LEO growth reduces alloy inhomogeneity and phase separation, improving coherence and entanglement visibility.
- *SiC/GaN:* High-efficiency, radiation-tolerant power and RF for space payloads; space-grown wafers show lower dislocation densities, higher breakdown-voltage uniformity, and lower noise for detectors and transceivers.
- *Diamond:* Thermally conductive, radiation-hard substrates for room-temperature qubits and single-photon sources; LEO growth lowers microcrack density and stabilizes color-center performance.

Bottom Line
Microgravity is a proven accelerator for crystalline quality. Higher-quality crystals enable higher-performance chips, which in turn unlock transformational advances in AI, quantum technologies, and secure communications. This represents a strategic inflection point with national security implications for the U.S.

Three Use Cases for National Security

The semiconductor industry has become inextricably linked to national defense and security infrastructure, including critical energy resources, making it a critical component of America's strategic capabilities. Semiconductors have provided significant societal benefits and play an essential role in U.S. defense applications, cybersecurity, and supply chain security, each a pillar of broader U.S. national security strategies.

1. Artificial Intelligence
AI is fundamentally reshaping how the semiconductor industry addresses challenges across defense, cybersecurity, and supply chain security. Semiconductors and AI drive each other in a

reinforcing cycle — advanced semiconductors provide massive computing power and the high memory bandwidth required to operate today's large AI models, while AI increasingly accelerates every stage of semiconductor design and manufacturing. These applications include data-driven process control, defect prediction, process optimization, and in-space semiconductor manufacturing workflows.

To maintain global leadership, the U.S. must continue to lead AI development and deploy these capabilities across next-generation semiconductors, advanced manufacturing, critical infrastructure, and modernized defense systems.

- **Defense Applications**

AI has become a central enabler of modern military systems, dramatically increasing the importance of advanced semiconductors. AI-driven capabilities —such as autonomous systems, real-time intelligence analysis, advanced radar processing, and missile-defense decision support—depend on high-performance chips capable of processing vast volumes of data with minimal latency and power consumption.

DRONES AND SEMICONDUCTORS

Drones have transformed the U.S. defense industry, with the military drone market gowning from $14.14 billion in 2023 to a projected $47.16 billion by 2032.[5] AI-enabled smart drones are capable of autonomous navigation, computer vision, sensor fusion, and real time decision making with minimal need for human interaction. These capabilities demand advanced low-power semiconductors that can operate within the size, weight, power, and cooling constraints of drone platforms.

Command-and-control systems, satellite communications, advanced warfare platforms, and autonomous weapons increasingly rely on advanced semiconductor chips with AI algorithms to detect threats, fuse sensor data, and support rapid decision-making. As warfare becomes more data-centric and algorithm-driven, access to state-of-the-art AI-optimized semiconductors has become as strategically significant as traditional military assets, directly shaping force readiness, deterrence, and battlefield advantage.

- **Cybersecurity**

AI plays a dual role in cybersecurity, strengthening defenses while simultaneously increasing the sophistication of potential threats. Hardware-based security features embedded in modern chips, such as trusted platform modules (TPMs), secure enclaves, and cryptographic accelerators, provide foundational layers of trust for AI enabled systems across government, industry, and critical infrastructure.

However, the complexity of AI workloads and globally distributed semiconductor manufacturing processes introduce security risks. Semiconductors may be compromised at multiple stages of their lifecycle, including design, fabrication, packaging, or assembly. The threat of hardware backdoors or malicious circuitry has elevated semiconductor security to a national priority.

AI is increasingly employed on the defensive side to detect anomalous behavior, identify potential hardware trojans, and monitor system integrity at scale. At the same time, adversaries may also leverage AI to conceal malicious circuitry or exploit subtle hardware vulnerabilities, intensifying the strategic importance of secure semiconductor design and manufacturing.

- **Supply Chain Security**

The semiconductor supply chain is notoriously complex, spanning dozens of countries and hundreds of suppliers. Its global nature presents significant vulnerabilities that have direct national security implications. During the COVID-19 pandemic, semiconductor shortages demonstrated how supply chain disruptions can cascade through the economy, affecting everything from automotive production to medical devices.

These risks have made supply chain security and the expansion of domestic semiconductor manufacturing capacity top strategic priorities. Reducing dependence on unstable or adversarial foreign sources is essential to maintaining U.S. control over the chips that power its defense systems and critical infrastructure.

AI systems bring visibility and threat detection to this complex supply chain. One example of this is AI systems authenticating chips by analyzing physical unclonable functions (PUFs) to help prevent counterfeit components from infiltrating critical systems at various points in the supply chain. Predictive analytics powered by AI can also help companies anticipate supply chain disruptions and diversify their supplier base or stockpile critical components in advance, thereby building a resilient supply chain.

2. Quantum Technologies

Quantum technologies are emerging as a strategic capability with profound implications for U.S. national security, economic competitiveness, and technological leadership. Advances in quantum computing, sensing, timing, and networking promise capabilities that surpass classical limits, while simultaneously introducing new national security risks if leadership in these technologies is lost. As quantum systems transition from laboratory research to deployable platforms, semiconductors and advanced materials have become foundational enablers—making their performance, reliability, and supply chain integrity matters of national importance.

Quantum computing platforms offer transformational potential for defense and intelligence missions, including cryptanalysis, complex optimization, advanced materials discovery, and large-scale data analysis. At the same time, the emergence of large-scale quantum computers threatens existing cryptographic systems, creating strategic urgency around quantum awareness, mitigation, and control. Maintaining leadership in quantum hardware, error correction, and scalable architectures is therefore integral to sustaining U.S. technological and security advantages.

- **Defense and National Security Applications**

Quantum technologies support a growing range of defense and intelligence use cases. Quantum sensors enable ultra precise measurement of time, position, gravity, and electromagnetic fields, offering decisive advantages for navigation, detection, and situational awareness in contested or GPS denied environments. Quantum computing platforms have the potential to accelerate mission planning, logistics optimization, weapons development, and intelligence analysis.

These capabilities depend critically on defect-controlled semiconductor materials and stable device physics, where small variations in material quality can determine overall system feasibility.

- **Technology Maturity and Hardware Trust**

The performance of quantum systems is fundamentally limited by materials quality, interface disorder, and noise sources embedded at the crystal and device level. Qubit coherence, gate fidelity, and scalability are directly tied to impurity concentrations, defect densities, and strain uniformity in semiconductor and solid-state platforms.

As quantum devices move toward operational deployment, ensuring trusted hardware—free of malicious modification, counterfeit components, or uncontrolled variability—becomes a central national security concern. Hardware level vulnerabilities in quantum systems could compromise system integrity in ways that are difficult to detect or remediate through software controls alone.

- **Supply Chain Security and Strategic Leadership**

The supply chains supporting quantum technologies are highly specialized, globally distributed, and often reliant on a small number of advanced material and device producers. This concentration presents strategic vulnerabilities, including exposure to geopolitical disruption, technology leakage, and foreign dependency.

Strengthening domestic and allied capacity across the quantum technology stack—from advanced materials and semiconductor fabrication to system integration and validation—is essential to ensuring U.S. control over critical quantum capabilities. Long term leadership in quantum technologies will require coordinated investment in manufacturing, workforce development, and trusted supply chains that can transition quantum systems from experimental platforms to secure, deployable national security assets.

3. Secure Communications

Secure communications are a foundational element of U.S. national security, underpinning military command and control, intelligence sharing, critical infrastructure protection, and diplomatic operations. As threats to information integrity grow more sophisticated and globally distributed, secure communication systems must provide resilience against interception, disruption, and compromise across terrestrial, airborne, maritime, and space-based domains.

Semiconductors and advanced communication technologies lie at the core of these systems, making their performance, trustworthiness, and supply chain integrity matters of strategic importance.

Next generation secure communications increasingly depend on advanced optical, photonic, and quantum enabled technologies to meet escalating demands for bandwidth, low latency, and security assurance. These systems — including high speed optical links, encrypted satellite communications, and emerging quantum secure networks — place stringent requirements on material purity, device reliability, and long- term operational stability.

Ensuring U.S. leadership in the hardware foundations of secure communications is therefore essential to maintaining secure information superiority.

- **Defense and National Security Applications**

Modern defense operations rely on secure, high-capacity communications to support joint and coalition forces, autonomous systems, and real time intelligence dissemination. Satellite communications, tactical data links, radar networks, and distributed sensing platforms all depend on semiconductor enabled transmitters, receivers, and signal processing hardware capable of operating in contested and degraded environments.

As adversaries develop more sophisticated electronic warfare and cyber capabilities, secure communications hardware must deliver not only cryptographic strength but also resilience to jamming, interference, and physical degradation.

- **Cryptographic Integrity and Hardware Trust**

Secure communications are only as strong as the hardware that implements encryption, key management, and signal generation. Hardware based security features—such as cryptographic accelerators, trusted execution environments, and secure key storage—provide foundational protection that software alone cannot guarantee.

However, the increasing complexity and global distribution of semiconductor manufacturing introduces risks of hardware compromise, counterfeit components, or latent vulnerabilities inserted during design, fabrication, or assembly. For secure communications systems, such compromises could enable undetected interception, data exfiltration, or denial of service, elevating hardware trust to a national security priority.

- **Resilience, Reliability, and Longevity**

National security communication systems are often required to operate continuously for decades, including in space and other harsh environments where maintenance and replacement are impractical. Device reliability, radiation tolerance, thermal management, and parametric stability over long lifetimes are therefore critical system attributes.

Variability or degradation at the materials and device level can directly undermine link integrity, encryption reliability, and network availability. Ensuring high quality, well characterized semiconductor technologies is essential to sustaining secure communications across extended operational timelines.

- **Supply Chain Security and Strategic Control**

The supply chains supporting secure communications hardware are complex and international, spanning advanced materials, semiconductor fabrication, photonic integration, and system level assembly. This global interdependence presents strategic vulnerabilities, including exposure to geopolitical shocks and reliance on non-trusted sources for critical components.

Strengthening domestic and allied manufacturing capacity for secure communications technologies is essential to maintaining U.S. control over the systems that protect military operations, government communications, and critical infrastructure. Long term national security depends on ensuring that secure communications hardware is not only advanced, but also trusted, resilient, and securely sourced.

U.S. Leadership

The U.S. semiconductor industry has been a cornerstone of the nation's technological leadership and global economic influence for decades.

Tech Innovation and Standard Setters

The U.S. has historically led the world in semiconductor innovation. During the twentieth century, Silicon Valley emerged as an epicenter for semiconductor manufacturing and developed a broader culture of risk-taking, entrepreneurship and rapid innovation that now permeates the technology and software industries.

American companies such as Apple, AMD, Amazon, NVIDIA, Broadcom, Qualcomm, IBM, META, Intel, and others continue to push the boundaries of chip design, integrating AI capabilities and supporting the development of advanced data center infrastructure. This concentration of ambition and expertise has enabled the U.S. to maintain its position as a global innovation leader in innovation and established the foundation for its enduring role in semiconductor development. That leadership extends across the full semiconductor ecosystem and into adjacent sectors such as software, cloud services, artificial intelligence, quantum computing, and secure communications.

U.S. companies and research institutions also play a leading role in shaping global technology standards and best practices. Through leadership in industry consortia, standards bodies, and cutting-edge academic research, the U.S. helps define the technical directions and governance frameworks that guide semiconductor and broader technology development worldwide.

Capitalizing on Emerging Technologies

Through the development of advanced processes that leverage the unique microgravity conditions in space, it is becoming increasingly clear that LEO can help address terrestrial manufacturing challenges driven by gravity-induced effects, such as uneven alloy composition and non-uniform crystal growth. Microgravity eliminates settling and buoyancy-driven convection, which improves compositional homogeneity and reduces inclusions, defects, and residual stresses. These effects enhance crystal quality overall and improve optical, thermal, and thermoelectric properties.

As a result, many crystallographers view space-grown seed crystals, particularly for novel and advanced materials – as a significant opportunity to unlock the full potential of emerging technologies such as artificial intelligence, quantum computing, and secure communications.

To sustain its competitive edge and global leadership position, the U.S., must aggressively leverage emerging technologies, including space-made materials, ahead of global competitors as part of a broader U.S. semiconductor strategy. These efforts include advancing emerging techniques such as float-zone crystal growth and vapor deposition techniques adapted for microgravity environment.

At the same time, AI is becoming a foundational capability across emerging technologies and national defense systems, reshaping how modern systems are designed, manufactured, and deployed. The computational power required to support next-generation AI and advanced technologies is immense and will demand new classes of materials that deliver higher performance and greater energy efficiency. To capitalize on these opportunities and sustain leadership in high-value industries, the U.S. must lead not only in AI development but also in shaping global technical standards and ethical frameworks.

Job Creation

The semiconductor and space industries have been powerful engines for high-quality employment and economic growth with far-reaching impact. The semiconductor industry directly employs thousands of highly skilled workers in the U.S., including chip designers, process engineers, manufacturing technicians, and quality control specialists.

Beyond direct employment, the industry creates a multiplier effect — each semiconductor job supports additional employment in supporting industries, including equipment manufacturing, materials supply, logistics, and business services. The industry also supports a vast ecosystem of design houses, testing facilities, and research laboratories led by highly paid technical professionals.

Economic Growth

Semiconductors form the foundation of some of the U.S.'s most successful export industries. American companies dominate the global markets for personal computers, smartphones, networking equipment, and data center infrastructure — industries built on semiconductor innovation. Companies like Apple, which design their own custom silicon, and cloud computing providers like Amazon and Google, which develop specialized chips for their data centers, all rely on semiconductor technology to maintain competitive advantages in global markets. IBM and NVIDIA similarly advance their competitiveness by developing specialized AI chips that will help unlock the next wave of AI-driven growth.

The export of semiconductor-enabled products and services contributes hundreds of billions of dollars to the U.S. economy annually and maintains a positive trade balance in technology sectors, even as manufacturing has shifted overseas. In addition, the intellectual property embedded in U.S. chip designs generate substantial ongoing licensing revenues enabling. reinvestment in research and development and creating a self-reinforcing cycle of innovation and economic growth.

STEM Education

By 2030, the U.S. semiconductor industry workforce is projected to grow substantially (Figure 1). Without strategic foresight to meet this increased demand, the U.S. risks falling short of the capacity growth, supply chain resiliency, and technology innovation required to maintain the U.S. global competitive edge.

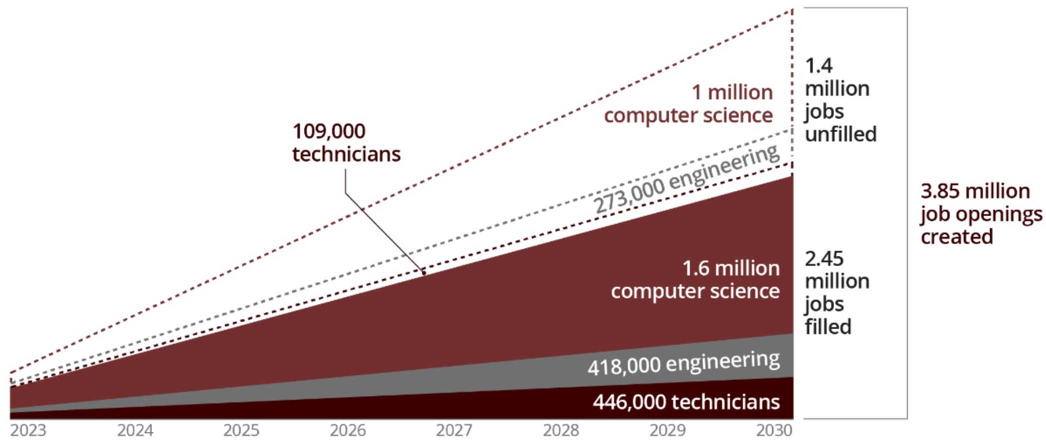


Figure 1. Projected U.S. demand for computer scientists, engineers, and technicians, 2023–2030

The need for highly trained technical workers in the semiconductor industry has historically helped drive the expansion of U.S. Science, Technology, Engineering, and Mathematics (STEM) programs. As the industry continues to grow and U.S. strategies prioritize domestic manufacturing and chip development, there must be a renewed focus on workforce development and on translating research into practice. Scaling existing educational programs to train technicians — particularly in regions experiencing workforce demand growth — is one way to bridge labor market gaps.

For engineers and computer scientists, whose postsecondary education programs typically take between four and 10 years, a broader effort to expand the STEM pipeline is necessary. This will require a comprehensive STEM strategy, starting with boosting student interest in STEM opportunities at the K–12 level. At the college level, students should be encouraged to pursue STEM careers and be made aware of job opportunities in the semiconductor industry. Industry, educational institutions, and government all play important roles in creating a long-term, comprehensive STEM strategy.

Demand for skilled engineers and technical workers in the semiconductor industry is global, with thousands of highly trained engineers leaving the U.S. each year. China has invested significantly in STEM education to develop a large pool of engineers to support semiconductor manufacturing.[6] Boosting the supply of U.S.-citizen engineers and computer science graduates is valuable for both economic and national security goals, as most master's- and PhD-level graduates are foreign nationals. In the short-to-medium term, it is crucial to retain graduates from U.S. institutions.

Six Key Themes from CHIPS in Space

1. Supply Chain Resilience and National Security

There is a need to establish an ecosystem that positions the U.S. as a leader in space semiconductor manufacturing, builds a robust, resilient supply chain, and reduces U.S. dependence on East Asia for semiconductor manufacturing. Countries such as China, Taiwan, South Korea, and Japan have a strong presence in the global semiconductor market. While the

U.S. has some semiconductor substrate and crystal manufacturing capabilities, many of these firms are not U.S. owned. Bringing semiconductor manufacturing back to the U.S. is a positive first step in reducing foreign dependence and providing national security advantages through critical infrastructure protection, economic security, job creation, and stronger cybersecurity and technology transfer safeguards.

Bringing semiconductor manufacturing back to the U.S. is a positive first step in reducing foreign dependence and providing national security advantages through critical infrastructure protection, economic security, job creation, and stronger cybersecurity and technology transfer safeguards. To maintain its competitive position on the global stage, the U.S. must also spearhead the expansion of in-space semiconductor manufacturing.
Several international groups are also beginning to establish strategic roadmaps for advanced materials in space. Multiple agencies within the European Union (EU), such as Horizon Europe and the European Space Agency (ESA), have been active in developing strategies and roadmaps for advanced materials and manufacturing technologies for space and terrestrial applications.

ESA Funded Space Applications

ESA funds research using Lunar regolith simulants and Lunar and Martian resources in advanced manufacturing and construction. ESA is also developing a 3D Biosystem to create cellular models for in-orbit research and to improve the current understanding of space-induced physiological changes.[8]

Rapid adoption of emerging technologies will strengthen the U.S.'s leadership position in the semiconductor manufacturing market in space and on Earth. Electronic design automation (EDA) and artificial intelligence (AI) are two tools that change how chips are transforming how chips are designed and validated. China's EDA industry has become a top priority in the country's broader semiconductor strategy. Although China continues to face restricted access to some EDA tools due to U.S. export controls, its share of the domestic EDA market has continued to grow.

One way the U.S. can maintain its leadership position is by increasing its participation in the in-space semiconductor manufacturing industry. Greater involvement from U.S. companies to participate in space manufacturing and in-space crystal growth is needed. Because this ecosystem is still relatively new, much of the supply chain has yet to be developed, and it lacks consistent, repeatable processes.

With broader industry participation the U.S. will be better positioned to influence supply chain standards such as planning, upmass, manufacturing, downmass, and storage. Partnerships between standard developers such as the National Institute of Standards and Technology (NIST) and commercial companies will be vital for setting efficient standards that function as catalysts for commercial volume production.

Having dependable, high-cadence upmass and downmass with sustainable recovery would help establish the U.S. as a strong leader in the in-space advanced materials manufacturing ecosystem. Many U.S. startups are working to improve upmass and downmass capabilities. Addressing

Upmass

The payload mass carried up to orbit from Earth.

Downmass

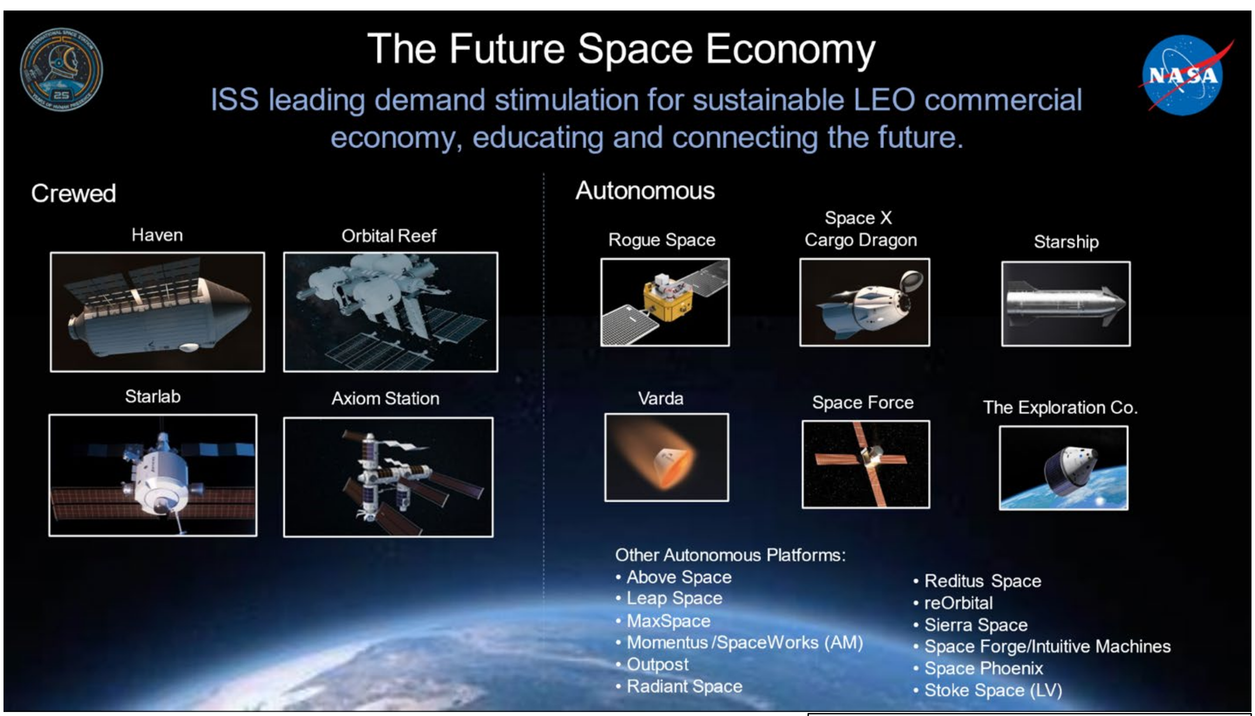
The payload mass carried down to Earth from low Earth orbit.

the current upmass and downmass challenges would solidify the U.S.'s position as a global industry leader and protect national security by giving the U.S. control over chips with low power and advanced computer processing for its defense systems and critical infrastructure. Space manufacturing represents not just a technological advancement but a strategic imperative to maintain U.S. leadership in critical semiconductor supply chains and to reduce reliance on potentially unstable or unsustainable foreign sources.

2. Access and Infrastructure Bottlenecks

Several critical access limitations and infrastructure bottlenecks are major barriers to advancing space-based semiconductor manufacturing. Many companies already participating in the in-space manufacturing market face challenges of limited access to space and have expressed a need for higher launch cadences. Some companies have expressed that they need missions every month, not every year, and have requested more funding to access space. There is also a critical need for dependable downmass capabilities and high cadence return services. Current infrastructure limitations, such as power, data, visualization, automation, edge computing, and robotics constraints, must be addressed to maximize the opportunity.

The urgency to resolve these bottlenecks is heightened by the approaching decommissioning of the International Space Station (ISS), expected in the early 2030s. Companies are operating on a compressed timelines and have emphasized the need to complete research and development (R&D) and the transition from research to production before that window closes. Some are exploring emerging solutions, such as commercial LEO platforms and more frequent short-duration missions (7–10 days). However, the current ecosystem contains significant limiting factors for the commercialization of space-based advanced materials manufacturing, including limited funding and infrastructure. Additional partnerships that create win-win situations across the industry will help address some of these bottlenecks.



Courtesy: NASA InSPA 2026

3. Public-Private Partnership Models

Fostering public-private partnerships and leveraging a variety of partnership models to advance space-based semiconductor manufacturing are critical priorities. Expanded collaboration enables commercial companies to move more quickly from laboratory research to market-ready applications, resulting in tangible end-use products and increased availability of data that can attract further private investment to advance the industry. The National Science Foundation (NSF) encourages researchers to collaborate with the private sector through its Translation to Practice funding program. Through the program, the partner organization can also be funded, creating a mutually beneficial arrangement.

NSF offers additional grants that may be leveraged to advance semiconductor manufacturing in space. For example, the Early-Concept Grants for Exploratory Research (EAGER) funding mechanism supports exploratory work at initial stages on untested but potentially transformative research ideas or approaches considered elevated - risk high - reward. A previous EAGER grant helped establish the In-Space Manufacturing Alliance (ISMA), which is part of the National Aeronautics and Space Administration's (NASA) broader strategy to establish U.S. leadership in the In-space Servicing, Assembly, and Manufacturing (ISAM) alliance. The grant has helped facilitate initial workshops and meetings to establish alliance objectives, roles, and collaborative frameworks. Seed funding supports projects exploring various aspects of semiconductor manufacturing in space and enables targeted partnerships among alliance members, facilitating knowledge exchange and resource sharing.

Incubation programs can serve as community connectors and help startups develop innovative technologies. This area holds significant potential to drive growth and innovation through academia or state-by-state initiatives. Higher education entities like the Texas A&M University System are positioning themselves as conveners and facilitators of these types of partnerships.

Accelerator programs can help connect startups, experts, and corporations to grow the in-space semiconductor manufacturing industry. Companies that pass through an accelerator outperform comparable firms, with accelerator companies raising 47 to 171 percent more investment funding in the two to three years following their participation.[7]

There is a strong culture of collective engagement and collaboration culture within the in-space semiconductor manufacturing community. Partnerships and expanded collaboration among all relevant participants are necessary not only to provide additional resources and funding opportunities but also to help mitigate infrastructure constraints, offer legal advice, and address limited access to crucial resources while operating within compressed development timelines.

Examples of public-private partnerships include the CHIPS Metrology Program and the CHIPS National Advanced Packaging Manufacturing Program (NAPMP). The Metrology Program emphasizes accurate measurements that are fit for purpose and prioritizes R&D in modeling and simulation of semiconductor manufacturing processes, materials, designs, and components, as well as strategic opportunities for U.S. semiconductor manufacturing.[8] The NAPMP strives to enable the development of an effective domestic advanced packaging ecosystem by driving the development of digital tools and establishing partnerships among industry, academia, training entities, and government to build an advanced packaging workforce.[9]

The government plays a key role in establishing and maintaining public-private partnerships. In 2024, the Department of Defense[10] awarded $49 million through its Industrial Base Analysis and Sustainment (IBAS) program to improve semiconductor packaging capabilities. The awarded contracts aim to revitalize advanced packaging capabilities and capacity for semiconductors used in defense applications. These awards were part of department's Re-shore Ecosystem for Secure Heterogeneous Advanced Packaged Electronics (RESHAPE) program efforts and directly support the National Defense Industrial Strategy's strategic priority of building resilient supply chains.[11]

4. Intellectual Property and Legal Framework Challenges

Intellectual property (IP) and legal framework challenges are significant barriers to in-space semiconductor manufacturing, as is the complex jurisdictional maze that arises when determining patent rights in space. The current system creates uncertainty through flags of convenience and forum shopping, where companies can potentially choose favorable jurisdictions based on which entity conducts or funds the launch.

Current governance treaties may serve as blueprints but do not provide concrete guidance on IP ownership or the potential jurisdictional challenges that may arise as the space manufacturing industry continues to expand. The Outer Space Treaty governs activities on celestial bodies. It prohibits national appropriation by claiming sovereignty, meaning that ownership and territorial claims are not permissible, and no nation can assert sovereignty in outer space. ISS governance, through the Intergovernmental Agreement and supporting memoranda of understanding, provides some framework for current operations, but commercial space stations raise new questions about IP enforcement, particularly when multiple countries or, in the U.S., multiple states, are involved.

Despite these challenges, IP ownership creates an opportunity for U.S. industry leadership. Some panelists suggested that the U.S. can take a leadership role in recognizing rights in physical ownership and serving as an example to our international partners and allies. The development of specialized arbitration systems and standardized legal frameworks was identified as crucial for reducing barriers to innovation, with participants emphasizing that clear legal standards would enable companies to better understand the legal landscape and thus innovate more freely. Having clear guidance on IP can help the industry grow and businesses generate revenue from their innovations, creations, and brands. This is especially important for small- and medium-sized companies. Finding innovative ways to monetize IP would allow small businesses to generate the revenue needed to secure additional investments.

Licensing

Licensing represents one of the most flexible and widely used methods for monetizing intellectual property, allowing IP owners to generate revenue while retaining ownership of their valuable assets.

Exclusive Licensing	Cross Licensing	Non-exclusive Licensing
Exclusive licensing grants a single licensee the sole right to use, produce, or sell a product or technology based on intellectual property.	Cross licensing occurs when two or more parties grant each other rights to use their respective intellectual property portfolios, creating a mutually beneficial exchange that can reduce costs and accelerate innovation.	Non-exclusive licensing allows IP owners to grant rights to multiple licensees simultaneously, maximizing market penetrations and revenue potential by serving multiple markets and applications.

Intellectual Property Backed Financing
Capital-building mechanisms, such as IP-backed financing, can be used to leverage intellectual property assets as collateral for loans. This allows companies to increase capital without selling equity or relinquishing IP ownership. Unlike equity financing, it does not dilute ownership, and unlike traditional bank loans, it leverages assets that might otherwise sit idle on balance sheets, generating no immediate return.

Intellectual Property Theft
Chinese entities have previously been accused of acquiring U.S. semiconductor technology through forced technology transfers, corporate espionage, and the use of shell companies, costing upwards of billions of dollars. Though the U.S. has prioritized stronger IP protection measures, enforcement remains a challenge due to foreign abilities to exploit regulatory loopholes, use third-country intermediaries, and leverage state-backed initiatives to circumvent restrictions.[12]

5. Market Validation and Investment Requirements

Market validation and investment challenges are critical and require a fundamental shift from proof-of-concept demonstrations to a quantitative value proposition with tangible products. Demonstrating the benefits of microgravity justifies the need to invest in space manufacturing and support market growth.

Due to its highly technical nature, investors outside the in-space manufacturing industry often lack familiarity, hindering investment and industry development. Educating investors and articulating the industry ecosystem, including remaining barriers and their implications, often fall on the industry itself. For example, outside the industry, the number of missions being conducted for space manufacturing is unknown. Knowledge sharing and education will be important to attract investment, especially from risk-tolerant investors, when end-use products may not be available.

An immediate short-term action is to better communicate the benefits of manufacturing in a microgravity environment, which the public or private sector could spearhead through collaborative partnerships. By articulating microgravity, it leads to improved physical,

LambdaVision Case Study

LambdaVision uses a layer-by-layer deposition to produce protein-based artificial retinas. This is done by successfully leveraging the unique characteristics of microgravity to improve manufacturing processes that were originally developed on Earth. It is a technique, most notably Atomic Layer Deposition (ALD), that creates thin films with atomic-scale precision. Consistently achieved full manufacturing cycles (200 layers) to create artificial retina thin films

Semiconductors have the same potential to tap into the benefits of microgravity to not only address manufacturing challenges that are unique to Earth, but also to create new products and use cases. https://www.lambdavision.com/

chemical, and biological responses, simplified processing, and higher-quality products, companies can attract private investment and grow the industry.
By moving production into space, companies can improve the homogeneity, stability, and performance of products.

Proving technical feasibility is dependable and sufficiently derisked is no longer the main barrier to market validation and investability; the issue is demonstrating the measurable value of the end product to attract investors and potential partners. For the semiconductor industry, articulating precise percentages of the improvement in crystal growth (size, uniformity, and structure) and how those improvements benefit wafer manufactures is essential.

Investors and partners are demanding analyses of the improvements and how they translate into tangible benefits, such as performance gains, power reductions, and cost efficiencies.

Potential customers and the investment community
Require this characterization data to quantify tangible benefits. This can then translate into marketplace value and additional potential use cases.

It is vital that companies can articulate the market landscape and potential opportunity to the investment community using clear, data-driven metrics.

Total Addressable Market (TAM)	Serviceable Available Market (SAM)	Serviceable Obtainable Market (SOM)
The maximum potential demand for a product across all possible customers globally.	A portion of the TAM that a product or service can realistically reach based on a company's business model, geographical region, or other constraints.	Also known as the Share of Market, this is the portion of the SAM that can be captured in the near- or medium-term. It is the most conservative estimate of the potential market size and helps businesses set realistic target revenues.

6. Workforce Development and Research Translation

Workforce development and research translation are fundamental pillars for establishing a sustainable space-based semiconductor manufacturing ecosystem. Continued investment in U.S. STEM programs and in public-private partnerships with academia is crucial to developing the next generation of semiconductor innovators. The Texas A&M University System targets both workforce development and research translation through an integrated strategy that trains students to transition into roles in government labs or corporate settings, while simultaneously building bridges from low Technical Readiness Levels (TRL) to commercialization.

Research translation can be a persistent bottleneck, especially for universities. There is a need for academia to move beyond conventional models that rely solely on faculty to develop IP and to secure commercial partnerships and investments. Effective translation will require innovative collaborative frameworks to accelerate the labs-to-markets pipeline. Universities need dedicated personnel to seek out partnerships, especially during periods of reduced funding and fewer federal grant opportunities.

Another crucial step is enabling universities to compete with research agencies and government agencies by developing accessible resources for students and faculty. This may be as simple as utilizing existing facilities and building new facilities, ensuring lab equipment is accessible, partnering with researchers, and leveraging entrepreneurial programs to launch startups or support business development.

Timeline constraints amplify the urgency of the workforce and translation challenge, as the space manufacturing sector will require trained professionals and reliable technologies ready for commercial deployment before the planned ISS decommissioning. There is an urgent need to invest in educational programs, workshops, and industry-academic partnerships to build the human capital required to support industry growth.

In-Space Semiconductor Manufacturing in the U.S.

Key areas of impact for the in-space semiconductor manufacturing industry are enhancing national security, positioning the U.S. as a global leader in in-space semiconductor manufacturing, and creating domestic jobs. Texas's public and private sectors are establishing the state as an industry leader and actively engaging in initiatives to accelerate these areas by building partnerships across the industry and providing grants that will lead to job creation.

Enhancing National Security

Semiconductors serve as the foundational technology enabling every modern military and defense system, making them critical to national security across multiple domains. However, many elements of the semiconductor ecosystem are concentrated and produced outside the U.S. For example, the U.S. has limited semiconductor substrate and crystal manufacturing capabilities, but many of these companies are not U.S. owned.

Foreign Competition

South Korea, Taiwan, and China are investing nearly $500 billion in all aspects of semiconductor manufacturing. China has been the most prolific country in the world doing crystal research for both biopharmaceutical and semiconductor applications using the Tiangong platform. These investments could propel them into a world-wide leadership position.

This endangers not only U.S. national security but also the U.S. and global economies. Additionally, many U.S. defense capabilities — including hypersonic weapons, drones, and satellites — are increasingly vulnerable to supply chain disruptions.[13]

Space-based semiconductor manufacturing is directly relevant to U.S. national security, making the need to identify, close or mitigate barriers to accelerating the space manufacturing industry of utmost importance. One of the most immediate concerns is supply chain security. Countries such as China, Taiwan, South Korea, and Japan have a strong presence in the global semiconductor manufacturing market.

Advanced semiconductors enable intelligence, surveillance, and reconnaissance (ISR) operations, autonomous systems, and next-generation weapons platforms. If a potential adversary surpasses the U.S. in semiconductors in the long term or abruptly cuts off the U.S. from advanced semiconductors entirely, it could gain the upper hand in military capabilities and threaten U.S. security. This would have serious implications for the safety and well-being of every U.S. citizen and resident.

Some of the specific materials targeted for In-space Manufacturing include gallium nitride integrated onto silicon substrates (GaN-on-Si), indium phosphide (InP), Silicon–Germanium (SiGe), Diamond, Silicon Carbide (SiC), Graphene, Molybdenum Disulfide (MoS2), and related compound and 2D materials. These materials support production of wide-bandgap (WBG), ultrawide-bandgap (UWBG), III–V, and 2D semiconductor devices. The demand for these materials is rapidly increasing due to their critical role in high-power and high-temperature electronics, radiation-hardened, high-frequency devices, quantum computing, photovoltaics, thermal imaging, electric vehicles (EV), radio frequency (RF), defense and aerospace sensors, advanced communications, and data infrastructure.

Global Leadership

As the in-space manufacturing industry continues to expand, the U.S. must establish itself as a leader and an aggressive competitor. At the same time, it is also crucial to reestablish U.S. leadership in semiconductor manufacturing more broadly. When semiconductors were first invented, the U.S. accounted for 100% of manufacturing capacity. Now, U.S. capacity is estimated at approximately 8%. Today, Taiwan Semiconductor Manufacturing Company (TSMC) is the largest and most advanced semiconductor manufacturer in the world, accounting for nearly 90% of the world's advanced semiconductor manufacturing.[14]

According to experts, America's position in the semiconductor industry remains intact; the equipment industry and the microarchitecture planning and system-level design used to make semiconductors are still strong. The issue lies in the end-use market. It is essential that the U.S. reshore some of the manufacturing and design of electronic products. This will build a more robust domestic market and provide additional insight into the future of chip design. Bringing semiconductor manufacturing back onto U.S. soil will provide insight into how to improve chip manufacturability, reliability, and performance. Furthermore, U.S.-based chip designers rely heavily on TSMC for supply. This reliance leaves the U.S. semiconductor industry at risk of disruption from geopolitical challenges, thereby significantly impacting products and markets that rely on semiconductor devices.

Understanding the manufacturing process on Earth will allow U.S. leaders and researchers to identify areas of that could be and improved to space and be improved by leveraging the unique characteristics of a microgravity environment, such as container interactions, thermal convection, flotation and sedimentation, and hydrostatic pressure.

Improving semiconductor manufacturability on Earth and in space will lead to innovative technologies and processes, and the development of proprietary intellectual property. This will help determine the course of future semiconductor design and help position the U.S. as a strong competitor. It is also important for the U.S. not to lose access to the end-use market, as establishing new partnerships will require additional resources.[15]

Innovation will be critical to the U.S.'s long-term semiconductor strategy. Maintaining leadership in semiconductor design and technological advancements is as important as reshoring manufacturing. To remain competitive in the global semiconductor race, the U.S. should increase investments in R&D for emerging technologies such as quantum computing and AI. Public-private partnerships will be crucial for driving innovation. Further, the federal government should continue to fund research to help derisk emerging technologies, thereby driving game-changing innovation and creating incentives for private companies to invest in semiconductor technologies.

Establishing a strong position will also depend on tax structure, antitrust laws, and long-term strategizing. Laws and policies can be leveraged to accelerate the U.S.'s position as a semiconductor manufacturing leader, or they can create bottlenecks and hinder future leadership opportunities. The federal government and Congress can play a role in enacting policies that support intellectual property protection, and collaboration between industry, academia, and government will help the U.S. maintain its technological edge in semiconductor manufacturing.[16] To remain competitive, the U.S. must advance and commercialize semiconductor technology more quickly and efficiently than global competitors.

Multilateral partnerships will also need to be leveraged to position the U.S. as a global leader in chip manufacturing on Earth and in space. U.S. leaders will need to pursue trade negotiations and other economic measures and initiatives to ensure that semiconductor production in America is cost-effective, boosts downstream demand, and increases the market base for US chips worldwide.[17]

Rebuilding the U.S. as a global leader in the semiconductor industry on Earth comes with a significant price tag. In 2022, the CHIPS Act committed $52 billion over five years to support investment, R&D, and additional capital in the semiconductor industry. TSMC itself spends nearly $40 billion on capital equipment and R&D annually.[18] TSMC has also committed a total of $165 billion to its Arizona operations. The U.S. will need to commit significant funds to help reestablish itself as a strong competitor in semiconductor manufacturing on Earth. Additional funds will be required to establish the U.S. as a leader within the semiconductor manufacturing sector in space.

The U.S. can position itself as a global leader in in-space manufacturing by encouraging more companies to manufacture semiconductors in space, leading the development of intellectual property rights and procedural processes, and developing policy and standards for in-space manufacturing. Reestablishing and reinforcing a domestic supply chain will be critical to make the U.S. a top competitor in the in-space manufacturing realm. This entails relying on U.S. upmass and downmass companies to create highly repeatable, sustainable cadence, and on investors to take risks on those companies.

Positioning Texas as a Leader in the U.S.

The state of Texas plays a crucial role in U.S. semiconductor manufacturing. It is the top state for semiconductor manufacturing, having led the nation in semiconductor exports for fourteen years.

When Congress passed the CHIPS and Science Act, the Texas A&M University System led proposals to leverage Texas' strengths to advance R&D and manufacturing. The Board of

Regents approved the establishment of the Texas A&M Semiconductor Institute in May 2023 to coordinate responses to state and federal CHIPS initiatives.

The Texas Semiconductor Innovation Fund (TSIF) is an incentive program designed to encourage Texas's continued leadership in semiconductor research, design, and manufacturing. In June 2023, Texas Governor Greg Abbott signed the Texas CHIPS Act (House Bill 5174), which established TSIF and the Texas Semiconductor Innovation Consortium (TSIC). The Texas Legislature appropriated $698.3 million to TSIF.[19]

The Texas Space Commission is also building partnerships to advance U.S. space-based semiconductor manufacturing. With the Commission's support, Space Forge (a British aerospace manufacturing company) and Intuitive Machines (a Houston-based space exploration company focused on commercial and government lunar exploration) have partnered to bring semiconductor manufacturing in space to the U.S. The integration of Space Forge's semiconductor reactor onto Intuitive Machines' Zephyr platform is designed to enable high-purity chip production in orbit — with reliable return to Earth. The partnership intends to strengthen domestic supply chains and propel U.S. leadership in advanced materials, in-space manufacturing, and return logistics.

The partnership reflects a growing trend of U.S.-U.K. collaborations in advanced manufacturing and space sustainability, aimed at unlocking the industrial potential of space. The collaborative effort is striving to deliver the U.S.'s first domestically integrated space-based semiconductor manufacturing solution.[20]

Job Creation in the U.S.

Space-based production offers transformative advantages for the semiconductor industry and job growth in the U.S., resource optimization, and the emergence of new markets.[21]

As of 2025, the U.S. semiconductor industry accounts for about 345,000 direct jobs and nearly two million additional indirect and induced U.S. jobs. Growth in the U.S. semiconductor industry can directly drive growth in other U.S. industries; one U.S. semiconductor job supports approximately 5.7 jobs in other sectors of the economy.[22]

Recently, government incentives and research investments have helped reignite a national commitment to strengthening U.S. leadership in semiconductor manufacturing. Government incentives and research investments have led to new U.S. semiconductor projects, which are expected to create and support more than 500,000 jobs and help triple U.S. chipmaking capacity by 2032. This includes 68,000 facility jobs in the semiconductor ecosystem, 122,000 construction jobs, and over 322,000 additional jobs supported throughout the U.S. economy. [23]

However, as the American semiconductor ecosystem expands, more qualified workers will be needed to fill jobs. According to the Semiconductor Industry Association (SIA), by 2030, the semiconductor industry will have a workforce gap of 67,000 workers.[24] Addressing this challenge will require government and industry to build the industry's longstanding workforce development efforts, expand the pipeline of STEM graduates in America, and retain and attract global talent.

Job Creation in Texas

Semiconductor manufacturing directly creates jobs in Texas. In March 2025, Governor Greg Abbott announced a TSIF grant to SpaceX for the expansion of its semiconductor R&D and advanced packaging facility in Bastrop, Texas. The $17.3 million grant is expected to create more than four hundred jobs and more than $280 million in capital investment.[25] This is a prime example of how state government spending can create win-win partnerships, drive state growth, and help de-risk the in-space semiconductor industry.

Commercially driven public-private partnerships such as Space Forge's collaboration with Intuitive Machines are also creating job opportunities in Texas and across the country. The partnership merges Space Forge's space semiconductor production technology with Intuitive Machines' reliable spacecraft return platform. It is helping the space industrial sector grow and create jobs with support from Texas's economic development programs.[26]

Next Steps

The Texas A&M Semiconductor Institute recognizes the urgent need to further explore opportunities for semiconductor manufacturing in space. To be clear, this does not mean creating a full semiconductor fabrication facility in space but rather identifying ways to collaborate with industry that operate autonomous and crewed platforms, offering opportunities to leverage emerging technologies such as float-zone crystal growth and vapor deposition techniques to advance microgravity crystal growth.

Moving forward, the institute will:

1. **Build and Amplify the Value Proposition of Manufacturing in a Microgravity Environment.**
    a. **Reduced Defect Density:** Growing crystals without buoyancy or convection currents can minimize dislocations, stacking faults, and other structural defects, leading to higher-quality materials.
    b. **Improved Purity:** Without sedimentation, it is possible to achieve more uniform doping and a higher degree of material purity.
    c. **Novel Materials:** Microgravity may enable the growth of new materials or crystal structures that are not possible on Earth.
2. **Expand upon Key Technical Pillars:**
    a. **Define a Metrology Roadmap:** Create a forward-looking roadmap outlining the specific measurement needs for in-space crystalline materials, from raw materials to finished products.
    b. **Develop In-situ Measurement Techniques:** Collaborate with researchers and industry to design and evaluate new in-situ and remote sensing measurement techniques that are compatible with the LEO environment.
    c. **Establish Standards and Best Practices:** Work with subject matter experts from the National Institute of Standards and Technology (NIST) and ISMA members to define new standards and protocols for characterizing the quality of in-space grown crystals, including metrics for defect density, purity, and structural integrity.

   d. **Establish Data and Hard Asset Repository:** Create a centralized, accessible hub for crystal growth data and hard assets to address the lack of analysis and samples from previous LEO experiments.
   e. **Prioritize Materials:** Work with NIST and industry to align advanced materials development with U.S. security and leadership needs.
   f. **Rank Infrastructure:** Categorize short-term to long-term needs for power, data, robotics, and thermal management.
   g. **Integrate AI Packaging:** Combine AI accelerators with sensors to enable autonomous data analysis.
   h. **Advance Predictive Modeling:** Develop physics-based, AI-driven models to predict growth and defects in microgravity.
   i. **Optimize Semiconductors:** Develop radiation-hardened, low-power architectures designed for foundational AI models.
3. **Expand upon Key Collaboration Pillars:**
   a. Leverage Established Partnerships: Build on their successful record of radiation-hardening testing at Texas A&M to support the development of space-ready AI architectures.
   b. Launch Student Program: Collaborate with NASA and the State of Texas on a student flight experiment program akin to the TAMU-SPIRIT model.
   c. Engage the Community: Host workshops and working group sessions to validate the roadmap and standards within the broader semiconductor and space manufacturing communities.
4. **Utilize existing** Texas A&M University System facilities and build a new fabrication facility to support R&D, workforce development, launch startups, or support business development.
5. **Maximize the Texas A&M Semiconductor Institute's New World-Class Shared User Facility.** An 80,000 sq.ft. facility, 30,000 sq.ft. of which is under filter: dual use, both terrestrial and space manufacturing, supporting R&D, workforce development, launching startup incubation, or supporting business development.
6. **Forge collaborations** with industry to launch low Earth orbit initiatives.
7. **Develop a 3-, 7- and 10-year roadmap** for in-space manufacturing that includes all the technology enablers like AI, quantum, edge computing, robotics, visualization, supply chain logistics, and power.

Interested in Collaborating for In-Space Manufacturing? Contact:
Gary Rodrigue
Associate Director, Research Development
https://www.linkedin.com/in/gary-rodrigue/
Email: grodrigue@tamus.edu
Cell: 760-902-0280

Appendix A: Acronyms and Abbreviations

AI	Artificial intelligence
ALD	Atomic Layer Deposition
AMD	Advanced Micro Devices, Inc.
ATI	Advanced Technology International
CHIPS	Creating Helpful Incentives to Produce Semiconductors
DoD	Department of Defense
EAGER	Early-Concept Grants for Exploratory Research
EDA	Electronic design automation
ESA	European Space Agency
EU	European Union
EV	Electric vehicle
GaN-on-Si	Advanced semiconductor technology that integrates Gallium Nitride (GaN) onto silicon substrates
IBAS	Industrial Base Analysis and Sustainment
III–V	A class of materials used in microelectronic applications
InP	Indium phosphide
IP	Intellectual property
ISMA	In-space Manufacturing Alliance
ISS	International Space Station
ISAM	In-space Servicing, Assembly, and Manufacturing
ISR	Intelligence, Surveillance, Reconnaissance
LEO	Low Earth orbit
MoS2	Molybdenum disulfide
NAPMP	National Advanced Packaging Manufacturing Program
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
PUF	Physical unclonable function
R&D	Research & Development
RESHAPE	Re-shore Ecosystem for Secure Heterogeneous Advanced Packaged Electronics
RF	Radio frequency
SAM	Serviceable Available Market
SIA	Semiconductor Industry Association
SiC	Silicon carbide
SiGe	Silicon–germanium
SOM	Serviceable Obtainable Market (also called “Share of Market”)
STEM	Science, Technology, Engineering and Mathematics
TAM	Total Addressable Market
TAMU	Texas A&M University
TPM	Trusted platform modules
TRL	Technical Readiness Levels
TSIC	Texas Semiconductor Innovation Consortium
TSIF	Texas Semiconductor Innovation Fund
TSMC	Taiwan Semiconductor Manufacturing Company
USSF	U.S. Space Force
UWBG	Ultrawide-bandgap
WBG	Wide-bandgap

Appendix B: Endnotes

[1] Yin Wan, Ding Liu, Jun-Chao Ren (2022), "Performance-driven semiconductor silicon crystal quality control," Journal of Process Control, Volume 120, Pages 68-85, ISSN 0959-1524, https://www.sciencedirect.com/science/article/abs/pii/S0959152422002013
[2] Ansari, M. P. (2025). Addressing America's Semiconductor Dependency on East Asia. Journal for Global Business and Community, 16(1), 5–7. https://doi.org/10.56020/001c.134052
[3] A meta-analysis of semiconductor materials fabricated in microgravity Ashley R. Wilkinson, Frances Brewer, Hannah Wright, Ben Whiteside, Amari Williams, Lynn Harper & Anne M. Wilson, Nature, https://www.nature.com/articles/s41526-024-00410-7.pdf
[4] On Demand Manufacturing of Electronics (ODME), NASA, https://ntrs.nasa.gov/api/citations/20240013706/downloads/ODME%20Overview%20for%20MP3%201024%20rev4.pdf
[5] U.S. government's spending on defense contracts for drones leading to a projected $47 billion market by 2032. (2025, October 16). *Globe Newswire*. https://www.globenewswire.com/news-release/2025/10/16/3167988/0/en/U-S-Government-s-Spending-on-Defense-Contracts-for-Drones-Leading-to-a-Projected-47-Billion-Market-By-2032.html
[6] William Reinsch and Altynay Junusova, "The Double-Edged Sword of Semiconductor Export Controls: Electronic Design Automation." CSIS, 2025, https://csis-website-prod.s3.amazonaws.com/s3fs-public/2025-10/251006_Reinsch_Semiconductor_Export_0.pdf?VersionId=5O2.u37f5mO7_d8bqMhRdM3hhc._Op8p
[7] "Do Accelerators Really Work?" UNC Kenan-Flagler, 2019, https://www.kenan-flagler.unc.edu/news/do-accelerators-really-work/#:~:text=The%20researchers%20discovered%20that%20the,best%20take%20advantage%20of%20them.
[8] NIST, Metrology Program, https://www.nist.gov/chips/research-development-programs/metrology-program
[9] NIST, National Advanced Packaging Manufacturing Program, https://www.nist.gov/chips/research-development-programs/national-advanced-packaging-manufacturing-program
[10] On September 5, 2025, President Donald Trump signed Executive Order 14347 to authorize the official use of the secondary title "Department of War" for U.S. Department of Defense.
[11] "DOD Awards $49 Million to Improve Advanced Semiconductor Packaging Capabilities." U.S. Department of War, 2024, https://www.war.gov/News/Releases/Release/Article/3655035/dod-awards-49-million-to-improve-advanced-semiconductor-packaging-capabilities/
[12] William Reinsch and Altynay Junusova, "The Double-Edged Sword of Semiconductor Export Controls: Electronic Design Automation." CSIS, 2025, https://csis-website-prod.s3.amazonaws.com/s3fs-public/2025-10/251006_Reinsch_Semiconductor_Export_0.pdf?VersionId=5O2.u37f5mO7_d8bqMhRdM3hhc._Op8p
[13] "National Security." CHIPS for America, NIST, 2025, https://www.nist.gov/chips/implementation-strategies/national-security
[14] "A Strategy for U.S. to Regain its Position in Semiconductor Manufacturing." CSIS, 2024, https://www.csis.org/analysis/strategy-united-states-regain-its-position-semiconductor-manufacturing
[15] "A Strategy for U.S. to Regain its Position in Semiconductor Manufacturing." CSIS, 2024, https://www.csis.org/analysis/strategy-united-states-regain-its-position-semiconductor-manufacturing
[16] "The Path to Securing the Future of U.S. Semiconductor Supply Chains." Stepwise Risk Outlook, Steptoe, 2024, https://www.steptoe.com/en/news-publications/stepwise-risk-outlook/stepwise-risk-outlook-deep-dive-the-path-to-securing-the-future-of-us-semiconductor-supply-chains.html
[17] "2025 State of the U.S. Semiconductor Industry." SIA, 2025, https://www.semiconductors.org/wp-content/uploads/2025/07/SIA-State-of-the-Industry-Report-2025.pdf
[18] "A Strategy for U.S. to Regain its Position in Semiconductor Manufacturing." CSIS, 2024, https://www.csis.org/analysis/strategy-united-states-regain-its-position-semiconductor-manufacturing
[19] "Texas Semiconductor Innovation Fund (TSIF)." Texas Economic Development & Tourism Office, https://gov.texas.gov/business/page/tsif
[20] "Space Forge and Intuitive Machines Partner to Advance U.S. Space-Based Semiconductor Manufacturing." Space Forge Insights, 2025, https://www.spaceforge.com/news/space-forge-and-intuitive-machines-partner-to-advance-u-s-space-based-semiconductor-manufacturing
[21] Subin Antony Jose et. al. "Inn-Space Manufacturing: Technologies, Challenges, and Future Horizons." MDPI, 2025, https://www.mdpi.com/2504-4494/9/3/84#:~:text=The%20economic%20impact%20of%20in%2Dspace%20manufacturing%20(ISM)%20and%2

0AM%20is%20anticipated%20to%20manifest%20in%20key%20areas%20such%20as%20job%20creation%2C%20resource%20optimization%2C%20and%20the%20emergence%20of%20new%20markets

[22] "2025 State of the U.S. Semiconductor Industry." SIA, 2025, https://www.semiconductors.org/wp-content/uploads/2025/07/SIA-State-of-the-Industry-Report-2025.pdf

[23] "2025 State of the U.S. Semiconductor Industry." SIA, 2025, https://www.semiconductors.org/wp-content/uploads/2025/07/SIA-State-of-the-Industry-Report-2025.pdf

[24] "2025 State of the U.S. Semiconductor Industry." SIA, 2025, https://www.semiconductors.org/wp-content/uploads/2025/07/SIA-State-of-the-Industry-Report-2025.pdf

[25] "Governor Abbott Announces Texas Semiconductor Innovation Fund Grant To SpaceX." Texas Economic Development & Tourism Office, 2025, https://gov.texas.gov/news/post/governor-abbott-announces-texas-semiconductor-innovation-fund-grant-to-spacex

[26] "Space Forge and Intuitive Machines Team Up to Transform Semiconductor Manufacturing In Space." S&S Insider, 2025, https://www.snsinsider.com/blogs/space-forge-and-intuitive-machines-team-up