Space Manufacturing Technology Report

Submitted to

The National Space Council

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Prepared by:

National Aeronautics and Space Administration
Department of Defense
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Executive Summary

On September 9, 2022, Vice President Kamala Harris convened the Biden-Harris Administration's second National Space Council meeting at the Johnson Space Center in Houston, Texas. This meeting focused on advancing Administration priorities including expanding space science, technology, engineering and mathematics (STEM) education and workforce, human space exploration, and rules for commercial novel space activities.

To harness the full potential of space, Council members underscored the need to grow, diversify, and strengthen our Nation's space-related industries and workforce. It was agreed that the National Aeronautics and Space Administration (NASA), Department of Defense (DOD), and Department of Commerce (DOC), within 180 days from September 9, 2022, would develop recommendations to ensure the space sector is included in federal programs, such as Manufacturing USA[1], to accelerate the Nation's capabilities in manufacturing space technologies while ramping up capacity to meet rising workforce demand in the space industrial base (SIB).

This report focuses on five areas and includes 14 recommendations that are actionable by NASA, DOD, DOC, and other federal departments and agencies. When implemented, these recommendations will lead to increased understanding of existing infrastructure and identification of current capabilities and future needs for space manufacturing. Cognizant entities will support and, where necessary, establish new partnerships between federal departments and agencies, industry, private sector organizations, and academia – domestically and internationally. Stakeholders will incubate and accelerate space manufacturing entrepreneurship while further aligning current and future federal investments that support space manufacturing technology needs. The report concludes with recommendations to grow and strengthen pathways to space manufacturing careers for people of all backgrounds.

This report also includes:

- A description of seven new and emerging space manufacturing technology needs for NASA, DOD, and DOC: 1) additive manufacturing; 2) advanced materials; 3) robotics and automation; 4) digital manufacturing systems; 5) clean and sustainable manufacturing; 6) electronics manufacturing; and 7) hypersonics.
- Discussion of existing public-private partnerships, focusing on expanding current Manufacturing USA Institutes to ensure a space-focused outcome.
- Exploration of EDA regional funding that align with space-related Technology Hubs.
- Identification of synergies with related federal programs, including the Hollings Manufacturing Extension Partnership Program.
- Description of areas of opportunity for the public and private sector to collaborate in ways that support the identified needs and included recommendations.

[1] Manufacturing USA https://www.manufacturingusa.com/

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INTRODUCTION

The global space industry can be traced back to just over 60 years. During the subsequent space-age, the world has undergone many changes and the space industry has made a profound impact on the way we live and work, shaping the course of history and the world we know today. Throughout this period, the United States has remained at the forefront of technological innovation and scientific advancement as the world's preeminent nation for space exploration.

The space sector has a vast potential for economic growth. The global space industry is valued at greater than $400 billion today and is rapidly expanding and evolving. The sector adds tens of billions of dollars annually to the Nation's balance of trade and provides support and stimulus for our country's high-technology industrial base, providing tens of thousands of well-paying and skilled jobs. As the sector grows, it provides a unique opportunity for developing a diverse and inclusive workforce from the factory floor to the C-suite, advancing equity and economic prosperity in the Nation. Worldwide, as more countries enter the space sector we will have exciting opportunities for international cooperation, peace, and diplomacy.

Today the space industry is at a tipping point in the form of changes, challenges, and opportunities driven largely by less expensive launch costs and a realization that the use of space has great potential for societal benefits on Earth. There is enormous interest in utilizing space by small and large companies worldwide. This will require a transformation in the way we operate across the entire breadth of manufacturing from academic research to product delivery in order to meet industry-relevant challenges of the future. While the government plays a crucial role in promoting and supporting research and development (R&D) that is essential for scientific advancement and economic growth, the burgeoning commercial space industry is spurring investment in research and development, leading to the creation of new and improved technologies for a variety of applications.

The exploration of space has long been a source of inspiration for people around the world tapping into the human desire to understand and discover more about the universe we live in. The space industry has the power to encourage and excite people of all ages. Its impact on education, culture, science, and the economy is undeniable. It inspires young people to pursue STEM careers. Space has also played a significant role in shaping popular culture, from science fiction literature and film to art and music.

Manufacturing & The Space Economy: Today, space systems development takes too long and costs too much, and the high cost of operating in the space industry limits new entrants and competition. Manufacturing technology advancements will play a critical role in maintaining U.S. industry leadership in a hypercompetitive global environment. In Europe, the European Space Agency's Advanced Manufacturing Initiative has the primary objective of identifying and spinning-in space business disruptive materials and manufacturing processes. The 2022 National Science and Technology Council (NSTC) National Strategy for Advanced Manufacturing[2] noted "advances in U.S. manufacturing enable the economy to continuously grow as new technologies and innovations increase productivity, enable next-generation products, support our capability to

[2] National Strategy for Advanced Manufacturing https://www.whitehouse.gov/wp-content/uploads/2022/10/National-Strategy-for-Advanced-Manufacturing-10072022.pdf

address the climate crisis, and create new, high-quality, and higher-paying jobs." The 2022 National Strategy for Advanced Manufacturing recommended that space manufacturing be a priority for government agencies.

Technology drives exploration and the space economy. NASA's Space Technology Mission Directorate (STMD)[3] is chartered to develop transformative, crosscutting technologies that enhance capabilities and reduce the cost of NASA, commercial, and other government missions. Through STMD, NASA invests in space manufacturing technology activities across the technology development spectrum in collaboration with other government agencies, the Nation's aerospace industry, and academia.

Manufacturing, STEM Education & Workforce Development: The explosion of advanced manufacturing technologies and the corresponding education revolution are projected to play a significant role in driving innovation and efficiency in an increasingly competitive global space marketplace. The overall space industry, advanced manufacturing, and workforce development all have a close relationship, as they rely heavily on technology and STEM eduation. Education and workforce development and particularly STEM eduation provides the knowledge and skills necessary to develop and implement the technology used in advanced manufacturing, such as digital design and manufacturing, robotics, and materials science. Additionally, many STEM-related jobs, such as engineers, scientists, and technicians are in high demand in the space manufacturing industry as the integration of digital and physical technologies are transforming the way we work throughout the end-to-end manufacturing operation. This report leverages the recent NSTC Interagency Roadmap to Support Space-Related STEM Education and Workforce[4] which represents the initial coordinated steps that the Federal government will take and will inform future space STEM education and workforce strategy.

This report is the result of an interagency activity. Recommendations are provided to relevant Departments and Agencies for consideration as they formulate priorities, activities, and future budget submissions. Assigned dates are projected for the start of the activities. Information on progress and completion status will be reported periodically to the National Space Council. It is anticipated that each of the recommendations will require further deliberations to understand applicable authority/appropriations, cost and schedule resources, impact to current activities and investments, and interagency coordination. Opportunities are provided to highlight areas where relevant Departments and Agencies can engage further in complementary activities.

PRIORITIZE INVESTMENTS IN NEW AND EMERGING SPACE MANUFACTURING TECHNOLOGIES FOR NASA, DOD, AND DOC

Recent advances in technology such as additive manufacturing, artificial intelligence, robotics, biotechnology, and new materials are creating new opportunities for space manufacturing. To compete globally, it is important for the United States to continue to develop and implement new and innovative manufacturing technologies. Advancing these nascent technologies requires

[3] NASA's Space Technology Mission Directorate https://www.nasa.gov/directorates/spacetech/home/index.html
[4] Interagency Roadmap to Support Space-Related STEM Education and Workforce https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Interagency-Roadmap-to-Support-Space-Related-STEM-Education-and-Workforce.pdf

investment in research and development, collaboration and partnership, and an environment that encourages continuous learning and innovation.

Federal interagency collaboration will fast-track innovative solutions by bringing together diverse mission perspectives, skills, and knowledge to create a culture of experimentation and learning and generate entirely new ideas. Additionally, the federal government should partner with industry and academia to invest in applied research and industry-relevant manufacturing technologies. The following transformative, cross-cutting technology areas will benefit from a concentrated focus and multi-agency collaboration and public-private partnerships.

New and Emerging Space Manufacturing Technology List:

1. *Additive Manufacturing*: Additive Manufacturing (AM), also known as 3D printing, is the "process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies[5]." AM allows for the creation of complex geometries and internal structures that are difficult or impossible to produce using traditional manufacturing methods and can offer significant cost and schedule improvements. AM is dramatically changing the design and manufacturing landscape, resulting in a new wave of advanced technologies to build hardware across many sectors.

2. *Advanced Materials*: Materials including composites, ceramics, lightweight metals, nanotechnology, and biotechnology that can be used to create new materials infusion with improved properties, such as increased strength, durability, and biocompatibility. These materials can be used in a variety of space technology applications. Requirements to exploit the potential of advanced materials include more efficient methods to identify, partner, cleanly extract, and manufacture components using rare earth metals and materials essential and largely unique to space systems.

3. *Robotics and Automation*: Robotics and automation are used to increase the efficiency and precision of manufacturing processes, allowing for faster production times and reduced labor costs, to allow manufacturing in hazardous environments or to performing tasks that are too dangerous for human workers, and to integrate digital manufacturing techniques to enable novel methods such as additive manufacturing. Improved use of robotics and automation will lead to more reliable, error-free production lines that create higher reliability space systems.

4. *Digital Manufacturing Systems*: The space industry is becoming extremely data driven. Almost all modern manufacturing operations, equipment, and infrastructure have been to some degree computerized and smart manufacturing systems use advanced technologies, such as internet of things, artificial intelligence, virtual reality, and digital twins, to replace physical work with digital methods to inform, optimize, and automate manufacturing processes.

[5] ASTM 52900, Additive manufacturing — General principles — Fundamentals and vocabulary https://www.astm.org/f3177-21.html

5. *Clean and Sustainable Manufacturing*: Modern manufacturing technologies allow methods and processes that minimize or eliminate negative impacts on the environment and human health, while also conserving resources and energy. These technologies enable the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances and provide opportunities for closed-loop manufacturing in which waste products and by-products are recycled or reused within the manufacturing process rather than being discarded.

6. *Electronics Manufacturing*: Manufacturing techniques that provide accurate reliability of space components at scale and the superior qualities of space manufactured semiconductors. Examples include radiation tolerant chips by design, GaN and InP components, large focal plane arrays, and solar panels. These advances will promote the onshoring of cost-effective domestically manufactured electrical, electronic, and electromechanical "triple E" components for space cabling and connectors.

7. *Hypersonics:* Manufacturing technologies that are critical to the development and ongoing advancement of successful hypersonic vehicles is a key factor in the continued growth and development of the space industry. These technologies include development of materials, thermal protection systems, propulsion systems, and lightweight, high-strength structures that can withstand the high temperatures and aerodynamic forces associated with hypersonic phases of space flight.

Recommendations:

1.1 Agencies should create and maintain an inventory of new and emerging space manufacturing technology capabilities, as well as a list of gaps, and ongoing activities. Agencies should provide awareness and promote leveraging among related federal interagency groups including the NSTC Subcommittees for Advanced Manufacturing, Nanotechnology, and Materials Genome. (Lead: NASA; Support: DOC, DOD, NSTC) (On-going)

1.2 Engage in partnerships with other government agencies, industry, private sector organizations, and academia in space manufacturing technologies. Agencies should seek to convene a national consortium to improve communication between government, industry, and academia to assess space manufacturing technology opportunities and needs. (Lead: NASA; Support: DOC and DOD) (CY 2024Q4)

1.3 Leverage international collaboration and evaluate how partnering with the international community to achieve common goals and objectives will enhance U.S. competitiveness. (Lead: State; Support: DOC, DOD, NASA) (On-going)

Opportunities:

1.A Collaborate to prioritize investments to develop space manufacturing technologies including civil-defense technology development that supports emerging space industries.

1.B Stimulate federal technology transfer to promote the commercialization and public use of federally funded space manufacturing research and development by transferring the technology to the private sector.

1.C Ensure that research prioritizes focus on synergistic developments where environmentally sustainable technologies target improvements in the effectiveness of space manufacturing technology solutions.

1.D Explore policy ramifications to ensure that space manufacturing technology related goods, products, materials, and services are procured from sources that will help American businesses compete in space industries.

EXPLORATION OF EXISTING PUBLIC-PRIVATE PARTNERSHIPS, FOCUSING ON THE EXPANSION OF CURRENT MANUFACTURING USA INSTITUTES TO ENSURE A SPACE-FOCUSED OUTCOME

Space manufacturing technology development and application is experiencing significant interest from academia and industry as evidenced by the cross-section of participants in the recently awarded Advanced Manufacturing Technology Roadmap award from the NIST Office of Advanced Manufacturing[6]. Through the roadmap teaming process, the participants have validated interest by industry in space manufacturing contingent upon further technology risk mitigation and clear market demand signals.

Manufacturing USA was created to capture U.S. innovation and with academic and industrial partners and turn it into applied technology, ensuring that the U.S. will continue to be a leader in global manufacturing into the future. The Manufacturing USA network, shown below in Figure 1, does this by fostering collaborative development of advanced manufacturing technologies through 16 manufacturing innovation institutes and their sponsoring federal agencies; the U.S. Departments of Commerce, Defense, and Energy. In 2022, the institutes were engaged in over 700 major applied research and development projects involving more than 2,500 different organizations and provided more than 106,000 people with advanced manufacturing workforce development and training. The Manufacturing USA model could help advance the development of a robust domestic space manufacturing sector by first leveraging current Manufacturing USA institutes' capabilities against space manufacturing challenges.

[6] NIST Office of Advanced Manufacturing – MFGTech https://www.nist.gov/oam/programs/advanced-manufacturing-technology-roadmap-mfgtech-program

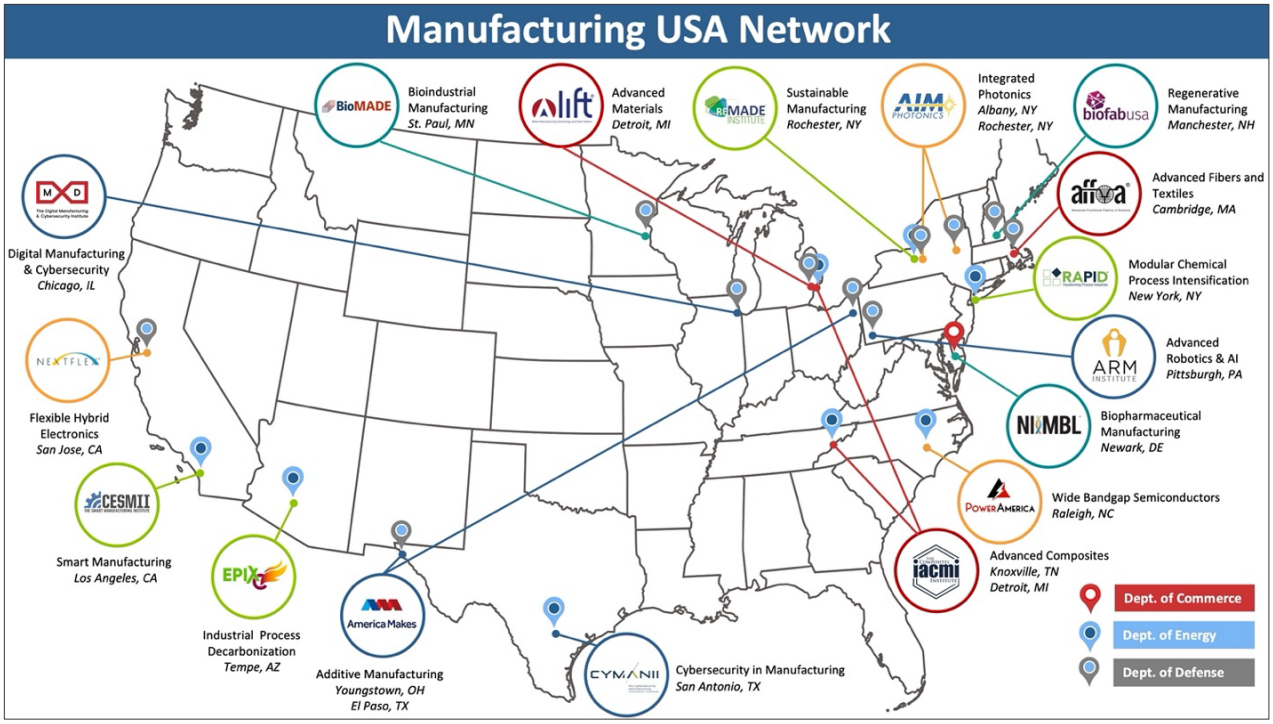

Figure 1: Manufacturing USA Network

Recommendations:

2.1 Support the NIST sponsored Advanced Manufacturing Technology roadmap on space manufacturing to clarify space manufacturing priorities, technology development gaps, and teaming opportunities. (Lead: DOC; Support: DOD, DOE, NASA) (On-going)

2.2 Evaluate the needs of industry and the ability to support future mission requirements through current or new institutes in the Manufacturing USA network. This recommendation is consistent with the goals of the CHIPS and Science Act of 2022. (Lead: DOC; Support: NASA and DOD) (CY 2024Q2)

2.3 Connect the Manufacturing USA network to EDA entrepreneurship, communities of practice, commercialization and workforce training projects and programs with applications to space manufacturing. (Lead: DOC; Support: DOD and NASA) (On-going)

Opportunities:

2.A Encourage identification, alignment, and additional funding to support technology projects in existing Manufacturing USA institutes that can enable aerospace manufacturing.

2.B Partner with MEP to create partnerships/engagements for small and medium-sized manufacturers (SMMs) with the new and existing Manufacturing USA institutes on space manufacturing.

EXPLORATION OF ECONOMIC DEVELOPMENT ADMINISTRATION REGIONAL FUNDING FOR SPACE-RELATED TECHNOLOGY HUBS

The Department of Commerce's Economic Development Administration (EDA) provides financial assistance to communities and regions to grow their innovation and entrepreneurship economies equitably and inclusively,[7] and supports critical infrastructure, systems, and networks that enable businesses to start, locate, and expand in the U.S.

EDA makes strategic investments that equip American workers with the skills that innovative businesses need to succeed. Building on EDA's experience building regional economic capacity, Congress recently appropriated an initial $500 million to the Regional Technology and Innovation Hub ("Tech Hubs") program[8], envisioned as a $10 billion program authorized by the CHIPS and Science Act of 2022. Tech Hubs investments aim to enable rapid evolution of regional economies toward self-sustaining growth in key industries[9], including those focused on advanced manufacturing and aerospace, to strengthen U.S. economic and national security and to best position the U.S. as the global leader in the industries of the future.

Recommendations:

3.1 Space manufacturing technology entrepreneurship: EDA should explore partnering with one or more of NASA, NIST, DOD, and other cognizant agencies on a collaborative funding opportunity[10] to create capacity for space manufacturing entrepreneurs to incubate and accelerate new businesses. (Lead: DOC; Support: NASA and DOD) (CY 2024Q3)

3.2 Regional technology commercialization and demonstration infrastructure: EDA should explore partnering with one or more cognizant agencies to create funding opportunities to build shared infrastructure (e.g., maker spaces, demonstration facilities, public labs, etc.) that enable space manufacturing entrepreneurs to accelerate the pace at which they bring new products to market. (Lead: DOC; Support: NASA and DOD) (CY 2024Q3)

Opportunities:

3.A Leveraging existing networks: EDA builds and maintains communities of practice, including two focused on the intersection of economic development with technology innovation and with manufacturing. EDA should invite relevant agencies to these communities of practice to share and learn about strategies that support economies with strong space manufacturing capacity or potential.

[7] See example innovation project models from Build to Scale and the Build Back Better Regional Challenge
[8] 15 U.S.C. § 3722a
[9] § 3722a(h)(1); *see* 42 U.S.C. § 19107.
[10] Technology-based economic development is one of EDA's investment priorities. Several EDA programs, including Build to Scale and Tech Hubs, make regional investments to accelerate technology- and innovation-centric economic growth, and Tech Hubs also explicitly aims to strengthen both economic and national security. Tech Hubs announced its inaugural cohort of Designated Tech Hubs on October 23, 2023, details of which can be found in the White House Fact Sheet, EDA's Fact Sheet, and at techhubs.gov.

IDENTIFICATION OF SYNERGIES WITH RELATED FEDERAL PROGRAMS, INCLUDING THE HOLLINGS MANUFACTURING EXTENSION PARTNERSHIP (MEP) PROGRAM

MEP's mission is to strengthen and empower U.S. manufacturers and provide them with access to the resources they need to succeed. MEP enables small and medium-sized manufacturers (SMMs) with projects like cybersecurity, supply chain optimization, industry 4.0, semiconductor, food safety, employee training, and raising capital for various improvement projects. The MEP is ideally suited to promote and coordinate public-private partnerships to assist U.S. SMMs in space technology areas. For example, MEP is aligned with NASA's emphasis in Smart Manufacturing by helping SMMs, including aerospace and transportation firms to integrate physical and digital processes within factories and across other supply chain functions to optimize current and future supply and demand requirements. These services include additive manufacturing, automation, robotics, and cybersecurity.

Recommendations:

4.1 Identify and interact with 10-20 SMMs with potential to expand and/or pivot their capabilities in the aerospace sector similar to previous efforts with Personal Protection Equipment suppliers during the COVID-19 pandemic. (Lead: DOC; Support: NASA and DOD) (CY 2024Q2)

4.2 Develop at least three partnerships and/or engagements with Manufacturing USA Institutes, Federal Agencies and National Laboratories to support space manufacturing technology transfer to SMMs for the benefit of the aerospace sector. (Lead: DOC; Support: NASA and DOD) (CY 2024Q3)

4.3 Collaborate closely with proposed sector specific Space Manufacturing Institute in the Manufacturing USA network taking advantage of the strategic and operational synergies between the programs. These include issues relating to supply chain, workforce, and technology/innovation are well considered in discussions and ultimate implementation. (Lead: NASA; Support: DOC, DOD, DOE) (CY 2024Q4)

Opportunities:

4.A Facilitate collaborations between SMMs, University researchers, and Community Colleges for space manufacturing technology and workforce development using MEP's existing network of ~20 University/Community Center based MEP Centers.

4.B Enhance MEP's existing collaboration with NASA to better understand the critical needs/opportunities for MEP to serve the space technologies sector.

MEET THE RISING WORKFORCE DEMAND IN THE SIB THROUGH EDUCATION AND WORKFORCE DEVELOPMENT INITIATIVES

The space industry provides support and stimulus for the country's high-technology industrial base, providing thousands of well-paying and skilled jobs. As the sector grows, it provides a unique opportunity for developing a diverse and inclusive workforce, advancing equity, and economic prosperity in the Nation. Federal leadership of public and private stakeholders will promote the sustainment and growth of the SIB. NASA and the Department of Defense are charged with space-based missions. Their expertise in the characteristics and growth of the SIB make them the most suitable leads for this federal effort. This document advocates a regional approach towards three recommendations to be used by NASA and DoD in consultation with federal agencies and the NSTC Interagency Roadmap group for Space-Related STEM Education and Workforce.

Recommendations:

5.1 Expand and diversify the advanced manufacturing talent pool for space manufacturing by promoting awareness of advance manufacturing careers, engaging underrepresented communities, and addressing social barriers for underserved groups. (Lead: DOD; Support: NASA, DOC, and the Department of Education) (On-going)

5.2 Workforce training: Explore expanding at least one existing EDA program, such as the STEM Talent Challenge to specifically address aerospace training needs in collaboration with other agencies. (Lead: DOC; Support: NASA and DOD) (CY 2024Q2)

5.3 Identify MEP workforce development services relevant to the space sector and offer them across the MEP National Network. Expanding MEP's existing workforce services for space manufacturing involves collaborating with community colleges, universities, and trade associations for appropriate recruitment, retention and retraining efforts. (Lead: DOC; Support: NASA, DOD, DOE) (CY 2023Q4)

Opportunities:

5.A Develop, scale, and promote advanced manufacturing education and training by introducing regional educators to advanced manufacturing as a component of STEM education, and encouraging modernization of legacy regional career technical education programs through regionally focused grants and industry-based efforts supporting advanced manufacturing education. This effort can be undertaken in consultation with the Department of Labor.

5.B Strengthen connections between employers and educational organizations by encouraging SIB manufacturers to expand work-based learning and apprenticeships, and to track changing occupational requirements and define new credentials for space-specific advanced manufacturing occupations.

5.C Focus on increasing the diversity in leadership positions across the space sector. Representation matters and when (historically) excluded groups see people like themselves in positions of leadership, they are more likely to join that sector's workforce and thus it is critical to focus on both ends of the workforce pipeline – from the factory floor to the C-suite.

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