Manufacturing +SPACE

Space manufacturing: The new horizon for industrial innovation

> SPACE'S STRATEGIC AND ECONOMIC IMPORTANCE IS GROWING ACROSS ALL NATIONS COUPLED WITH MORE AFFORDABLE LAUNCH COSTS AND TREMENDOUS INNOVATION. WE'RE WITNESSING A SECTOR THAT IS BOOMING WHERE MORE RESEARCH, PRODUCTION, AND MANUFACTURING WILL TAKE PLACE IN SPACE, USHERING IN A NEW ERA OF INDUSTRIAL, MANUFACTURING, AND TECHNOLOGICAL REVOLUTION.
>
> – JONATHON GILL, PARTNER, GLOBAL & UK HEAD OF INDUSTRIAL MANUFACTURING & DEFENCE

WHY IS THIS IMPORTANT?

Manufacturing is experiencing a reinvention in the form of broad system transformation and breakthrough technology.

New systems, with high standards of observability, fully integrate the digital and physical worlds, including the human factor, as well as the broader business context. Connecting data from the manufacturing process and impacts to the business creates a new paradigm for data-based decision-making. Visibility of the human element within the system represents a broader contextualization of external factors that can disrupt otherwise predictable processes. This move brings human ingenuity and creativity front and center to the manufacturing value chain. The next era of manufacturing will emphasize this human-to-machine feedback loop as a multiplier to the digital transformation that's been taking place over the past decade.

Also characterizing this moment in manufacturing are the product innovations enabled by new materials and new manufacturing techniques, miniaturization of tech enabled by battery technology and high-capacity semiconductors, and the enhancement of robotics and autonomous processes advancements in spatial computing. The breakthrough technology and processes emerging from the manufacturing sector are the other main pillar of reinvention facing the industry.

Modernization has not arrived as a broad brushstroke across all of manufacturing. There have been challenges in recent years related to workforce shortages, offshoring, regulatory flux, raw materials availability and price fluctuations, inflation—the list goes on. However, the trends addressed above speak to the vast opportunity landscape for manufacturers in the coming decade. If we look across a time horizon of now (1–2 years), near (3–5 years) and next (6–10 years), then one of the most exciting areas worth considering for manufacturing companies seeking to thrive within this new landscape is happening in space.

Manufacturing for space:

Cutting-edge manufacturing has always been central to space exploration. Building never-before achieved products and pushing limits of engineering have been the mandate of government space programs since the early space race, and are now the norm to be successful in the sector.

To be successful in getting equipment to space and using in orbit, there has been a drive for miniaturization and space hardening of products. This is due to the enormous cost of transporting weight into orbit as well as the challenges of operating in a high-radiation, extremely low temperatures, and vacuum environment.

There are also additional challenges to solve for operating in space that have driven significant innovation—the inability to refuel or service satellites and spacecraft for example, has driven great advancement in solar power and battery capacity.

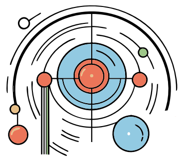
As a result, there is a long list of examples where manufacturing has benefited for terrestrial applications due to the advancement of the space sector.

THE LESSONS LEARNED FROM MANUFACTURING IN SPACE, INCLUDING THE DEVELOPMENT OF HIGHLY PRECISE AND DURABLE ROBOTIC SYSTEMS, ARE BEING APPLIED TO EARTH-BASED MANUFACTURING, RESULTING IN MORE RESILIENT AND ADAPTABLE SYSTEMS… SO CRITICAL FOR THE CONTINUED EVOLUTION OF MANUFACTURING.

– CLAUDIA SARAN, US SECTOR LEADER, INDUSTRIAL MANUFACTURING

Manufacturing in space:

There is now the possibility of manufacturing in space, which is only going to accelerate the learnings and innovation we will benefit from. We believe there are three key drivers of why manufacturers will look to develop, test, and manufacture products in space:



Manufacturing quality improved in microgravity:

Many advanced manufacturing processes can be improved in microgravity due to the reduced likelihood of impurities and defects. Pharmaceutical development, materials like fiber optics, and even human organ transplants have already proven the benefits of microgravity manufacturing.

While the economics of returning manufactured products to Earth is challenging, there are already a number of platforms in orbit testing biomedical manufacturing and testing in space with the hope they can be leveraged on Earth.

Product testing, placement, and advertising:

Many companies over the years have offered consumers the opportunity to engage with and be "closer to space" through products like beer tested in space (Four Pines), coffee machines that work on the space station (Lavazza and Argotech's ISSpresso), and even launching the cremated ashes of loved ones into space. As the space sector becomes more accessible to consumers, particularly through increased commercial astronaut flights, more companies are looking for a competitive edge through the space sector.

This is clear in the collaboration of Prada on Axiom's space suits and Virgin Galactic's activewear brand designed suits but is already going further.

Nokia is developing technology for a future lunar cellular network, with their Lunar Surface Communication System being tested on Intuitive Machines' upcoming IM-2 lander mission.

On the same Intuitive Machines' mission, which forms part of the NASA Commercial Lunar Payload Services program, Columbia is testing material for its outdoor clothing and equipment to show that it can be used in extreme climates.

Elsewhere, Hilton has partnered with Voyager on its Starlab space station development to elevate the guest experience in space and in turn improve guest experiences on Earth.

It is not unreasonable to assume, therefore, that one day there will be the demand for products manufactured in space.

Necessity for living and operating in space:

As we get closer to having people return to the moon and eventually travel onto Mars as part of the NASA Artemis program, not everything people will need to comfortably survive for long-duration deep-space missions is possible to carry from the Earth's surface. This covers a broad range of necessities we take for granted on Earth such as food and accommodations.

The nutritional benefit of food stored for more than three years is negligible regardless of how it has been preserved. For people to survive on long trips in space, they will need to grow and process their own food.

Living spaces are difficult to launch from Earth due to confined architectures to fit in rockets which is why significant work is underway to develop dwellings on the moon and Mars using the regolith (dirt) that is already available. Additive manufacturing techniques are being adapted to the materials available to achieve this. This is expected to have translatable benefit to rapid housing development on Earth.

The impacts of launch are significant with high G forces and vibrations experienced. This limits the design of many spacecraft so that they can function after launch. The ability to manufacture in space may make assembly of more complex spacecraft possible in orbit—by just launching the raw materials. Future technologies, such as solar power generated in space being transmitted back to Earth to power cities, are technically feasible—however, the architecture of a constellation to generate enough power is cost prohibitive and challenging, meaning in-space manufacture and assembly are essential.

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WHAT THESE COMMON TRENDS SHOW IS A GROUNDWORK FOR GROWTH OPPORTUNITIES FOR MANUFACTURERS OF ALL STRIPES TO LEARN FROM, PARTNER WITH, SELL TO, BUY FROM, AND EVEN MERGE WITH SPACE MANUFACTURING BUSINESSES.

Space manufacturing translating to the broader manufacturing sector

Topics like In-Space Assembly and Manufacturing (ISAM) are starting to be discussed in more nonspace manufacturing forums. For example, a special edition of the Journal of Manufacturing Science and Engineering on the topic of ISAM was produced by the American Society of Mechanical Engineers in December 2024.[1] The manufacturing sector is already closely intertwined with the space sector; however, many manufacturing operations are not in industrial manufacturing or do not see a direct correlation between developments in advanced manufacturing and their business. What these common trends show is a groundwork for growth opportunities for manufacturers of all stripes to learn from, partner with, sell to, buy from, and even merge with space manufacturing businesses.

Government primes, for decades, have been the dominant suppliers of manufacturing services for government programs, often acquiring smaller specialist manufacturers to diversify their capabilities as required. Now that commercial companies are entering the space ecosystem, as customers and competitors, demand for lower-cost and innovative alternatives is growing. This has sparked a flurry of start-up activity in the manufacturing sector, with Space Capital counting 623 rounds of funding in manufacturing and components for the satellite category alone since 2009.[2]

Along with the demand for innovation and the desire for competitive bidding, specializations are in demand. Customers with unique needs—not one-size-fits-all—are inspiring a new generation of start-ups to form and address those specific use cases. This creates opportunities for smaller operations to cater to specific elements of space assets—solar panels, composites and alloys, insulation, etc.—and for well-established manufacturers to expand into space part/component/system production.

Further, geopolitical dynamics are influencing the global supply chain for manufacturing that is driving reshoring of production in different regions, while export controls from the US drive customers to seek suppliers across the rest of the globe. The same national security concerns that drive export controls also drive cybersecurity standards that apply to hardware and software components of space assets.

Finally, we need to consider both the evolving opportunities for traditional manufacturers on Earth to build things for space and to take learnings from engineering solutions designed for space, and the implications of in-space manufacturing as a platform for new markets and business models, and also a treasure-trove of knowledge to innovate manufacturing and raw materials on Earth.

NOW: HOW MANUFACTURERS ARE ALREADY INNOVATING IN AND ADJACENT TO SPACE

Space is one of the toughest domains for manufacturing, requiring ingenuity, patience, and unique considerations for testing before a machine or equipment can be operated in its intended environment. Additionally, most space assets must operate without human presence, and are not serviceable, driving innovation in the interconnection between hardware and software. Finally, the movement of raw materials, components, and data around the globe to craft and assemble spacecraft is subject to rigorous import and export controls.

These multiple factors are currently facing the manufacturers of spacecraft, and represent immediate opportunities for nonspace manufacturers to engage:

The rigorous development and testing process produces otherwise untapped learnings and discoveries that have applications in other domains.

Manufacturing for space also provides **new use cases for digital technology, marrying hardware and software** to monitor, respond, collect, analyze, report, etc., where no human is present to intervene or participate in the process.

The extreme environments in space require materials with particular hardiness. Whether for insulation or durability against debris or abrasion, there are examples from apparel and safety gear to architecture and metal alloys of trickle-downs.

Export controls, cybersecurity, and supply chain management are operational challenges that require business solutions along with technical solutions. These activities drive growing markets in and of themselves.

To address these dynamics, manufacturers and customers are looking to adjacent industries to develop new capabilities, including production speed while maintaining quality, novel materials such as metal alloys, and additive manufacturing of highly complex components.

What does this look like in practice?

Real examples of manufacturers for space, whose original business is not space or where space is just part of a diversified portfolio:

Materials and component parts: ADDMAN,[3] United States

- Addman made strategic acquisitions, including of metal additive manufacturing operation Castheon, which position it to serve the specific needs of the space sector by producing mission-critical parts. The team can machine parts through additive manufacturing of niobium in ways that weren't previously possible and can withstand the heat required for propulsion applications.
- Addman has aligned services to the needs and development pace of commercial space companies and has expanded their business (see Keselowski Advanced Manufacturing acquisition)[4] allowing them to provide customers with development services from design through production, building in speed and efficiency for the fast-moving space industry.

Manufacturing and assembly: Toyota, Japan

- Toyota announced[5] a $44.3 million investment in Interstellar Technologies in January 2025. This included a personnel swap and exchange of knowledge, with Interstellar's 3D printing expertise and Toyota's manufacturing expertise.
- Toyota is also collaborating with JAXA[6] on the Lunar Cruiser project. Since 2019, the two organizations have been collaborating on a pressurized lunar rover running on fuel elective vehicle technologies.
- The Toyota Production System (TPS) maximizes the human role alongside automation within the manufacturing process in line with the principles of Industry 5.0.[7]

Integrating artificial intelligence (AI) across these capabilities is already transforming manufacturing operations. Industrial AI now enables predictive maintenance, initiates process optimization, and dynamically manages inventory and supply chains. With sensors integrated throughout the production environment, AI-driven visual analysis powers activities from quality control and compliance monitoring to orchestrating robotics and drones preforming inspections, to packaging and labeling verification.

Visual analysis enabled by AI has opened another dimension of performance and insights for manufacturers. Automating these traditionally labor-intensive activities not only accelerates throughput but also removes the human bottleneck, creating a step-change in capacity and consistency.

The implications for in-space manufacturing are vast. As autonomous systems and robotics are deployed for tasks like in-situ fabrication of space assets, the proven quality assurance and safety verification capabilities of industrial AI make these ambitious operations far more viable and reliable.

A look at the numbers

The ecosystem of space companies spans early stage start-ups to multibillion-dollar behemoths. At different stages of market development, and with different funding resources, this mix of stages of organizational maturity and market maturity creates a dynamic environment for innovation, competition, and varying risk appetites.

Sierra Space, US

$1.72 BILLION

Est. 2008
(as a spin-off of Sierra Nevada Corporation, founded in 1963)

Primary manufacturing activities: Developing spaceplanes, inflatable habitats, and various space systems and components

In-space assembly

Key competitors:
Radian Aerospace, Impulse Space, Firefly Aerospace, SpaceX, and Voyager Space

Varda, US

$147.4 MILLION

Est. 2021

Primary manufacturing activities: Manufacturing pharmaceuticals in microgravity

In-space manufacturing

Key competitors:
Space Tango, ATMOS, Space Cargo Unlimited, In Orbit Aerospace, and Space Forge*

Space Forge, UK

$22.75 MILLION

Est. 2018

Primary manufacturing activities: Developing reusable on-orbit fabrication for semiconductors and alloys in microgravity

In-space manufacturing

Key competitors:
CisLunar Industries, Orbital Composites, and Space DOTS

**Space Forge also offers "Microgravity as a Service" through its ForgeStar Platform, competing with companies like Varda*

References: 8,9

Space Forge highlights the unique attributes of manufacturing in space: weightlessness, natural vacuum, no contamination, extreme temperature range, and flawless mixing, which is essential for alloys.

As **Varda** has tapped into, the pharmaceutical industry is one of the leading customers for access to such an environment. Previously, their only option was a lengthy process to get research onto the International Space Station (ISS) through partnership with the National Lab. Remove some of the complexity of astronaut time (human overhead) and provide more options in terms of launch and return, and a new market is born. Within this context, we can start to envision what the near future might hold for manufacturing companies.

THE UNIQUE AND HARSH CONDITIONS OF SPACE ARE ENABLING BREAKTHROUGHS IN ADDITIVE MANUFACTURING AND MATERIALS SCIENCE THAT WERE PREVIOUSLY UNATTAINABLE, PAVING THE WAY FOR INNOVATIONS THROUGHOUT THE BROAD MANUFACTURING SECTOR.

– BEE LEVETT, AUSTRALIA SPACE LEAD

NEAR: SYSTEM, PROCESS, AND ADVANCED TECHNOLOGY APPLICATIONS

Tech transfer from space is not new, but the integration of space systems into our global infrastructure has created a heightened awareness of the benefits of space technology to other sectors.

Tech transfer and spin-off management:

The challenge of connecting those many discoveries to the right use case, team, and industry environment to find scalable applications requires effort and coordination. NASA has developed programs specifically to enable its technology to be operationalized in a commercial context, for the benefit of society.

Specialized training in adapting space IP for manufacturing more broadly can support these efforts. Organizations can also initiate programs to scan NASA IP for good matches to their capabilities and established markets. The two-way relationship between industry and civil space exploration is one of the catalysts for commercial ecosystem.

While we are already seeing impacts from these areas in manufacturing, the integration of other advanced technologies like AI and sensor engineering will unleash a whole new era of innovation:

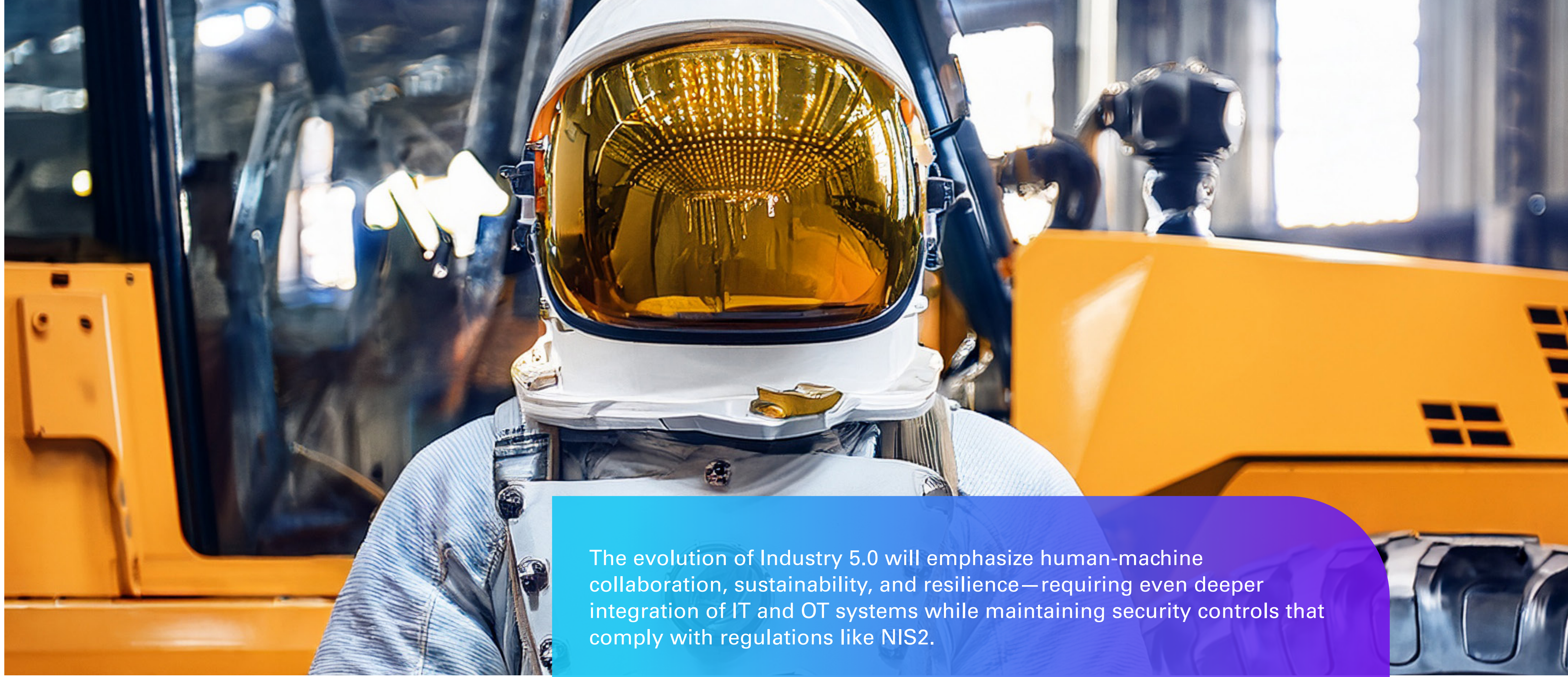
Digital twin technology: Manufacturing is making strides in applying digital twin capabilities for both products and processes; advanced simulation and modeling developments for space applications can be adopted by manufacturing operations in other sectors. Concepts like "digital thread" are closing the loop with the physical and digital worlds, creating a common data model to inform business decisions.

Robotics and automation: Extreme space environments necessitate the development of highly precise, durable, and autonomous robotic systems capable of operating in vacuum conditions and withstanding intense radiation. These advancements are trickling down to Earth-based manufacturing, leading to more resilient and adaptable automation systems. For instance, robotic arms designed for satellite servicing in orbit are inspiring new automated assembly techniques for intricate electronic components. Additionally, robots developed for exploring extraterrestrial surfaces are informing the creation of more intelligent and adaptive manufacturing robots—and cobots—capable of making real-time decisions in complex, dynamic factory environments.

Additive manufacturing: The space industry's unique requirements are pushing the boundaries of additive manufacturing capabilities. This is leading to the development of techniques for 3D printing complex alloys and multimaterial components that were previously impossible to produce. These advancements are enabling the creation of lighter, stronger, and more efficient parts for space applications, with potential benefits for industries ranging from aerospace to medical devices. The ability to manufacture spare parts on-demand through 3D printing in space is also driving innovations in portable, flexible manufacturing systems that could revolutionize supply chains across industries.

The dual management of information technology (IT) and operational technology (OT) is critical in space manufacturing for cybersecurity reasons and the de-risking of assets overall. Space manufacturing requires seamless integration of information systems with operational processes to ensure precision, reliability, and safety. This convergence is driving the development of more robust cybersecurity protocols and resilient manufacturing systems that can withstand extreme conditions and potential cyber threats. The lessons learned from managing IT/OT integration in space manufacturing are informing best practices for critical infrastructure protection across industries.

Industry 5.0 represents the culmination of innovative forces in manufacturing today, with particular relevance to the space sector. It emphasizes human-machine collaboration, sustainable and resilient production processes, and the integration of advanced technologies to solve complex challenges.[10] The space industry, with its unique requirements and extreme operating conditions, is at the forefront of implementing Industry 5.0 principles. Innovations developed for space manufacturing, such as AI-assisted design processes and human-robot collaborative systems, are setting new standards for efficiency, sustainability, and adaptability in manufacturing across all sectors.



The evolution of Industry 5.0 will emphasize human-machine collaboration, sustainability, and resilience—requiring even deeper integration of IT and OT systems while maintaining security controls that comply with regulations like NIS2.

Now (1–2 years)

Growing integration of IT/OT systems, creating new security challenges

Legacy OT systems being connected to modern IT networks

Increased attack surface, as previously isolated systems become networked

Need for unified security monitoring across both domains

Near (3–5 years)

NIS2 directive is driving change – Mandatory incident reporting; space sector faces fines up to 10 million euros or 2 percent revenue and manufacturing faces up to 7 million euros or 1.4 percent revenue in fines for noncompliance. Management bodies are directly liable for cybersecurity failures; there is required implementation of cyber risk management measures across both IT and OT.[11]

Digital twin deployment bridging the IT and OT divide

AI-powered anomaly detection across integrated systems

Secure remote access solutions for distributed operations

Zero-trust architectures spanning both domains

Next (6–10 years)

Full IT/OT convergence

Seamless integration of space-based and terrestrial manufacturing systems

Quantum-safe cryptography protecting critical infrastructure

Autonomous systems requiring new security paradigms

Advanced supply chain security measures

NEXT

Where are we headed?

Sustainability

In space, sustainability has a specific connotation of long-term access to Low-Earth Orbit (LEO) and the protection of valuable assets that reside and operate there. Currently, this challenge can only be addressed from the ground, through modernizations to satellites that give them longer lifespans. However, several new businesses are exploring innovative ways to reduce the risk of collisions and provide a second life to defunct or aging satellites. These include in-space robotic servicing, in-space recycling concepts, and even hypersonic satellites that act like spaceplanes and can deorbit safely and be relaunched for new missions.

Manufacturers of satellites will be increasingly expected to ensure longevity in the operational life of the satellite and incorporate modularity for in-orbit repair. Standardization and interoperability will likely become integrated into satellite design and engineering in order to benefit from the developing in-space services.

In-space manufacturing and in-situ resource utilization

The complexity of in-space infrastructure will continue to evolve as more commercial space stations, constellations, and signals are beaming up and down from the sky. While launch capacity has grown and the cost has come down, limitations remain in form factor of payloads. Some assembly, like with the ISS, will have to happen in orbit. This type of form factor restriction has led to innovation in self-assembling solar panels that are already in use, and even inflatable space station modules that have undergone successful simulation testing.

The things we can't bring with us will drive the need for in-situ solutions. We referenced the example of building habitats with lunar or Mars regolith. Other use cases are launch pads to decrease the disruption to the surface with each launch and landing as traffic becomes more consistent. The fuel required for launches from the moon, returning to Earth, or heading on to Mars and deep space can also be made from the hydrogen in lunar ice. As crews begin to populate the bases built there, oxygen will also need to be created from the existing lunar ice. This whole system will be precarious without closed-loop systems like the one that regenerates resources on the ISS. Taking learnings from the space environment, there are cost-saving, resource-management, and sustainability motivations for applying closed loop systems on Earth.

> **ORBITAL FACTORIES WILL BECOME A REALISTIC OPTION FOR A VARIETY OF MANUFACTURING INDUSTRIES, WITH HIGH-QUALITY PRODUCTS MADE IN ORBITAL FACTORIES FOR USE IN SPACE AND ON EARTH.**
>
> **– SUSUMU MIYAHARA, SPACE SECTOR LEAD, KPMG IN JAPAN**

Microgravity manufacturing developments

Some early wins are encouraging, but not yet scalable. What is the potential when these do reach scale? Pharmaceutical development is becoming an established in-space manufacturing market. Entire business models, such as Varda mentioned above, are betting on growth in this area. We know that drug formulations can be achieved in microgravity that would not be possible in Earth's environment, for example, and there is lucrative potential for drug discovery and new patents for marketable drugs on Earth. Additionally, bioprinting in microgravity, from retinas to entire organs, is becoming technically feasible and the economics are evolving in the right direction towards eventual market viability as well.

There is still massive untapped potential in microgravity manufacturing. Constraints include limited access, an obscure process for securing space, and even lack of imagination. However, it is likely that as more capacity opens up through commercial space stations and price optionality expands through operations like Varda, we'll see a broader range of experiments from different sectors looking for breakthroughs in microgravity. Further, a small amount of data from a microgravity experiment can lead to rich insights through simulations. Thus, microgravity research can continue in labs and research and development departments on Earth.

Many of the trends we discuss above will come full circle to support the future ecosystem of manufacturing in and for space. The integration of IT and OT, digital twin modernization, and the layers of AI and predictive analytics will enhance preparedness for disruptions, and breakthroughs in engineering, additive manufacturing, and materials science will trickle down from space to other sectors. Manufacturing leaders who want to be part of this evolution can, by being informed and by making connections, be positioned for the right opportunities when they present themselves.

BRINGING IT TO LIFE

The future of manufacturing is going to take place in an array of environments off of Earth. Manufacturing in LEO will be a dynamic market in the next decade, with the lunar surface and Mars in our sights. Already we see crossover from the examples above impacting the way we think about building things in our everyday. As we know, the world around us requires the manufacture of goods. We also know that those methods are ripe for change and await the killer app of fully circular production.

Operating in the space environment comes with some incredibly hard-to-replicate design constraints. Operating off-planet is a resource-deprived environment for everything from basic needs, like water and oxygen, to material supplies, like aluminum and concrete.

The world of in-situ resource utilization—building and deriving necessary resources like energy, water, and oxygen, from what is already on-site, rather than shipping it—is primed to teach invaluable lessons that can be applied on earth. When new discoveries in microgravity manufacturing lead to breakthroughs in treatment for cancer and Alzheimer's, we won't see LEO as a far-away concept; it will be an integral part of how we progress human well-being.

What role will your organization play in that future?

AS MANUFACTURING AND MINING CONSTRAINTS ON EARTH PERSIST AND HEIGHTEN, THE INDUSTRY HAS BEEN SEEKING ALTERNATIVE ROUTES WHERE IT SEEMS THAT SPACE IS THE INEVITABLE SOLUTION. THERE'S BEEN A SPIKE IN INVESTMENT INTO THIS AREA ACROSS THE GLOBE, WHERE THE SPACE MANUFACTURING MARKET HAS BEEN PREDICTED TO REACH $10 BILLION BY 2030 AND WE'RE LIKELY TO SEE A STARK INCREASE IN THIS TREND IN BOTH THE SHORT AND LONG-TERM FUTURE.

– SABRINA ALAM, EU SPACE LEAD

Considerations for manufacturing leaders:

Now (1–2 years)

How might we invest in advanced manufacturing technologies like 3D printing, robotics, and digital twins to improve efficiency and prepare for potential space-related contracts?

How might we explore partnerships with space companies to understand industry needs and potential manufacturing opportunities?

Near (3–5 years)

How might we develop capabilities in manufacturing specialized materials and components for the growing satellite market, as the number of active satellites is rapidly increasing?

Next (6–10 years)

How might we learn from manufacturing in microgravity environments, as space "factories" become more prevalent?

How might we prepare for new manufacturing possibilities in orbit enabled by large-scale space transportation systems?

> THE CONVERGENCE OF ADVANCED MANUFACTURING AND SPACE EXPLORATION PRESENTS A UNIQUE OPPORTUNITY FOR INDUSTRIAL INNOVATION. AS TERRESTRIAL MANUFACTURING FACES INCREASING CONSTRAINTS, THE UNIQUE ENVIRONMENT OF SPACE—FROM MICROGRAVITY MANUFACTURING TO IN-SITU RESOURCE UTILISATION—OFFERS A COMPELLING NEW FRONTIER. WE'RE WITNESSING A BURGEONING ECOSYSTEM OF COMPANIES LEVERAGING SPACE-GRADE TECHNOLOGIES AND PROCESSES TO CREATE BREAKTHROUGHS IN MATERIALS SCIENCE, ROBOTICS, AND SUSTAINABLE PRODUCTION. NOT ONLY IS THIS MANUFACTURING IN SPACE; IT'S ABOUT THE TRANSFORMATIVE KNOWLEDGE AND CAPABILITIES GAINED THAT WILL RESHAPE MANUFACTURING ON EARTH, DRIVING EFFICIENCY, RESILIENCE, AND A NEW ERA OF INDUSTRIAL INNOVATION.
>
> – JONATHON GILL, GLOBAL HEAD OF INDUSTRIAL MANUFACTURING AND DEFENCE

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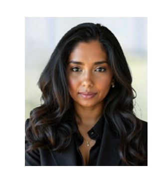

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TIMELINE OF POTENTIAL ADVANCEMENTS

MANUFACTURING +SPACE (2025-2035)

2025

Further integration of 3D printing into space hardware production, enhancing part complexity and reducing production time

Increased focus on miniaturization and space hardening of products for space missions

Collaborations between space companies and terrestrial manufacturers increase, focusing on leveraging space-grade technology for unique materials production

2026

Autonomous robotic systems will start being used more extensively in space factories for continuous production and efficiency

Research into materials with superior qualities will accelerate, driven by the need for lightweight yet durable components for space applications

Governments will launch more initiatives to support private-sector involvement in space manufacturing, including funding and regulatory support

2027

Technologies for recycling materials in space will begin to be commercialized, enhancing sustainability in long-term missions

The first commercial space-based manufacturing facilities will be established, offering services for producing high-value materials

AI will be increasingly used to optimize manufacturing processes both on Earth and in space

2028

Modular and scalable design principles will become standard in space manufacturing, allowing for easier assembly and repair in orbit

Digital twins will be widely adopted to simulate and optimize space manufacturing processes, reducing costs and improving efficiency

Efforts to establish international standards for space manufacturing will intensify, facilitating global cooperation and trade

2029

Advanced space factories with integrated robotics and AI will be launched, enabling continuous production of complex components

Companies will offer in-space assembly services for satellites and other spacecraft, reducing launch costs and enhancing mission flexibility

Full IT/OT convergence will enable seamless integration of space-based and terrestrial systems

2030

Initial lunar bases will be set up for manufacturing purposes, utilizing local resources for construction materials

Space-based solar power systems will start being commercialized, offering a new source of renewable energy for in-space manufacturing

More terrestrial industries will establish a presence in space, leveraging unique environments for production and research

2031

Biotechnology research and production will expand in space, leveraging microgravity for novel biological products

New propulsion technologies will be developed to support the growth of space manufacturing and exploration

Sustainability in space manufacturing will become a priority, with a focus on minimizing waste and using local resources

2032

In Situ Resource Utilization (ISRU) will become more prevalent, enabling the use of lunar or Martian resources for manufacturing and propulsion

Space-based data services will grow, providing critical information for Earth-based applications and space operations

Governments will establish clearer regulatory frameworks to support the expansion of space manufacturing

2033

Companies will commercially launch services for manufacturing and repairing satellites directly in orbit

Advancements in end-of-life planning will enable new channels for a circular manufacturing economy

International agreements on space manufacturing standards will be finalized, facilitating global trade and cooperation

2034

Initial plans for establishing manufacturing facilities on Mars will be laid out, focusing on utilizing Martian resources

AI will play a central role in planning and executing deep-space missions, including manufacturing and resource utilization

Educational programs focused on space manufacturing and exploration will become more widespread, preparing the next generation of space professionals

2035

Space-based manufacturing will become a fully commercialized industry, with multiple companies offering a range of services

New materials with unique properties will be developed in space, driving innovation in various industries

Manufacturing will be play a key role in the sustainability of the space economy, including terrestrial manufacturing, manufacturing via ISRU, and microgravity manufacturing

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