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Space

The commercialization of low Earth orbit

The promise of human spaceflight stands to transform our economy by leveraging the untapped power of LEO

Volume 4: Bringing Earth to space

Fall 2022

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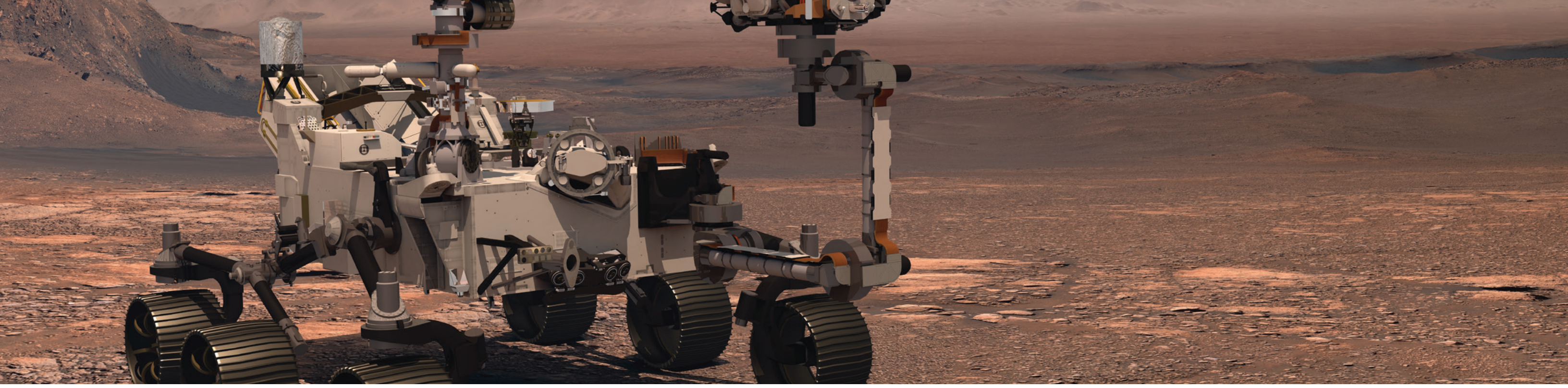
This is the fourth volume in a series of Deloitte Consulting publications on the commercialization of low Earth orbit (LEO) and its associated impact. In this volume, we conduct a deep dive into the research and development (R&D) and manufacturing segments of the LEO economy value chain, exploring key market dynamics and charting several potential future scenarios for the segments through 2035.



Scanning the horizon

Off-world potential for the next industrial revolution

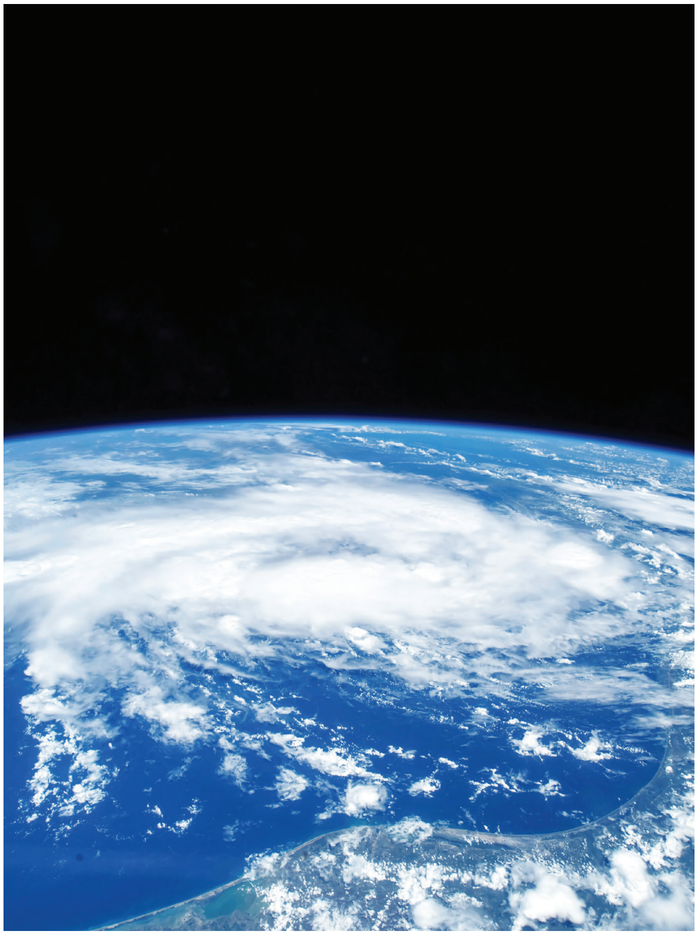
Whizzing around Earth at nearly 5 miles per second, the International Space Station (ISS) is a laboratory like no other. Since it became operational in 2000, the facility has provided humankind a spectacular vantage point in LEO—allowing crew to not only peer down at wondrous views of Earth but also study the effects of orbiting in space. As a research facility, the ISS enables cutting-edge science and the development of technology only possible in a sustained microgravity environment.

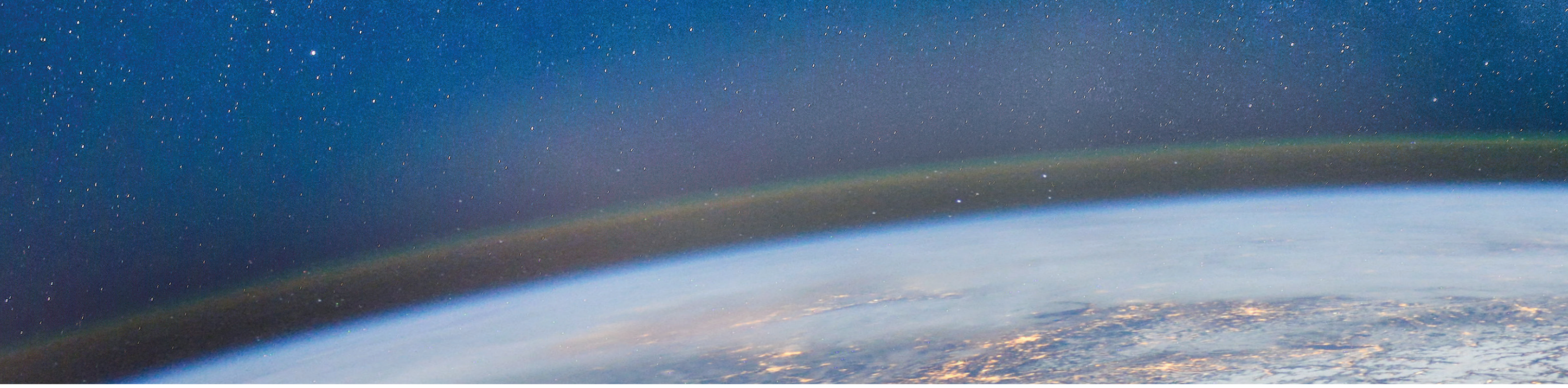
> From unlocking fundamental secrets of the universe to creating new drugs and therapies that save lives on Earth, orbiting labs like the ISS have a profound impact on human health, society, and our economy.

NASA and its international partners use the station to better understand Earth, space, and physical and life sciences. But with downstream applications ranging from cancer treatment to next-generation computing and telecom, there is also strong interest for commercial use. In the not-so-distant future, we can envision a commercial LEO ecosystem that supports a growing number of customers from across the Fortune 500 and academia, including both traditional players and new entrants. Building this industrial capacity in space is also likely needed to support human exploration deeper into our solar system. As humanity continues to reach for the stars, return to the moon, and put boots on Mars, we must unlock the power of space-based R&D and manufacturing as part of the next industrial revolution.

However, the high cost and complexity of operating onboard the ISS and the inherent scarcity of laboratory resources have prevented most commercial use cases from taking off, to this point. To realize the future potential for R&D and manufacturing in LEO, it's clear that we need new orbital platforms and additional launch capacity for crew and cargo transportation to and from orbit—all for a fraction of the cost available today. But even if the supply of enabling infrastructure grows to meet demand at the right price points, an array of business, legal, and operational challenges must be solved to make space-based R&D and manufacturing viable at scale for commercial players. Simply put, growing the market will take much more careful consideration than "if we build it, they will come."

In this volume of the *Commercialization of low Earth orbit* series, we take a closer look at what it will take to achieve the off-world potential for R&D and manufacturing. Through the sections that follow, we introduce structures for analyzing these market segments, examine the major market forces at play, review a variety of use cases that show potential for growth, and suggest actions that industry and government can take in the near term to accelerate toward a vibrant future for R&D and manufacturing in LEO.





Finding lessons in the recent past

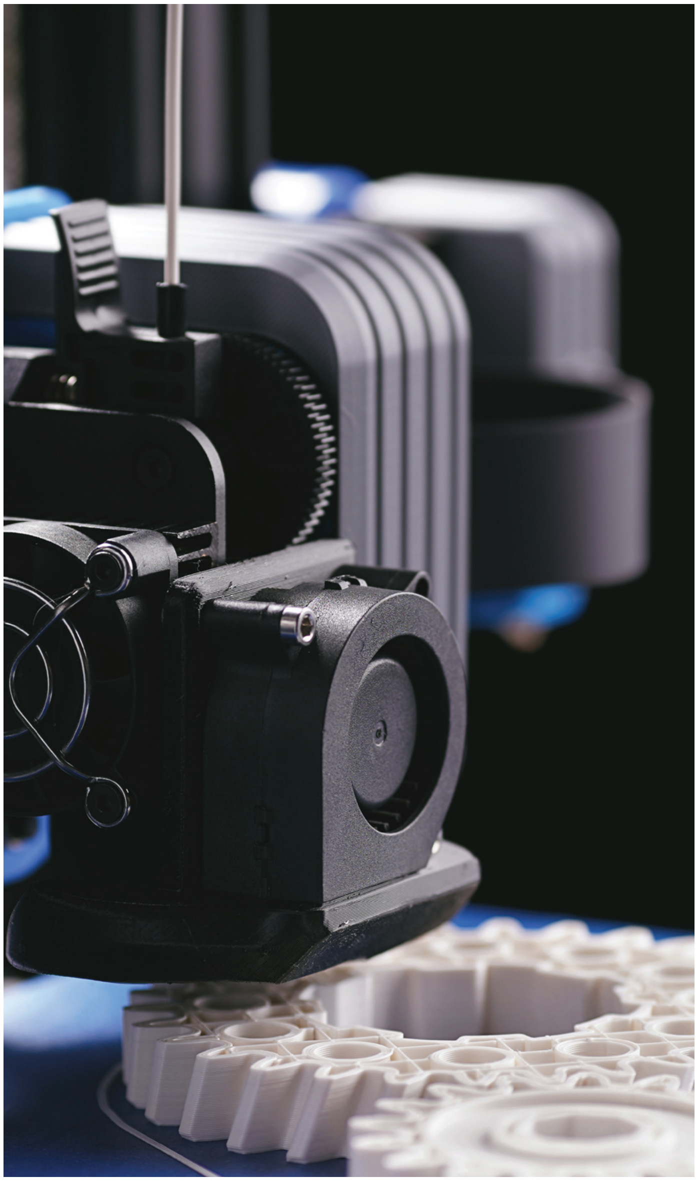
When 3D printing was patented in 1981, few could have envisioned the far-reaching applications and massive economic growth the technology would enable over the half century that followed. Even though the first 3D printer was built in 1987, most uses for them remained out of reach until the early 2000s due to high costs and limited materials to print.[1] Between 2010 and 2020, the industry grew by an average of more than 27% per year.[2] Today, additive manufacturing (AM) is transforming markets from health care to heavy industry and is considered a key component of the Fourth Industrial Revolution.[3]

While commercial R&D and manufacturing in LEO are still relatively nascent endeavors, we see many parallels between these segments of the LEO economy value chain and the transformative power of technologies like AM. The following are some of the dynamics shared by AM and space-based R&D and manufacturing.

Fundamental physical advantages: Just as the speed, precision, and intricacy of 3D printing unlocked new products and use cases not possible with traditional manufacturing methods, the unique physical properties of microgravity provide fundamental advantages for R&D and manufacturing. The "zero-gravity" environment eliminates forces of sedimentation, convection, and vibration and can be used to better isolate material from containers, which enables us to study processes and make things that simply cannot be done on Earth.

Emergence of enabling infrastructure: The proliferation of computer-aided design (CAD) and engineering simulation software, as well as advancements in materials science, were key to realizing mass-market applications for 3D printing. For space-based R&D and manufacturing, the increasing launch rate, investment in on-orbit destinations, and addition of new cargo return (downmass) services are signals that the infrastructure needed for growth may be available in the near term.

Emerging market conditions: Space-based R&D and manufacturing share some of the constraints faced by early-stage AM, both in terms of limited capacity and the high cost of operations. Continued investment in infrastructure and supporting technologies has the potential to reduce these barriers and make commercial R&D and manufacturing a high-growth segment of the LEO market. Our analysis suggests that under the right conditions to stimulate growth and build capacity, the potential upside for R&D and manufacturing could mirror the explosive growth of additive manufacturing—meeting or even exceeding 20% annual growth over the next decade.



Scanning the horizon

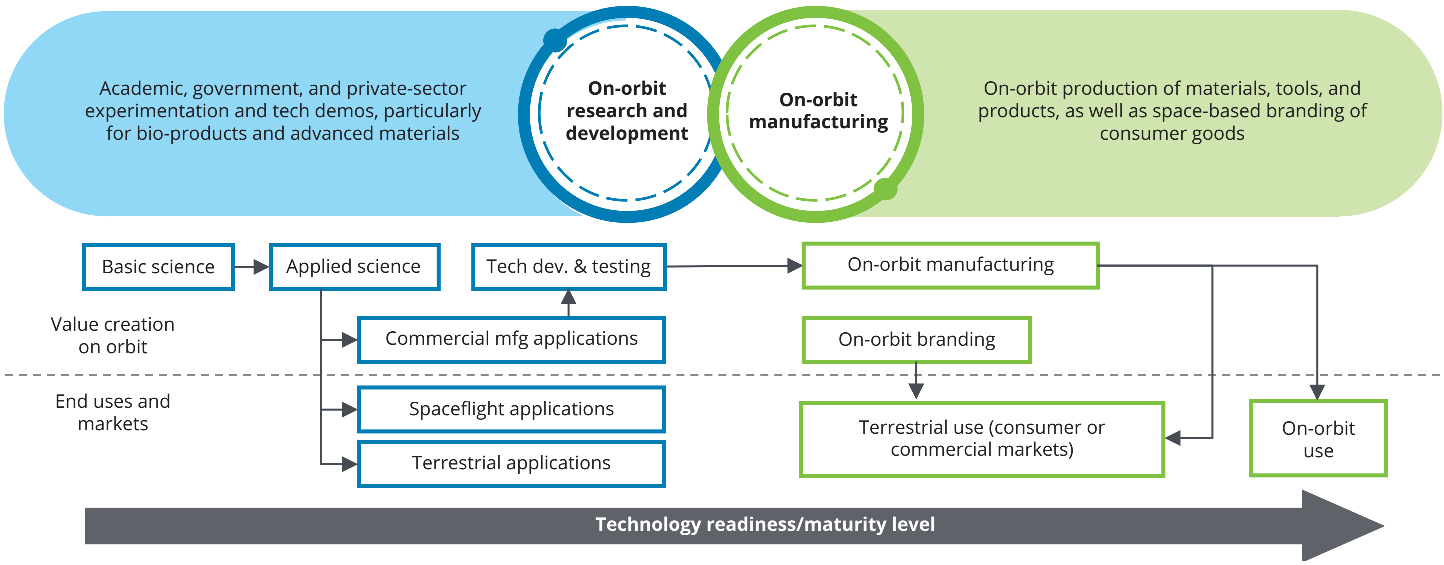
Supply and demand for R&D and manufacturing

Defining R&D and manufacturing within the LEO value chain

We view R&D and manufacturing as tightly coupled segments within the commercial LEO economy value chain because findings from microgravity R&D often inform—either intentionally or incidentally, based on novel findings—the possible use cases for on-orbit manufacturing. In practice, the pipeline for most on-orbit manufacturing use cases will indeed require initial studies to understand material properties, refine manufacturing processes, and test the underlying cost and value assumptions needed to close the business case. However, each segment also includes activities (or subsegments) that can generate value independent of the other. Figure 1 depicts our view of the on-orbit R&D and manufacturing segments of the LEO economy value chain, including both coupled and independent use cases for R&D and manufacturing.

FIGURE 1

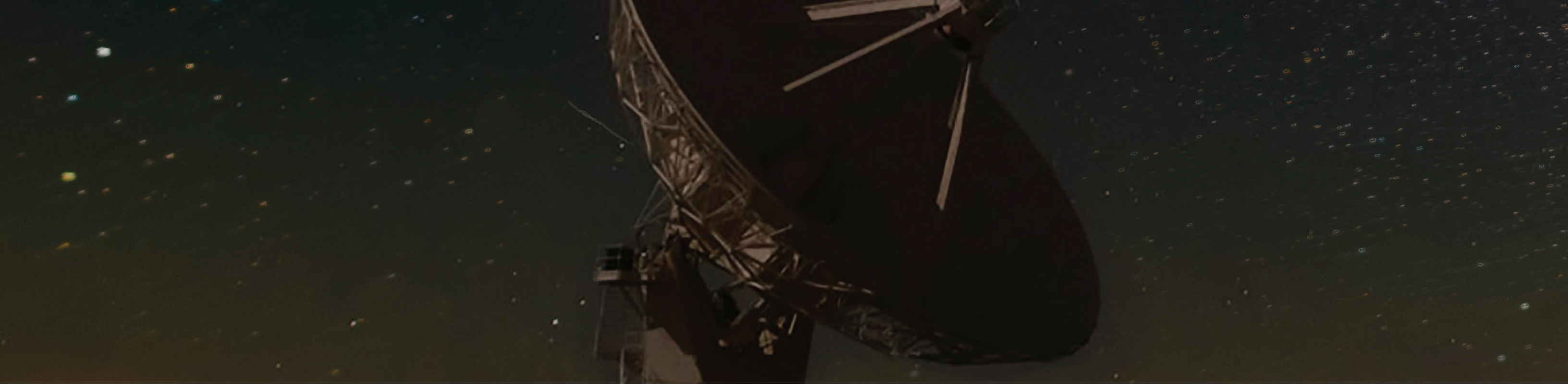
Activities and use cases across the on-orbit R&D and manufacturing segments of the LEO value chain



Research and development segment

We define on-orbit R&D as all basic and applied science, research, development, demonstration, and testing conducted in LEO. The fundamental value of these R&D activities is to understand physical phenomena in the absence of gravity and then apply that knowledge to improve terrestrial products or services, refine spaceflight technology, or serve as a pathfinder for future manufacturing cases. As such, we group R&D activities into the following subsegments, based on the nature of their economic contributions and relationship to other segments of the commercial LEO value chain.

1. **Terrestrial applications:** Use cases with primarily terrestrial benefits, such as better understanding fundamental physical properties of materials for applications on Earth.



2. **Spaceflight applications:** Use cases intended to improve future spaceflight endeavors, such as improving on-orbit infrastructure and better understanding how living in microgravity affects human health.
3. **Commercial manufacturing applications:** Use cases that focus on realizing or refining in-space production of goods for either terrestrial or on-orbit use and consumption.

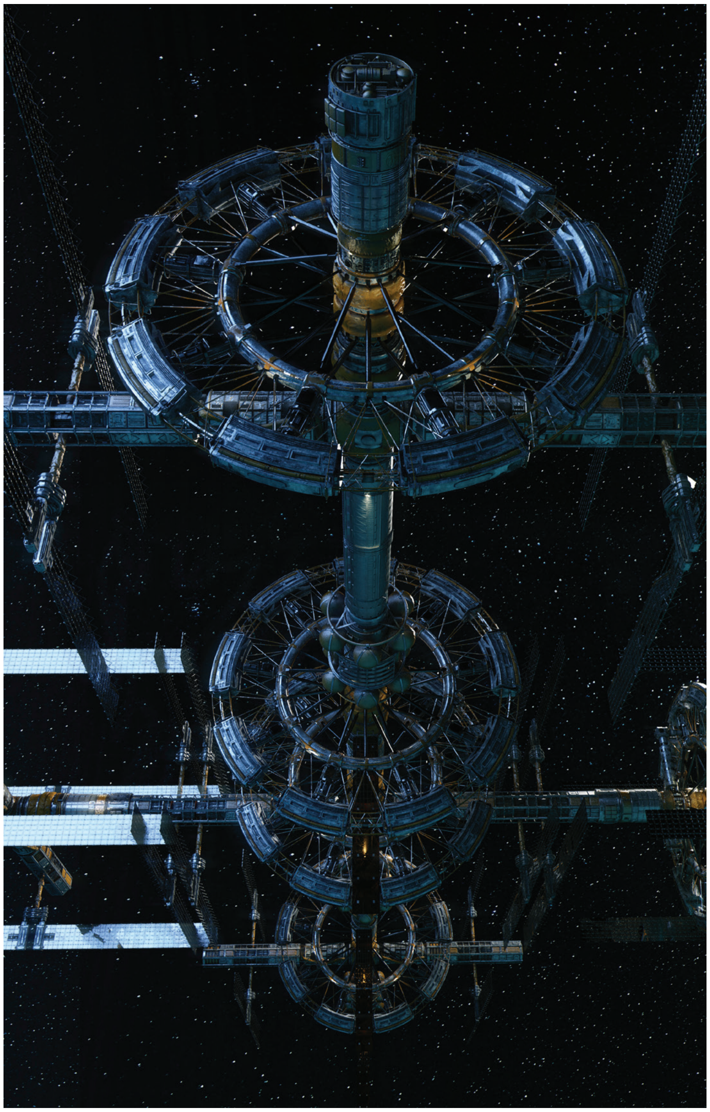
Most of the economic value derived from R&D activity with terrestrial applications is downstream, in the terrestrial economy. For example, life sciences research in microgravity can lead to substantial value in subsequent pharmaceutical manufacturing on Earth. While we don't discount the massive importance of this value in supporting a healthy pipeline of demand—about $1.2 billion[4] in funding has been raised by startups after conducting experiments in LEO—our models and forecasts only consider the value of the on-orbit R&D as part of the commercial LEO economy. As manufacturing-oriented R&D activities progress from technology demonstration to commercial production (even at a small scale), we consider that activity as part of the on-orbit manufacturing segment.

Manufacturing segment

In analyzing on-orbit manufacturing, we recognize the fundamental differences in the basic cost structure, and thus business case dynamics, of the use cases we have considered. As such, we catalogue manufacturing activities into subsegments based on the operational mode or mission architecture. Manufacturing subsegments include:

1. **On-orbit manufacturing for on-orbit use**, such as production of space infrastructure and tools. These use cases require upmass and orbital production infrastructure but no significant downmass capability.
2. **On-orbit manufacturing for terrestrial use** (primarily industrial), such as high-quality crystals and optical devices. These use cases require upmass, orbital production infrastructure, and downmass capability.
3. **On-orbit branding of consumer products** for terrestrial consumer markets, such as premium goods whose value is increased through affinity with space and/or a brand.

In modeling and forecasting the economic contributions of these subsegments, we consider the full value of end products as part of the commercial LEO market because the value is dependent on operations in LEO. We consider the third use case group as part of the value-creation process of final goods, even if the good itself is not functionally dependent on the LEO environment.



Supply-side analysis

The ISS has been the premier orbital research facility for the past two decades. With a pressurized volume similar to a 747 and an acre of solar arrays providing up to 90 kilowatts of power, the station is a technological marvel. Onboard, two modules—Destiny and Kibo—are the primary research facilities of the US Orbital Segment (USOS) of the ISS. Each module is outfitted with racks covering all four walls of experimental payloads and supporting hardware. The station's exterior is also packed to the brim; more than 20 different research payloads can be hosted outside the station at once.[5]

Half of the USOS resources are reserved for NASA-led activities, while the other half is allocated to non-NASA R&D through the ISS National Laboratory. The Center for the Advancement of Science in Space (CASIS) allocates ISS National Lab resources by soliciting, reviewing, and selecting projects from a combination of commercial, government, and academic institutions.[6] CASIS also maintains a network of commercial implementation partners that facilitates research activities by helping institutions to design, build, and integrate their experiments on the commercial partners' 17 onboard facilities. To date, this model has allowed the ISS National Lab to sponsor more than 530 research, technology maturation, and manufacturing payloads across 39 commercial flights. Figure 2 shows the distribution of projects in the CASIS pipeline as of January 2021.[7]

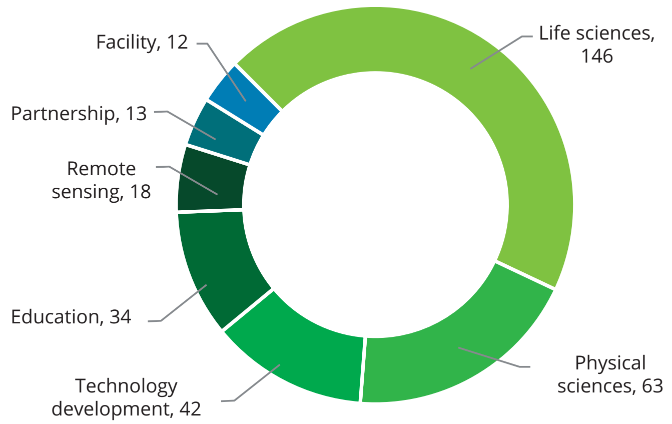
Capable as the platform may be, though, the ISS is a scarce asset. According to CASIS, the National Lab maximized utilization of allocated resources in FY2021[8], demonstrating that the ISS's finite capacity is today's greatest supply-side constraint for orbital R&D and manufacturing. In fact, our research suggests that it's not even the physical infrastructure of the ISS that presents the greatest constraint. Instead, astronaut time may be the limiting factor among ISS resources.

> Astronaut time may be the limiting factor among ISS resources.

However, the current supply landscape is showing early signs of change. On April 24, 2022, the first fully private commercial crew mission to the ISS (led by Axiom Space and called Ax-1) undocked and returned safely to Earth the next day. While the three paying customers may be viewed as tourists by some, they and their pilot conducted more than 100 hours of research for two dozen experiments.[9] By using commercial launch services and private astronauts to conduct on-orbit R&D, the Ax-1 mission represents an important step on the journey to a fully commercial marketplace.

FIGURE 2

ISS National Laboratory research pipeline, January 2021



Meanwhile, competing platforms are beginning to take shape. Looking ahead to the late 2020s, several US companies plan to have commercial stations operational in LEO and have received NASA funding to build them.[10] Demand for orbiting labs and factories has also led to interest from venture capital firms. For example, Varda Space recently secured $42 million in Series A funding to build a commercial manufacturing facility in LEO.[11] If these commercial projects succeed as planned, the capacity of orbital platforms stands to double within the decade. However, as those platforms are also targeting tourism, media, and other uses, the capacity for R&D and manufacturing may not significantly increase if the ISS is retired as planned during the same time frame. We also caution that these

projects are highly ambitious, and industry leaders have publicly acknowledged it's not likely all will succeed.

It's important to note that these domestic US players are not alone. China's Tiangong space station, now being assembled in LEO, is slated to have roughly one-third the habitable volume of the ISS—a material expansion of the global supply for orbital platforms. The first module of Tiangong was launched in 2021, and a second two modules are planned to launch in 2022 to expand the station's laboratory capacity for R&D and manufacturing. China has stated it is open to using Tiangong for commercial activity, including from international participants, making the station a direct competitor to the ISS and any commercially operated space stations that come online in the next decade.[12] This may cause the US government to consider further incentivizing commercial destinations and free flyers.

Lastly, there are other means to accessing microgravity, including suborbital and parabolic flights, as well as non-destination spaceflights in LEO and beyond. However, without the power, space, and other capabilities of well-equipped facilities like the ISS, these means are more likely to support limited-run or early-stage research and demonstrations.

Demand-side analysis

Research and development segment

To date, relatively healthy demand for R&D in LEO has been demonstrated by a select group of buyers across commercial industry, government, and academia. At least, that is, within the current cooperative model facilitated by CASIS. The research performed under awards issued by CASIS typically include significant in-kind contributions from the research institution (more than 85% on average in FY2021), but the cost of integration, launch, and use of ISS National Lab resources in orbit are fully subsidized. Without these costs covered, demand would likely decrease, but studies have indicated it would be unlikely to fall below current capacity levels.[13]

While demand for R&D has been healthy, participation has been relatively concentrated within a few industries. In industry groupings commonly used by Deloitte, we see that government and public services (including higher education), life sciences and health care, and energy, resources, and industrials (including aerospace and defense) account for 91% of CASIS-funded projects completed to date. Very few participants come from the broader Fortune 500, instead representing a relatively niche set of life sciences, A&D, and academic institutions. To find opportunities for untapped demand, we compared the industry participation in on-orbit R&D with terrestrial industry expenditures on R&D (figure 3). Recognizing that some industries have more use cases for on-orbit R&D and manufacturing than others, we also categorized industries by the potential relevance of R&D and manufacturing in LEO (from very low to very high). Our results suggest that the technology, media, and telecommunications (TMT) industry, which spent more than $216 billion on R&D in 2019,[14] may be significantly underutilizing the microgravity environment. Considering the potential value in downstream manufacturing applications for fiber optic cables, semiconductors, and other technologies, it may be worthwhile to re-double near-term efforts to educate and stimulate participation by the TMT industry.

FIGURE 3

Comparison by industry of on-orbit R&D and manufacturing relevance, R&D expenditures, and participation in on-orbit R&D to date

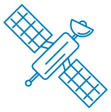
Industry[1]	Relevance of known use cases	Average R&D spend (% of domestic sales)	Share of commercial R&D spend	Share of ISS National Lab projects
Consumer	Low	**2.0%**	**2.9%**	**3.6%**
Energy, Resources, & Industrials	Very high	**4.0%**	**42.3%**	**25%**
Financial Services	Very low	**0.7%**	**2.3%**	**0%**
Government and Public Services	High	**5.4%**	**N/A (excluded)**	**41.1%**
Life Sciences & Health Care	High	**4.8%**	**4.8%**	**25.9%**
Technology, Media, & Telecom	High	**8.2%**	**47.6%**	**4.5%**

[1]For reference, Deloitte defines industry groupings as follows:
Consumer: Automotive; Consumer Products; Retail, Wholesale, & Distribution; and Transportation, Hospitality, & Services
Energy, Resources, & Industrials: Aerospace & Defense; Chemicals & Specialty Materials; Engineering & Construction; Industrial Manufacturing; Mining & Metals; Oil & Gas; Power & Utilities; and Renewable Energy
Financial Services: Banking & Capital Markets; Insurance; Investment Management; and Real Estate
Government and Public Services: Defense, Security, & Justice; Federal Health; Civil Government; State & Local Government; and Higher Education
Life Sciences & Health Care: Life Sciences; Health Care
Technology, Media, & Telecom: Technology; Telecommunications, Media, & Entertainment

Source: R&D expenditures as a share of domestic sales (2019) based on National Science Foundation's *Business enterprise research and development report*[15] and recharacterized to align with Deloitte industry groupings.

Manufacturing segment

On-orbit manufacturing is among the most nascent segments of the commercial LEO economy and due to the early stage of production technology and severe capacity constraints, production to date has been mostly experimental. Even so, a handful of products made in space have demonstrated commercially desirable attributes. For example, as early as the initial years of the Space Shuttle Program, NASA's Microgravity Science Division produced approximately 1 billion latex spheres, each 1/100,000 of an inch in diameter, on-orbit. The zero-gravity environment allowed them to achieve the highest degree of precision for spheres of this size ever created, which had useful applications for equipment used by research labs, hospitals, pharmaceutical companies, and industrial manufacturers.[16] In addition, it has been reported that Redwire (formerly Made in Space) has identified potential customers for specialized fiber optic cables it has already begun producing in orbit.[17] While manufacturing demonstrations like this are encouraging—and have supported consistent activity in LEO since the ISS was completed—we have not yet seen production at scale. Below we provide an overview of constraints and limiting factors for each manufacturing subsegment.



On-orbit production for on-orbit use

Applications for on-orbit manufacturing of goods for on-orbit use are not mature enough today to support significant market growth, even if supply capabilities existed. Applications for 3D printed tools have achieved proof-of-concept status, with ongoing utility for astronauts aboard the ISS. In this case, Redwire's Additive Manufacturing Facility (AMF) has produced more than 200 parts and tools for the ISS crew.[18] While the ISS is the only serviceable orbital infrastructure in existence today, the demonstrated value of AMF suggests that demand for 3D printed tools will likely scale up with the addition of proposed commercial space stations over the next decade. Other applications, namely on-orbit assembly, will likely scale in the same manner—remaining tightly coupled with the introduction of new orbital infrastructure platforms.

On-orbit production for terrestrial use

Today, most hypothetical use cases for industrial and scientific goods produced in microgravity remain in early stages of the product development cycle. Additional R&D will be required to demonstrate the feasibility to manufacture superior quality goods at a competitive value. Even products mature enough to prove a business case that closes at scale are limited in the near term by hard constraints on production capacity and downmass (cargo return) capability. Therefore, given the supply-side limitations faced today, we anticipate long lead times before this subsegment can substantially grow.

On-orbit branding of consumer products

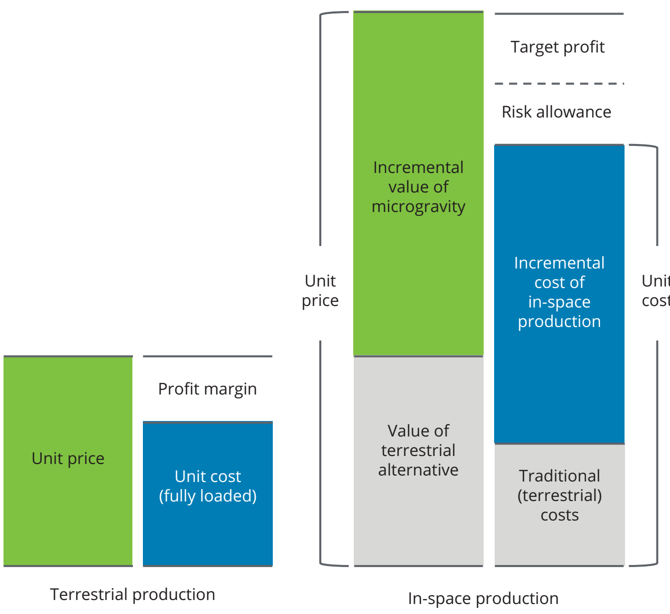
Over the past decade, launch activity and the media's coverage of significant launch events have generated renewed public interest in space. With growing interest, we see opportunities for the consumer goods industry to capitalize on affinity and aspirational branding strategies by making consumer products on-orbit or transporting them through LEO. The appeal and excitement of access to space or space-related goods carries real value. Because branding campaigns like this typically would not require pressurized cargo, or specialized orbital platforms, and limited-run production can be designed flexibly to integrate with other complementary missions, we believe this subsegment presents the most significant near-term opportunity for growth.

Making a profit with on-orbit R&D and manufacturing

Ultimately, at the intersection of supply and demand forces is price. For a business case to be commercially viable, companies need customers who will pay a premium for on-orbit R&D or products made in microgravity. As figure 4 illustrates, the theoretical cost and price structure needed to yield profit on a per-unit basis is relatively simple. When compared to terrestrial alternatives, space-based products and services need to provide more incremental value than incremental cost. In practice, though, both the added cost and market value can be difficult to project for novel R&D and manufacturing applications. As such, firms and their investors will likely seek per-unit margins that are large enough to cover inherent risks. For example, they will need to cover operational risks like potential launch delays as well as market risks like the speed of adoption for new products and services.

FIGURE 4

Illustrative comparison of per-unit cost and price for terrestrial vs. in-space goods and services



Taking a closer look at incremental costs, we recognize that each use case will have a unique mission architecture but can expect a combination of capital investments and operating costs like those outlined in figure 5. While some terrestrial costs may be avoided by operating in space, the cost for most on-orbit R&D and manufacturing endeavors will be higher and include more complexity.

FIGURE 5

Example costs for on-orbit R&D and manufacturing missions

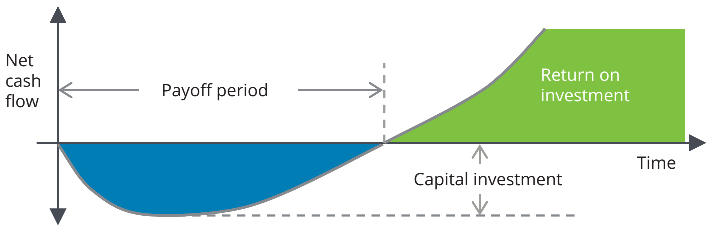
Cost type	Example costs
Capital investment	• Design, manufacture, testing, and certification of research equipment or production tooling • Orbital facilities (if bespoke)
Operating costs	• Hardware integration • Mission support (safety and certification) • Supply chain logistics to/from launch facility • Orbital launch and return (i.e., cost per kg and per passenger) • Orbital facilities (if leased commercially) • Astronaut time • Utilities and consumables (e.g., life support) • Licensing and other fees • Engineering, legal, and other overhead

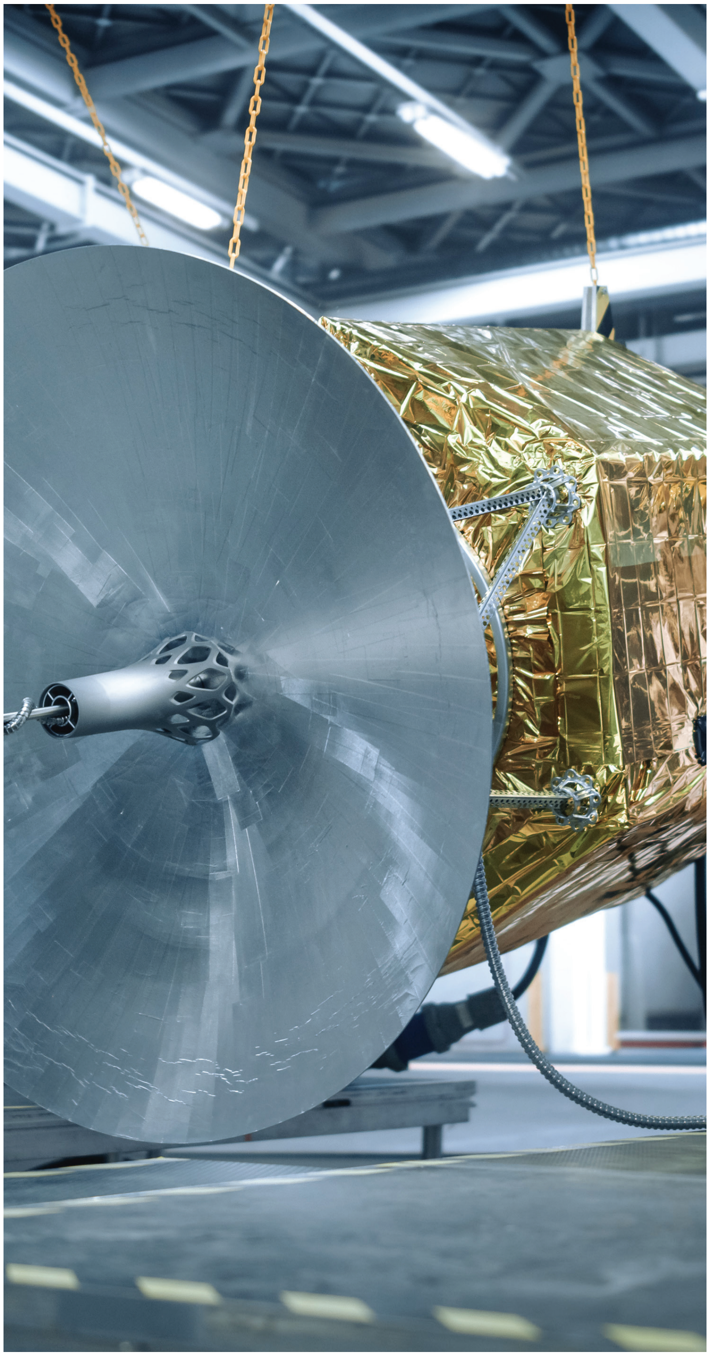
Especially for new entrants, determining what is needed to pull off a mission to space and estimating the cost to do so can be daunting. Businesses that offer mission planning and integration services will likely continue to play an important role in making LEO accessible for companies that see space as an opportunity rather than a business. However, we anticipate that new entrants will need to explore the cost structure of potential use cases well before they begin planning an actual mission. Rich market data and modeling tools are critical assets for performing the scenario planning and “what if” analyses needed to understand the business case dynamics for R&D and manufacturing applications in space.

Closing the business case also requires a satisfactory payoff period, wherein companies and their investors can recuperate capital investments needed for the basic infrastructure required to operate in LEO. Forecasting the breakeven point, after which firms stand to make a positive return on investment (ROI), can be challenging when the size and depth of the demand pool is largely untested. Even if a few initial customers are willing to pay high premiums, are there enough buyers to create healthy returns in acceptable timelines? Deloitte has and continues to study the potential demand for novel R&D and manufacturing use cases in LEO, using a combination of industry engagement, secondary market research, and direct consumer surveys to model the elasticity of demand across a variety of price points (figure 6).

FIGURE 6

Illustrative depiction of net cash flow over time for a new space-based product or service





Assessing the pipeline

Exploring select use cases for manufacturing

Within the manufacturing segment, potential use cases range widely in maturity, from the purely theoretical to the commercially viable and near-production ready. As we have explored, the proven demand for the ISS National Lab indicates a relatively stable market for conducting R&D in microgravity. Manufacturing use cases, on the other hand, remain at earlier stages of maturity due to several factors challenging successful business cases under today's market conditions. Specifically, we view the following as key factors for success.

1. **Incremental value relative to alternatives:** To be commercially viable, products made in space must have a significant competitive advantage over any terrestrial, digital, or non-orbital microgravity alternatives.
2. **Addressable demand:** Buyers are fundamental to any business case, but the issues of demand for on-orbit manufacturing extend beyond the ability and willingness of prospective customers to pay. A general lack of understanding of what is possible in LEO can also be a significant barrier to realizing potential addressable demand.
3. **Availability and cost of infrastructure:** Even when a product has demonstrated a competitive advantage that is desirable in the market, the tipping point for commercial viability is when production at a scale enables per-unit costs—and, in turn, prices—to reach enough demand to break even. For most use cases, the infrastructure required for sustainable business cases does not exist today. Therefore, success depends on the ability to ramp up production infrastructure at a rate, cost, and level of risk that is acceptable for the investor community.

On the following pages, we use these factors to briefly summarize the market potential and barriers facing select use cases that demonstrate promise for on-orbit manufacturing but have yet to be scaled.
We group use cases according to their equivalent terrestrial industry or segment to emphasize the importance of aligning space-based technologies with the businesses and consumers the space industry must engage for demand sensing, investment, and further development.

Our qualitative ratings for the potential value, demand, and infrastructure for each use case are based on a variety of assumptions about future events and are therefore subjective. We caution that growth for each use case is dependent on further investment and will likely be influenced by a complex set of market conditions. As such, our qualitative ratings indicate the relative potential for each use case in general terms; they are not predictions of future outcomes.

Industrial and scientific use cases

Space structure manufacturing

Manufacturing parts and components in space has been a long-running industry conversation, with several research efforts conducted to date. For example, Redwire's space-based 3D printer has demonstrated the ability to make small, disposable tools and parts.[19] Emerging capabilities for autonomous fabrication and assembly in space also have the potential to enable larger structures than current launch systems can serve while reducing payload mass since parts fabricated in space would not have to withstand the loads and stresses associated with orbital launches. NASA funding through the On-Orbit Servicing, Assembly, and Manufacturing 2 (OSAM-2) program,[20] as well as support driven by the US In-Space Servicing, Assembly, and Manufacturing (ISAM) National Strategy, may help pave the way for this capability.[21]

Commercial success factors

High incremental value	Potential value stems from reduced constraints on fairing volume and upmass, increased flexibility and reusability of 3D printed tools, and potential cost advantages.
Moderate demand potential	Future demand is likely from commercial destinations and free flyers proposed in the late 2020s and 2030s; limited applications for robotic missions in the near term.
Strong infrastructure potential	Capability has been demonstrated for 3D printing tools and parts on the ISS; further development of ISAM capability is seeing steady public and private support.

Metallic glass synthesis

Bulk metallic glass (BMG) is a non-crystalline metallic alloy that exhibits unique properties native to metals and glasses, such as high mechanical strength, corrosion resistance, lubricity, and elasticity—particularly at the cryogenic temperatures present in space.[22] BMG has attracted interest from NASA, which established the Bulk Metallic Glass Gears project (BMGG) at the Jet Propulsion Laboratory in Southern California and supported a commercial spin-off called Amorphology.[23] These organizations are developing manufacturing methods for BMGs with both terrestrial and in-space applications, which include mechanical parts for planetary exploration rovers and hardware for shielding from space debris.

Commercial success factors

Limited incremental value	While microgravity is valuable for research on material properties and manufacturing processes, there may be limited value in production at scale on-orbit.
Moderate demand potential	Potential applications abound for in-space habitats, satellites, and rovers; however, demand for in-space production at scale may exceed the time horizon of our forecasts.
Limited infrastructure potential	Capacity is currently limited to R&D facilities; significant investment is needed to establish orbital production facilities at scale.

Life sciences and health care use cases

Biologic drugs

Biologic drugs are made from large, complex molecules that are often difficult to produce with uniformity on Earth. One category of biologics, monoclonal antibodies (MABs), is used to treat diseases from COVID-19 to various cancers. The microgravity environment aboard the ISS National Lab has allowed researchers to produce higher quality protein crystals for MABs, which have the potential to improve the safety and quality of life for patients and their caregivers.[24] To date, most of the orbital R&D conducted on MABs has been used to benefit terrestrial manufacturing processes. However, under the right market conditions, MABs produced on-orbit could eventually see high demand on Earth.

Commercial success factors

High incremental value	Experiments show superior crystal quality and consistency, which may improve drug formulation, administration, and storage.[25]
Strong demand potential	Biologic drugs have direct applicability within large, established pharmaceutical markets.
Moderate infrastructure potential	In-development space vehicles may provide the needed capacity, frequency, and cargo return capability (e.g., low-g with flexible landing location); significant investment will be needed for production facilities.

Tissue engineering

While researchers have been able to produce cell cultures on Earth for this purpose, terrestrial techniques face limitations in the complexity and consistency of cell systems that can be developed. Without shearing and sedimentation forces present, microgravity allows researchers to create larger, more complex, and more delicate tissues, such as blood vessels, that enable the formation of more complex organoid systems. Organoids are 3D aggregates of cells in which the cells' normal shape and macroscopic structure more closely resemble that of full organs.[26] These complex, engineered tissues improve researchers' ability to study diseases, aging, the effects of new drugs, and other biological processes at a fundamental level.

Commercial success factors

High incremental value	When made in space, tissues are a more sophisticated and realistic test bed for complex biopharma research.
Moderate demand potential	Engineered tissue already supports a pipeline of demand for life sciences R&D in space; terrestrial demand may be limited in our forecast horizon.
Moderate infrastructure potential	Capability exists for experimental efforts; more capacity on orbital platforms will be required for growth; transformative cost reduction and cargo return capabilities are needed to enable terrestrial use cases.

Technology and telecommunication use cases

Space structure manufacturing

The global market for semiconductors, which encompasses a vast range of electronics applications, is expected to exceed $600 billion in 2022.[27] The near-vacuum and microgravity environment of space enables the production of semiconductor wafers and chips with better quality and fewer defects, improving their performance. While improving consumer-grade electronics may not warrant the added cost of in-space manufacturing, a variety of potential use cases exist for more exotic electronics. For example, silicon carbide (SiC) wafers can withstand higher temperatures, electromagnetic fields, and other radiation and are therefore useful in a wide range of harsh environments, including space.[28] When manufactured or reprocessed in microgravity, SiC wafers have been made with 99% fewer defects, further enhancing their commercial value.[29]

Commercial success factors

Limited incremental value	Higher quality wafers and chips made in space have competition from alternative manufacturing techniques, both on Earth and with parabolic flights simulating microgravity.
Strong demand potential	The market for SiC and other semiconductors is large and forecast to continue to grow over the next decade.
Moderate infrastructure potential	Capability exists for experimental production, but at costs that introduce significant challenges to closing the business case; lower cost access and additional production capability would be needed.

Fiber optic cables and other optical devices

Use cases for optical devices made in microgravity have garnered significant interest and investment from the private sector, and noteworthy R&D has been conducted to date. The unique microgravity environment allows for production of several crystalline and glass structures with extremely high purity that are useful in many applications such as specialized lenses, sensors, lasers, quantum optics, and more. ZBLAN, a type of fiber optic cable, is arguably the most mature application of specialized optical devices made in space. When "pulled" in space, ZBLAN exhibits 10x-100x better performance relative to conventional alternatives. Demand for fiber optics has rapidly accelerated, with nearly $150 billion invested in the US fiber optic infrastructure in recent years.[30] ZBLAN's significant speed benefit relative to terrestrially produced optical fibers demonstrates potential as a viable alternative for enterprises that need ZBLAN for ultra-low latency applications.[31]

Commercial success factors

Strong incremental value	Experiments show superior quality over terrestrial alternatives for ZBLAN and other optical devices.
Strong demand potential	The market for fiber optic cables is large and forecast to continue to grow over the next decade; other specialty optics uses exist, but demand is nascent and difficult to forecast.
Moderate infrastructure potential	Limited run production of ZBLAN has been successful, and additional investment from public and private entities may lead to more mature production capabilities.[32]

Consumer goods use cases

Tapping the full potential of LEO means looking beyond traditional use cases for microgravity. As the largely government-directed allocation of resources in LEO gives way to a commercial market structure, it will be possible for more consumer goods to be made in space or branded based on an affinity for space. Consumer categories such as beverages, luxury apparel, jewelry, and beauty and cosmetics may all find unique opportunities to differentiate their products and brands.

Affinity-based branding

Retail and consumer brands have long marketed their products using associations with spaceflight. In some cases, these campaigns have gone beyond notional branding by selling items that flew to space as cargo on other missions. This trend may be picking up steam as commercial access to LEO increases. In 2021, Boston Beer Company supported the Inspiration4 mission with a charitable donation and by sending 66 pounds of hops on the flight, which it used to brew a West Coast IPA it calls Space Craft.[33] Our research shows that self-proclaimed "space enthusiasts" may be willing to pay 10x price premiums or higher for goods like this. In fact, there may be more than 11 million adults in the United States willing to pay that level of premium.[34] This product category not only shows the potential for space to be a catalyst for marketing and customer acquisition, but also demonstrates a viable business case that supports increased demand for orbital flights.

More than 11 million US adults may be willing to pay 10x premiums or higher for consumer goods flown in space.

Commercial success factors

Incremental value:
Moderate

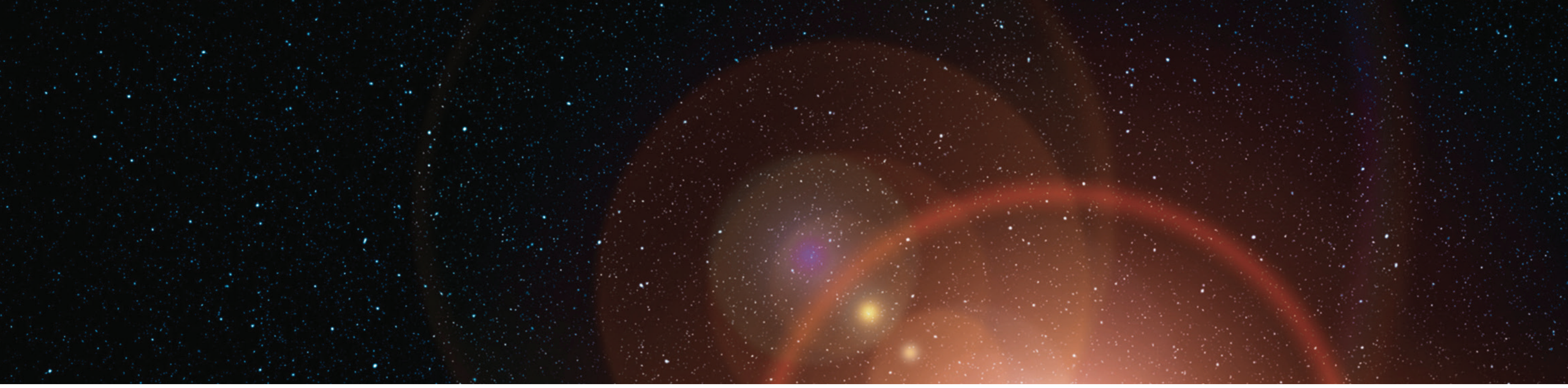
Most of the value derived from items flown to space is based on affinity or perceived exclusivity of the item, essentially adding extrinsic rather than intrinsic value. However, the value added by affinity-based branding is very real for luxury goods sold with premium pricing. Based on a Deloitte survey in 2022, our analysis indicates that on average, US consumers place a 65% premium on space-flown goods, and the top decile of "space enthusiasts" would pay a premium of 400% or more.

Demand potential:
Moderate

The top 100 luxury goods companies achieved more than $250 billion in aggregate sales in FY2020. Even as the luxury goods market receded during the COVID-19 pandemic in 2020, luxury brands that were focused on clothing, footwear, and jewelry were among the strongest performers in terms of year-over-year sales and net profit margins.[35] We view these segments as prime targets for space-based affinity branding given their relatively low mass compared to retail value. However, we caution that the perceived exclusivity of space may wane over time as commercial space activity becomes more mainstream, limiting the ability of space-flown goods to command premium prices in the long run.

Infrastructure potential:
Strong

Today's supply of crewed and uncrewed flights can continue supporting branding campaigns in a rideshare model alongside other missions. The flexibility for these projects to fill excess capacity, both pressurized and unpressurized, can play an important role in maximizing the ROI of launch vehicles and stimulating demand growth in the infrastructure and services segment broadly. The one significant constraint today is the disparity between upmass and downmass capability, which results in higher prices per kilogram returned to Earth.



Key dynamics for R&D and manufacturing in LEO

Demand for R&D remains strong, and the outlook for manufacturing use cases, while varied, includes promising concepts that have the potential to cement microgravity's role in the Fourth Industrial Revolution. As R&D and manufacturing segments continue their commercialization journey, several dynamics stand to influence their speed to self-sustaining markets. Below, we outline our point of view on four major dynamics we envision will have the greatest potential to shape the market trajectory. Then, we will translate these dynamics into assumptions that constitute plausible scenarios for the future, ranging from pessimistic to optimistic, and assess the potential growth for R&D and manufacturing in each.

Slow cycle times and uncertainty may continue to dampen R&D demand

While the outlook for R&D is stable, our research suggests that much of the potential upside for growth is inhibited by two key business risks: long lead times and uncertainty in future laboratory capabilities. Even for R&D departments with the money to spend on microgravity research (many life sciences and pharmaceutical R&D budgets exceed $1 billion annually), the opportunity cost of conducting experiments on the ISS National Laboratory is often just too high. In 2021 and 2022, commercial providers flew cargo resupply missions to the ISS about once per quarter, and only half of those missions were on vehicles capable of returning cargo to Earth.[36] Increasing the frequency of flights would begin to provide more capacity for R&D and manufacturing, especially for activities that require relatively short amounts of time in microgravity (e.g., experiments that can be run in a few weeks or less).

> Our analysis identified industry concerns—whether real or perceived—that the backlog of CASIS projects and limited astronaut time may limit the ability of suppliers to deliver on research objectives within necessary timelines, thereby reducing demand.

However, flight rate is not the only constraint driving slow cycle times. Preparatory activities like mission planning, payload design and integration, and safety reviews take between six months to two years,[37] whereas terrestrial alternatives can be readied in days or weeks. In this environment, companies run the risk that their flightworthy hardware will become obsolete by the time of launch, thereby diminishing the value of any research conducted. The ISS National Lab's implementation partners are beginning to streamline planning and integration procedures, but NASA still requires thorough reviews, especially for safety aboard the ISS. The extent to which ISS National Lab industry partners and related companies can provide mission integration services that demonstrate speed and agility will likely be just as important as increasing the rate of access to orbital labs like the ISS.

Manufacturing at scale will require a revolution of infrastructure

Among the many fascinating candidates for goods to be made in space, few (if any) use cases can be scaled given today's infrastructure. Large-scale production of goods in the pipeline will require heavy equipment that needs significantly more electric power and cooling capacity than what is available in an ISS-like facility. Technologies with the potential to overcome those barriers, like compact nuclear reactors, are in late-stage development but will require more investment to reach their full potential.[38] With today's launch capabilities and per-kilogram launch costs, it's difficult to make the case for that level of infrastructure investment. Next-generation launch vehicles capable of transporting larger payloads at lower costs through reuse and other innovations will likely be critical to making the business cases close. Similarly, advancements in in-space assembly may also accelerate infrastructure development needed to manufacture at scale.

And getting there is just half the battle—as mentioned earlier, downmass is also a key constraint. Current cargo transport providers lack the frequency, mass, and volume capability to support the production levels needed to close most business cases. Even where capacity exists, reentry and descent back to Earth on today's vehicles subjects return cargo to substantial vibration and G-forces before landing in a remote desert or the ocean, all of which add complexity and cost to the supply chain. Therefore, new payload return capabilities are also needed if manufacturing is going to take off.

Lastly, growing the market will also require more laboratory capacity. As we explored in our supply-side analysis, the scarcity of ISS facilities and astronaut time pose a hard constraint on the level of R&D and manufacturing activity in LEO today. Several companies are already working on new orbital laboratories, but our analysis suggests that even the most optimistic outcome for NASA-funded commercial destinations and free flyers would only result in doubling the capacity available today in terms of pressurized volume. As such, commercial space station operators will likely need to employ new technologies, such as advanced robotics and edge computing, that improve the flexibility and throughput per cubic meter of station volume.

CASIS, as one of many customers, creates a new paradigm

In many ways, CASIS has always aimed to spur economic growth based on utilization of the ISS National Lab. Economic impact has long been one of the core criteria for selecting recipients of the National Lab Research Announcement (NLRA) awards, with proximity to commercial application being one of many economic factors.[39] In 2021, CASIS took another step forward for manufacturing applications by introducing in-space production as one of its research areas for NLRA awards.[40] The funding and support provided through these awards play a key role in helping advance science and technologies.

To date, CASIS has also played an important role in determining how the scarce resources for R&D aboard the ISS are used. However, its relatively narrow set of selection criteria may be limiting the potential pool of commercial participants. As we move toward a future with a combination of government and commercially operated modules and free-flying stations in LEO, the future for CASIS is uncertain. Its role will likely need to evolve in response to key questions: Who will manage the portfolio of R&D activity to balance basic science and in-space production, support participation across disciplines, and ensure equity for all parties? How will CASIS avoid undermining the competitiveness of commercial operators and their partners? Indeed, a clearer road map is needed for how government and the private sector will cooperate in the future of R&D in LEO.

Cutting-edge technologies may shift the tides for R&D and manufacturing

In 2021, Deloitte surveyed 150 leaders across the R&D value chain from large biopharma companies (revenue of US$1 billion or more) across the United States, Europe, and Asia. Survey respondents said that their organizations are currently prioritizing investments in AI (81%) and cloud (71%) as two means to accelerate progress toward breakthrough therapies.[41] Such uses of AI, supercomputing, and quantum computing have the potential to mimic the microgravity environment, enabling researchers to achieve the same or similar results without leaving Earth's surface. While this may pose a risk of competition to on-orbit R&D, it may also alleviate a key bottleneck for early-stage research necessary before technology demonstration and manufacturing. In essence, we believe these technologies may serve as a low-cost, high-volume accelerator for the pipeline of nascent manufacturing use cases.

Looking ahead in R&D and manufacturing

Both R&D and manufacturing segments of the commercial LEO market are poised for growth, but most use cases are limited by the vehicles and space stations in operation today. To understand what can be achieved on a 10- to 15-year time horizon, we envisioned several plausible scenarios rooted in both optimistic and pessimistic assumptions for infrastructure development and the major market dynamics revealed through our analysis. We then analyzed the financial business case and modeled the potential market size and growth rates for each scenario. Below, we present a range of estimates for the R&D segment (figure 7) and manufacturing segment (figure 8) between now and 2035 based on our models.

A constrained view: The production line is stalled

In what we envision as a pessimistic scenario, upmass and downmass costs decline gradually from their current price point, supporting a steady stream of R&D and manufacturing activities that resembles today's market. Most of the commercial space stations under development fold before taking off, preventing significant growth for R&D. Profits are attainable for space-based branding in limited runs, but consumer demand cools as the novelty of such goods fades over time. Demand materializes for the terrestrial use of industrial products made in space, but development delays for new launch (and return) vehicles keeps production at scale out of reach. By 2035, the market could reach $121 million for R&D and $590 million for manufacturing.

A steady-growth view: Bottlenecks begin to ease

In a middle case scenario, the introduction of new launch vehicles drives down the cost of access to space and adds diversity to launch and return capabilities. In turn, the business cases for several manufacturing applications begin to close. Healthy demand for multiple terrestrial use cases supports the ROI forecast by first movers, which entices additional investment to scale operations and start up new ventures. By the end of the decade, net-new capacity on commercial space stations unlocks additional demand for R&D that further invigorates the manufacturing segment. By 2035, the market could reach $242 million for R&D and $1.2 billion for manufacturing.

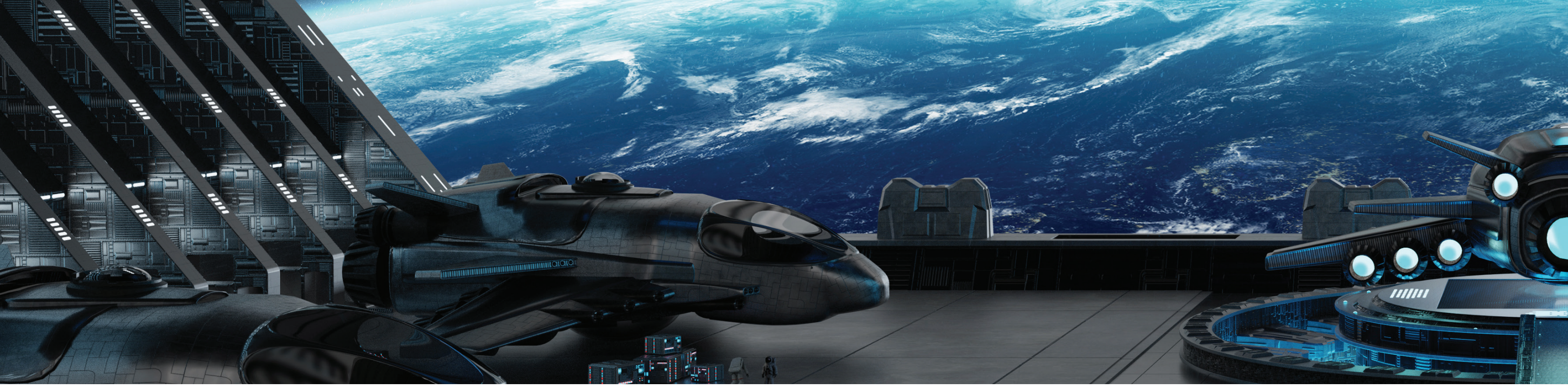
A high-growth view: The Fourth Industrial Revolution takes to space

In our most optimistic scenario, we anticipate that next-generation spacecraft enter the market on schedule, enabling transformative cost reductions in access to LEO. The resulting launch frequency supports rapid development cycles and enables first movers to begin scaling manufacturing capabilities before the end of the decade. R&D grows as quickly as orbital laboratory capacity can fulfill it, and the resulting breakthroughs in biopharma and other fields lead to high levels of investment. The net impact of successful industrial, scientific, and health care ventures reinforces consumer affinity for space and leads to sustained interest in luxury goods made or flown in space. In this scenario, we anticipate the market for R&D could exceed $384 million, with manufacturing approaching $2.4 billion annually by 2035.

Market estimates

For the R&D segment, we broadly assume that demand for microgravity research will remain strong and be limited by available capacity in orbital laboratories. As such, our models are driven by supply-side assumptions regarding the potential timing of new facilities coming online. We acknowledge the importance of downstream revenue created by firms participating in microgravity research but do not include that value in our estimates.

For manufacturing, we combined assumptions for capital investments (such as establishing production infrastructure on-orbit) and operational costs (such as materials, labor, and transport) with demand data from a variety of sources to test the business cases for a mix of goods. Because the market for space-made goods is so new, our demand analysis draws from a combination of industry benchmarks, comparable goods, and direct consumer research. Some opportunities, like affinity-based branding, are not reliant on



specialized infrastructure in orbit and can feasibly be scaled in the near term. Most on-orbit production use cases, on the other hand, will depend heavily on new infrastructure to be developed. As such, our market estimates only include cases of on-orbit production where the necessary technology either exists or is in development today.

With this approach, we estimate that the combined R&D and manufacturing markets could generate between $710 million and $2.74 billion in value by 2035. In figures 7 and 8, we explore three potential future scenarios, ranging from constrained to high-growth, that could unfold. However, we caution that these estimates are highly speculative. Delays are likely in the key infrastructure projects needed to provide launch and return, power generation, and other capabilities for growth.

FIGURE 7

Orbital R&D market size by year across scenarios

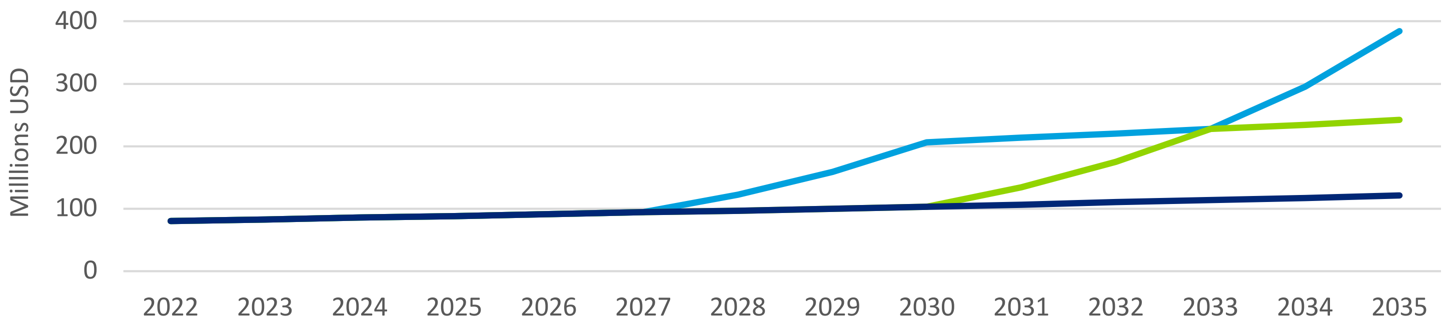
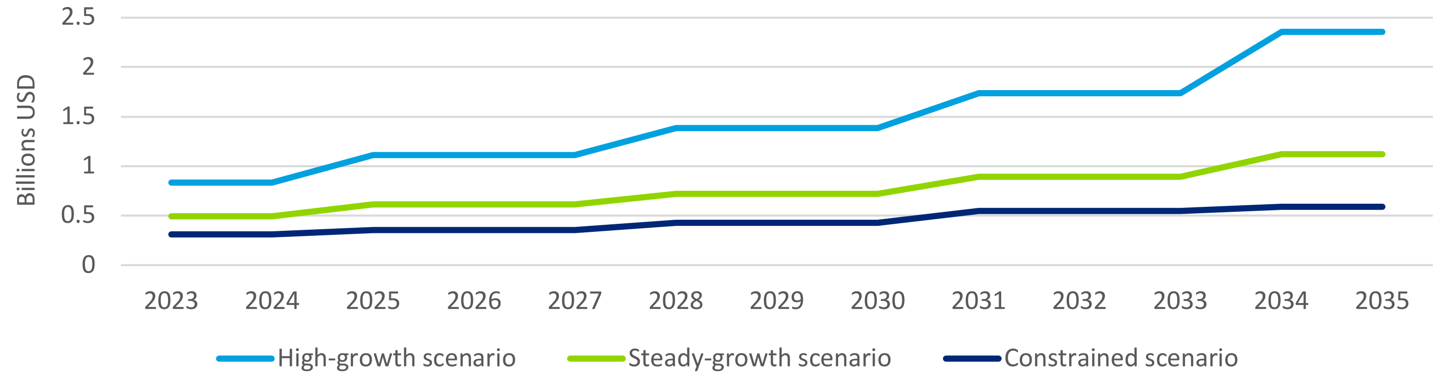
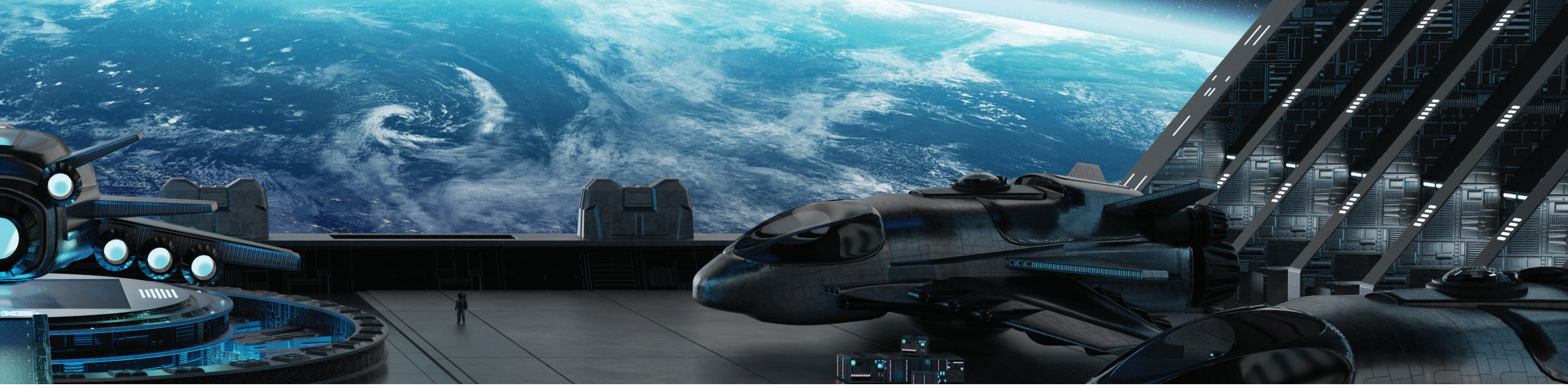


FIGURE 8

In-space manufacturing and affinity branding market size by year across scenarios





Delivering the future

What is it going to take to bring Earth to space via R&D and manufacturing?

Guided by the market dynamics we have explored, we turn our focus to the near-term steps industry and government can take to navigate toward the end state we envision for R&D and manufacturing in LEO. Building a successful market will require a multisector approach to stimulate short-term demand while establishing the foundational infrastructure that will support long-term growth. What follows are six interdependent strategies we believe can be applied in the next six to 12 months to accelerate that journey.

Building capacity for launch, return, and orbital platforms through direct incentives

Due to current supply-side constraints, growing the R&D and manufacturing segments will require more frequent and lower-cost access to LEO, more capacity and diversity in cargo return vehicles, and successful development of new orbital destinations and free flyers. Until these critical infrastructure components are realized, government may need to continue incentives for first movers and early adopters. To build the foundational capability to enable a self-sustaining economy, we suggest prioritizing business cases that close at scale for products made in space. CASIS's recent focus on in-space production is an important start, but we believe a greater focus may be needed on direct incentives for infrastructure development that resolves key near-term constraints: upmass cost and increased downmass capability. This will serve to drive down risk for prospective market entrants, while laying the foundations for the market. These efforts may also entice further private sector investment to build momentum toward a self-sustaining future.

Aligning priorities and investments for R&D across the innovation curve

A healthy R&D portfolio is one that balances investment along the entire innovation curve—from basic science to proof of concept and beyond—while supporting an equitable mix of commercial and public interests. However, we recognize that there is no single entity empowered to actively manage the R&D portfolio across a mix of government and commercial programs. Achieving a balance that continues to meet the needs of diverse stakeholders and contributes to a pipeline of on-orbit use cases will likely require close collaboration across government, industry, and academia. Collectively, these groups should review and reassess the portfolio and seek to align investment in the priorities best served by each sector.

We also see the potential value of "farm systems," such as suborbital flight opportunities, drop towers, digital twins, simulation, and other strategies, that can help reduce risk for R&D at low-technology readiness levels. Even with deep government subsidies, the commitment required to take a payload from an idea to the ISS is generally measured in months to years. Terrestrial and suborbital farm systems, on the other hand, may provide a more attractive opening for a wider base of potential users. Dedicating resources to systems like these may reduce portfolio risk at low additional cost, increasing the ROI for dollars spent on orbital R&D. As such, NASA and industry should consider defining and developing pathways for relevant use cases to obtain early and reliable access to a variety of farm systems as an on-ramp to commercial activities in LEO.

Operating at the speed of business

To increase participation among the Fortune 500, there is a clear need to improve the speed and efficiency of orbital R&D to better align with the technology development life cycle in terrestrial industries. Simply put, the market needs to move at the speed of business. Private industry—particularly the companies aiming to support R&D on new private space stations—should consider building the operating models, capabilities, and services needed to address this issue. For example, working upstream to integrate the capabilities needed to offer "microgravity as a service" may help shorten lead times and make space accessible for new customers without flight-ready payloads. We also suggest that NASA consider implementing strategies to foster a more fully commercial "free market" option for R&D (i.e., independent of CASIS NRLA solicitations and support) between 2023 and 2024, to help industry test new operating models and assess price points the market will support.

Working in sync with commercial customers will also require more clarity around intellectual property (IP) rights, taxation, data ownership, privacy, and other legal matters related to commerce. For example, NASA has indicated that it will not reach into corporate IP, but governmentwide legislation governing IP has not yet been established.[42] The US legislative branch should consider moving

quickly, in coordination with NASA, the US Office of Space Commerce, and other relevant agencies, to establish laws and policies that provide industry and the investor community with the clarity they need to move confidently forward in commercial space ventures.

Capitalizing on the consumer affinity for space

Building the future infrastructure for commercial R&D and manufacturing in LEO is an expensive proposition. And while the investment landscape has been healthy of late, it's also critical for industry to leverage current assets to the maximum extent possible to generate positive cash flow. To this end, we suggest that commercial crew and cargo providers today—as well as new entrants to the launch services market—consider prioritizing subsegments of demand that are commercially viable now. To this end, we believe firms should nurture a pipeline of campaigns for affinity-based premium goods that can be executed in concert with other mission objectives, thus maximizing the value of each flight. Of course, pulling this off profitably is easier said than done. Relying on the scarcity and novelty of space-flown goods without savvy marketing and branding may be a losing proposition. To succeed in this space, we suggest close collaboration with established brands to create winning campaigns.

Engaging industry with capabilities and strategies that resonate

Realizing near-term growth in space manufacturing will require the private and public sectors to think creatively about terrestrial demand for space-based products. Tapping into established markets by offering specialized products that fill a niche in demand can be a logical point of entry to help mitigate risk. However, we also suggest engaging more broadly with prospective customers across the Fortune 500—especially those outside of industries like biopharma that are already engaged in microgravity R&D.

As with affinity-based branding, we continue to find evidence of how important it is for space technology companies to adapt their strategies and capabilities within the context of each market segment, if not for each customer. We suggest the space industry look closely at the prevalent business strategies of successful companies that represent future customers. This includes customers ranging from life sciences and pharmaceuticals to industrials and heavy machinery. Understand and apply strategies from each industry in how you go to market, learn to communicate based on your capabilities rather than your technologies, and look for opportunities to get your customers' skin in the game using win-win strategies for long-term value capture. For example, partnerships based on exclusivity or that apply value-based fee structures have potential to entice customers earlier in the development cycle.

Collaborating to efficiently serve early markets

The term *complementarity* refers to a relationship between goods and services that, when they exist in the market together, creates more demand. In other words, the whole is greater than the sum of its parts. Our vision for a thriving R&D and manufacturing market in LEO is full of complements, and many of the companies in "new space" have business models that rely heavily on others to succeed. With this as a prevailing dynamic, the most likely ways to succeed are either to maximize integration—both vertically and horizontally—or to seek interoperability and partner with others to build synergies. There are advantages to each approach, but the reality is that no one entity can do it alone. Even the "lone wolves" targeting a certain corner of the market may find that "hunting in packs" is a useful strategy. As industry and government seek to build a self-sustaining industrial base in LEO, it will likely be important for emerging suppliers to continue collaborating, communicate their core capabilities within the marketplace, and embrace opportunities to develop standards that support interoperability.

NASA and CASIS should consider developing and sharing a concrete road map for the ISS National Laboratory during the transition from the ISS, both during a period of mixed public and private infrastructure and for a fully commercial set of facilities in LEO. This includes defining a procurement strategy and expected quantities for leasing or buying space and resources on commercial facilities, as well as clearly delineated focus areas and criteria for what R&D projects will be supported with NASA funding. For example, NASA

and the ISS National Lab may designate a technology readiness level (TRL) as the threshold for off-ramping projects to commercial operations. Without that clarity, suppliers may perceive the possibility that NASA could subsidize their customers' projects as too great a risk to make the capacity investments needed. A useful road map for the ISS National Laboratory could also include near-term steps that allow R&D partners to begin testing business and operating models that resemble a fully commercialized market. Finally, subsequent awards for commercial destinations and free flyers may improve overall market viability by guiding and incentivizing more differentiation between the R&D and in-space production capabilities NASA is seeking from each partner. In essence, this strategy may support the development of an ecosystem of complements that could be difficult to achieve in a free market scenario.

The Deloitte game plan for stimulating R&D and manufacturing in LEO

While acknowledging uncertainty and challenges that lie ahead, we believe that a pragmatic, collaborative, and value-driven approach will enable steady growth toward a self-sustaining industrial base in LEO. If we, as a collective industry, can build successful models to increase microgravity utilization among the Fortune 500, capitalize on the near-term revenue opportunities, and synchronize development cycles with the right public and private investment, there is likely to be significant long-term upside in commercial R&D and manufacturing in LEO.

We believe LEO has a major role in the next industrial revolution and have identified ways in which economically viable business cases can generate substantial revenue in both the near and long term. Going forward, we will continue to engage across sectors and industries to understand and identify the greatest challenges and opportunities for growth. We invite you to join us on this journey to the future, today.

Let's talk

Deloitte Space is the world's first professional services practice devoted to supporting the entire space value chain, from both government and private sectors, and from Fortune 500 companies and aerospace stalwarts to emerging space companies and startups that we currently support. We have space professionals in Washington (DC), Colorado, California, Texas, and Alabama, as well as globally in the United Kingdom, Australia, Canada, Japan, Luxembourg, New Zealand, and the United Arab Emirates. In addition, we are a premier provider of supporting capabilities such as finance, cyber, technology, data, and other professional services for government space agencies, commercial aerospace companies, and academic entities focused on space science and systems.

Deloitte is confident that we have and will continue to demonstrate a strong understanding of the space enterprise. Our 360-degree perspective underscores our fresh and holistic thinking about challenges in space. We possess differentiated knowledge of New Space, as well as outside perspectives on the United States Department of Defense, government, open architecture, and enterprise transformation. Our specialists have helped launch rockets, deploy satellite remote-sensing systems, implement global telecom solutions leveraging commercial satcom, analyze the commercial space economy, and secure private investment for space technology companies. An advantage we have over our competitors is the broad array of resources available at any given time, allowing us to leverage experience, eminence, skills, credentials, and—most importantly—perspectives that very few can match.

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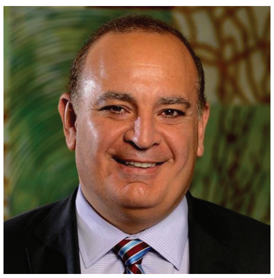
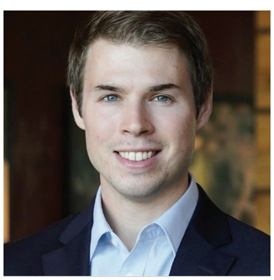


Sam Kapreilian
Principal
US Consulting Space Leader
Deloitte Consulting LLP
skapreilian@deloitte.com
+1 617 797 7440

Keith Pfromer
Managing Director
Civil Space Leader
Deloitte Consulting LLP
kpfromer@deloitte.com
+1 703 939 0011

Emily Carr
Managing Director
Civil Space Leader
Deloitte Consulting LLP
ecarr@deloitte.com
+1 703 258 2606

Arthur Anglin
Manager
Lead Author
Deloitte Consulting LLP
aanglin@deloitte.com
+1 678 296 6580



Andrew Stiles
Senior Consultant
Contributing Author
Deloitte Consulting LLP
astiles@deloitte.com
+1 571 814 7016

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