1.1 Executive Summary

Axiom Space has concluded that a transition from the International Space Station (ISS) to a fully commercial Low Earth Orbit (LEO) human rated platform is both achievable and essential. A transition to a commercial platform will ensure continuous and uninterrupted U.S. leadership in space and enable the growth of a self-sustaining and thriving economy in LEO. A transition will also allow the government to afford human exploration beyond LEO. The study also concludes that implementation of such a transition will require immediate action by NASA to ensure a capable platform from an experienced provider is available and fully operational when the ISS is retired thus avoiding a gap in LEO capability.

If a transition is executed in an expeditious manner, NASA, the International Partners and new commercial entities will have uninterrupted access to a LEO platform when the partner governments decide the cost of operating ISS outweighs its benefits. The cancellation of the Space Shuttle program before a viable US crew transportation capability was available is a stark reminder that the ISS program, which costs even more than the Space Shuttle program did, is at risk. The current administration is already considering an end date for ISS in 2025. NASA needs to act now to make certain a viable replacement for ISS is on orbit and ready for stand-alone operations by the time the ISS is de-orbited.

Axiom Space has been actively working towards the design and development of a commercial space station for three years. Progress has been made both in the Axiom station design and a viable long-term business case for development, launch and operation of the Axiom commercial space station. Axiom is uniquely positioned to support and maximize the commercialization of LEO in line with NASA's goals.

Six user types have been identified that will or already have taken advantage of the ISS and the market is expected to grow as a broadening user base exploits the capabilities of a human-rated platform in LEO. These users and the expected revenue are discussed in detail in the Axiom study.

The ISS has been critical in developing technical and operational capabilities in LEO, including the development of commercial crew and cargo transportation capabilities. The ISS will continue to be critical to the transition to a fully commercial market. However, certain issues hinder its use as the basis for long term commercial activities. These issues include the complexity of coordinating with the International Partnership on commercial business decisions; the relatively high, and likely rising, cost of sustaining and operating the current platform; and, the enormous liability associated with the 900+ million pound platform, not specifically designed to be de-orbited, that prevents the government from handing responsibility to another entity.

Axiom has identified a number of specific recommendations that NASA and the US Government should take to ensure a successful transition to a commercial LEO marketplace where private business supplies services to government and commercial customers. Some of these

recommendations are summarized here. All of our recommendations and the details of the ones included here are addressed in the study report.

Complete the award of an ISS port as soon as possible. The single available port on ISS is critical to enabling a commercial space station that NASA can rely on by the time ISS is cancelled. As previously noted, delaying this award risks a potential gap in American astronaut presence in space and threatens U.S. global leadership in space.

Avoid competition with commercial providers. Commercial providers will be building their critical early markets by sales of services on orbit. These represent available markets today that indeed NASA could service should it desire. NASA's entry into such markets as a "vendor" will effectively eliminate commercial entities from competing there, as none have the ability to match NASA's resources and brand recognition.

Adjust the ISS Code of Conduct. Since it is expected that the ISS Code of Conduct will apply to astronauts flown by a commercial provider to the ISS, the limitations on advertising should be relaxed to allow these commercial providers to sell advertising and sponsorships as part of developing the commercial market.

Remove Intellectual Property (IP) restrictions. Under present policy, there are restrictions on IP ownership constraining commercial markets. Users of a commercial service will want to retain exclusive rights to IP developed under commercial contracts. The policies should be clarified such that IP developed commercially is retained by the commercial developer.

Clarify On-Orbit Authority. While launch and reentry licensing has been assigned to the Federal Aviation Administration (FAA), there is currently no single federal authority dealing with LEO spaceflight.

Implementing such a commercial transition naturally entails risks, including technical risk associated with designing a complex human-rated space station and financial risk as potential LEO markets grow and mature. These risks can be mitigated via the extensive knowledge of an experienced LEO station provider team and through incremental demonstration of the team's ability to obtain financing, secure customers and achieve the operational tempo necessary to safely operate a LEO station. Recommended demonstration milestones are discussed in the study. It is important to mitigate these risks appropriately, but rest assured they will not be completely mitigated to everyones satisfaction. However, there arguably exists an even greater risk in failing to take immediate steps in a direction that will permit a commercial station to be ready when ISS is cancelled. This risk of cancellation has never been more obvious than today, as we anxiously await an operational commercial crew vehicle to become available before our Soyuz options to get US crews to ISS run out.

Axiom Space created a multi-phased approach to satisfy the incremental demonstrations outlined above. The Axiom vision for commercializing LEO includes the development of an evolvable commercial space station that will, in the early stages of assembly, be comprised of multiple modules attached to the ISS. The additional user infrastructure and crew time available to the ISS once Axiom begins assembly will increase opportunity for ISS National Laboratory scientific output as well as provide new commercial in-space manufacturing opportunities.

The initial configuration of the Axiom Station will provide capabilities on a scale that will meet projected near-term demand, and the station will grow incrementally in both size and capability as demand grows. Upon ISS retirement, the Axiom Station will separate and operate as a free-flying commercial space station providing LEO services and capabilities for NASA and its partners, for the National Lab and for commercial users.

BLUE ORIGIN

LEO Commercialization Study Executive Summary

This study of Low-Earth Orbit (LEO) commercialization provides an early first step for Blue Origin to investigate the path toward our vision of "millions of people living and working in space." Executing on this vision requires many incremental steps to drive down costs and increase both government and commercial access to space. The reuse of space systems is a critical step to dramatically reduce costs and enable the creation of new markets/products for use on the earth and in space. We look forward to developing systems that are part of NASA's and Blue Origin's space architecture.

As part of the study, Blue Origin studied a variety of potential commercial LEO markets to understand their current size, potential for growth, and the key attributes required of the technical solutions that enable them. The assessed market areas were habitable volumes, education/entertainment, manufacturing, operational hubs, satellite assembly/deployment/servicing, and science and technology testbeds. Our near term market forecast focused on more mature orbital markets for immediate commercialization, resulting in fairly conservative estimates of the in-space manufacturing and the in-space satellite assembly, deployment, and servicing markets.

Given these findings, we define the near-term market as one where potential revenues are dominated by the government astronaut and research market, with potential ancillary revenue from orbital tourism and commercial applications (such as in-space manufacturing). We believe a commercially operated habitat, architected to reduce construction and operations costs, best serves this market — although it will still require decreased transportation costs and other potential interventions to become financially sustainable businesses.

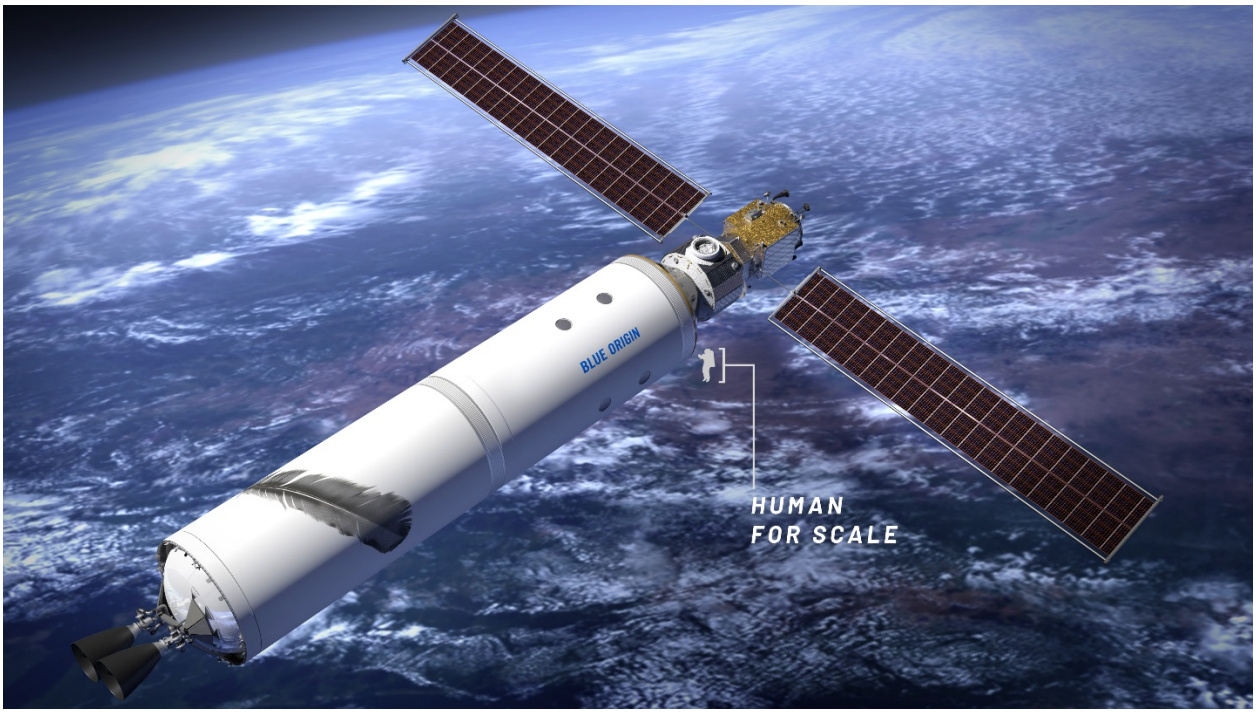
We believe that achieving significant life-cycle cost reductions is what will enable other, longer-term markets to form, not the passage of time or the retirement of existing LEO capabilities.

Given this, industry should focus on cost innovations, rather than market expansion Blue Origin's approach is a single-launch orbital complex supported by an ecosystem of products and capabilities. Suborbital launches on New Shepard enable a path to rapidly de-risk and deploy disruptive and innovative LEO ventures. New Glenn enables inexpensive transportation to LEO for orbital accommodations, payload resupply, and human transportation.

The orbital complex supports NASA's ISS Transition Principles and maintains a continuous human presence in space after the ISS is retired, but does not depend on ISS retirement in order to be financially sustainable. The proposed operational orbit is similar to ISS. This enables existing crew and cargo transport vehicles to service the complex. It also means the ISS (and its crew) could potentially provide emergency or operational support, especially during initial deployment, check-out, and early operations.

Blue Origin's orbital complex architecture is designed to reduce the estimated development and operational costs by at least an order of magnitude compared to historical systems, both in absolute terms and on a cost per unit of pressurized volume basis. The low cost architecture is possible because it leverages and reuses several critical subsystems that are part of the New Glenn launch vehicle upper stage (e.g. avionics, propulsion, sensor suites, etc.), as well as tooling and manufacturing processes already developed for the New Glenn program. The habitat is also designed to reduce the on-orbit labor required to outfit the complex (another source of cost reduction), primarily by building design features into the habitat that eliminate the need for extra-vehicular activities and enabling final outfitting to occur in a shirt-sleeve

environment instead of pressure suits. Blue Origin's orbital complex is envisioned primarily as a free flying habitat, although interactions with ISS are technically feasible.



After accounting for these cost-reduction measures, the resulting cost driver is the development and operational costs of particular subsystems. As such, a potential way that NASA could support the commercialization of LEO is to provide government property and/or spearhead the development and use of commercial-grade, low cost subsystems that enable an order of magnitude reduction in development and operating costs for NASA and the commercial sector.

NASA's continued willingness to embrace commercial contracting approaches, such as funded Space Act Agreements, Public-Private Partnerships, and commercial services contracts is another important element that will expedite the commercialization of LEO. These approaches reduce the cost of compliance (compared to traditional contracting methods), broaden the eligible industrial base, share the risk burden more equitably, and encourage companies to demonstrate their commitment to the product, market, and mission by putting their own capital at risk in development.

Executive Summary

United States leadership in human spaceflight necessitates an innovative and sustainable Low Earth Orbit (LEO) program which leverages ISS to incubate commercial opportunities and grow the demand for space services in LEO. We endorse the continued operation of ISS as long as the Station is able to operate safely and reliably, even as we work together to return to the moon and press beyond into deep space. Based on our study, an orderly approach to transition LEO from a predominately government dominated environment to a mixed economy consisting of public and private enterprise benefits both NASA and U.S. industrial competitiveness.

Growing the LEO market requires time. ISS has the capacity to satisfy all commercial market opportunities, but the likelihood these opportunities fund the entire ISS by 2025 is low, if even possible. ISS should serve as an incubator to establish a pathway to these future commercial opportunities. Once the market matures and privately owned space platforms are operational, NASA becomes one of many customers.

MARKET FORECAST

Bryce Space and Technology, a space market assessment leader, provided an independent and data driven 15-year (2025-2039) market forecast for LEO commercial activities. Bryce identified LEO market segments with associated risks and uncertainties. Bryce then applied a market-specific methodology to model revenue scenarios. Our team estimates the market for a LEO platform operator at $12.3 billion for the 15-year period, excluding transportation-derived revenue. Our team developed a range of government actions likely to grow the commercial LEO market (Figure 1).

Figure 1: Market Segments

LEO DESTINATIONS

The technical concepts include destination options and capabilities which encompass the range of general industry concepts. These concepts are utilized for business analysis. Actual designs will be dependent on emerging commercial LEO markets. All concepts are designed to operate at an altitude of 400km and an inclination of 51.6 degrees (Figure 2).

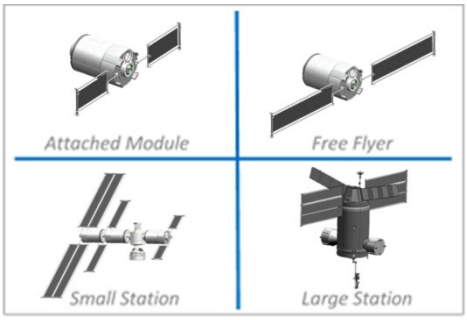


Figure 2: LEO Destinations

BUSINESS ANALYSIS

Boeing performed a business analysis using standard industry practices to determine whether the business scenarios are attractive to investors. The analysis used an aggressive, pragmatic approach. The baseline scenario evaluated the market revenue against total engineering estimates for development, operations, and transportation and resulted in negative after-tax net present value (NPV) for the forecasted period. In pursuit of an attractive business scenario, we assessed options where the values for development, transportation, and both development and transportation were

Executive Summary

set to zero. Overall, the after-tax NPV for all scenarios remained negative throughout the forecasted period. To achieve a positive after-tax NPV, LEO demand must grow 8 to 50 times the market revenue.

ISS TRANSITION

Our study assesses the ISS program and determines a full transition to industry is viable. Industry has demonstrated capabilities and experience addressing the full scope of the program. We examine a range of options and opportunities and develop innovative approaches to reduce ISS operating costs while maintaining safety.

We also examine ISS customer interface options that facilitate a transition from a government owned and operated ISS to a commercially operated model. A transformation of the customer interface sets the stage to leverage investment in ISS to incubate commercial opportunities and provide continuity of research.

CHALLENGES

Our study identifies key challenges for LEO commercialization including potential mitigation steps (Figure 3).

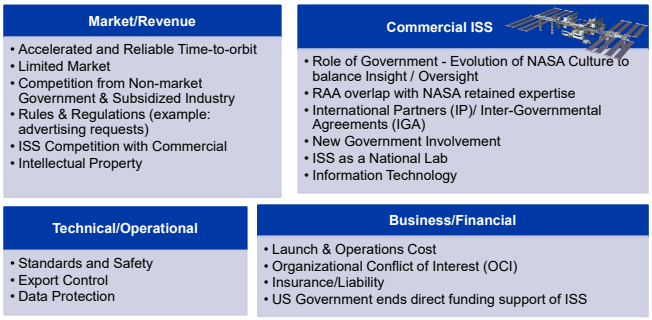


Figure 3: Challenges

ROADMAP

Our roadmap outlines the path to future commercialization of LEO. The current need is to stimulate market demand. The U.S. should leverage the ISS to incubate new and emerging markets, increasing commercial demand until it drives a need for new platforms. A transition of ISS operations to industry can be used to drive costs lower. Once the market reaches maturity, NASA can become one of many customers (Figure 4).

Figure 4: Roadmap

Executive Summary

INTRODUCTION

Deloitte Consulting conducted a study to evaluate the viability of the human spaceflight (HSF) industry in low earth orbit (LEO) as a self-sustaining, stand-alone, commercial enterprise with the goal of NASA being one of many customers. The study was conducted from September to December 2018. Leveraging business and economic analyses, the study developed insights about market conditions, supply and demand, drivers, risks, and future scenarios. The results concluded that the current market conditions do not yield a self-sustaining, stand-alone, commercial human spaceflight industry in LEO. With this in mind, the study asserts that demand for HSF can be enabled with actions in four areas of in-space activity: tourism, manufacturing, life sciences research, and media, advertising, and entertainment. NASA has a prominent role in shaping the future of HSF in LEO and can support the continued growth and development of the commercial industry with actions and policy. The study concludes that implementing the recommendations to enable demand may jump start commercialization. These actions will support the market, enable subsequent use cases, prove feasibility of new capabilities, open new markets, create capital for investment, and most importantly, put more humans in orbit. In the absence of action by NASA, the current structure of the industry may not experience the transformation needed to serve NASA as one of many customers.

APPROACH

Our approach to conducting this study began by developing a holistic commercial industry baseline that examined multiple forces and factors driving value creation within the commercial space economy. A baseline allowed for the analysis of structural factors and external forces on supply, demand, and market attractiveness characteristics that limit growth of individual HSF value chain components. In conjunction with the baseline and value chain analysis, the study assessed future HSF use cases that provided key insights into enabling factors for tourism and manufacturing. Lastly, the study examined how other government agencies incentivized commercial demand, often with limited resources, in complex industries. The summation of the analysis is presented in the findings, recommendations, and roadmap.

FINDINGS

The study approach generated five findings about the HSF industry in LEO. The overarching conclusion is that HSF is not self-sustaining as a stand-alone industry, in current market conditions. The following findings outline the rationale for this conclusion.

1	Structural barriers are significantly limiting the market's ability to satisfy demand on-orbit.
2	Launch costs represent the highest barrier to increased human spaceflight value generation.
3	Non-NASA demand is difficult to characterize and size.
4	Supply is optimized for NASA's needs, but not for commercial business.
5	Value chain segments are interconnected and not maturing in a complementary way.

The findings highlight that the underpinnings of the commercial HSF industry, as it currently stands, are enmeshed in risks. These risks impede the development of the industry and are so intertwined that one realized risk could trigger failure across the value chain. Industry risks fall into the categories of financial, business, strategic, and regulatory. It is with this four-pronged lens that the impact of the value chain's interconnectedness can be truly understood as complex.

Financial risks. The HSF value chain is characterized by high development costs and low sales volumes. Unless the market is able to scale and amortize development costs over more units, prices will remain high. In addition, venture capital has not taken a strong interest in the HSF value chain. Unless companies can access capital, growth will be limited.

Business risks. The HSF value chain continues to be plagued by delays and backlogs, which dampens expectations for supply and reduces demand. With dependencies among the segments, these trickle through the value chain in the form of increased costs and lost opportunities. Unless suppliers are able to make improvements in timelines, buyer confidence will continue to waver. Further, the HSF value chain is dependent on continued operation of the ISS. Uncertainties regarding its lifetime does not encourage market entry and long-term business decisions. Unless there is a clear timeframe for ISS operations, suppliers and investors may be deterred by the diminishing lifetime of the ISS.

Strategic risks. High launch costs hinder the growth of the HSF value chain. The price of goods and services will remain out of reach for most commercial buyers without appreciable decreases in launch costs. The HSF value chain is constantly under threat from cheaper and faster alternatives. Unless LEO continues to demonstrate its comparative and competitive advantage, buyers may go elsewhere.

Regulatory risks. NASA provides transportation and integration costs for National Lab users, lowering the costs to buyers. Demand will decrease if National Lab users must bear the full costs of using the ISS. Further, the HSF value chain faces a mix of policies and regulations. Human rating requirements and spaceports are two areas with significant oversight, while manufacturing is a new area of space activity with little regulation. Unless there is clarity on how government will engage with existing and new areas of space commerce, uncertainty in the market may stifle growth.

RECOMMENDATIONS & ROADMAP

Despite the aforementioned risks, demand for HSF can be enabled. When activities or operations supported by HSF are incentivized, demand, and therefore value generation, increases to an inflection point that supports additional humans on-orbit and grows nascent HSF markets. Therefore, the study recommends focus on four key areas to stimulate demand.

Tourism, when enabled, has the potential to put the most humans into space and has a sizable demand pool. Implementing these recommendations increases the demand for HSF and enables subsequent use cases. Potential demand, when fully enabled and incentivized, could result in a total addressable market of $3,094M. Under the study's assumptions, this level of demand could place approximately 387 additional humans in orbit per year.

Support the designation of a financial entity that will accomplish the following:

1. Create a capital pool to create subsidies or offsets for space tourism or infrastructure required to support space tourism.
2. To fund this capital pool, leverage capital or revenue sources outside of the traditional federal budgeting cycle such as media and brand monetization revenue.
3. Aim to subsidize the per seat costs so that price per seat is between $8M and $11.5M to create the largest inflection point.

When enabled, **Manufacturing** has the largest demand pool and subset of uses as it could potentially service multiple types of consumers, corporations, and/or governments. Implementing these recommendations validates in-space manufacturing at scale through the production of premium consumer goods and exotic materials. Potential demand, when enabled and incentivized to produce at scale, could result in a total addressable market of $40M per year with expectations of further growth as at-scale production is demonstrated. Based on the study's assumptions, this may translate to an additional 9 humans in orbit, depending on the specific manufacturing activities undertaken, per year.

Recommendations are as follows:

1. Subsidize an initial run of exotic, space-made materials (e.g., ZBLAN fiber) to validate at-scale production, applications, and the terrestrial market.
2. Support the identification of additional, consumer-focused products that can be made in space at scale and de-risk further manufacturing of other exotic materials.
3. Leverage the NASA brand, allowed through expanded media, advertising, and education activities, to drive consumer awareness of the potential for space-made consumer-focused products, thereby increasing the terrestrial demand for on-orbit manufactured goods.

The **Life Sciences** use case is already enabled and has the largest untapped addressable market in the short term with room for growth and expansion on a global scale. The potential outcome of implementing the recommendations includes growth of the current market and space station utilization. Potential demand, when fully enabled and incentivized, could result in total addressable market of $519M per year. Based on the study's assumptions, this may translate to an additional 9 humans in orbit, depending on the specific manufacturing activities undertaken, per year.

We recommend that NASA:

1. Support a campaign to better disseminate the applicability of microgravity to the life sciences domain, as well as the capabilities and value generation from experiments in microgravity.
2. Engage more with industry and industry experts to better understand non-traditional space actors, their competitive pressures, and the market dynamics around life sciences R&D.
3. Coordinate with commercial industry on how to best align ISS experimentation pipeline planning to the R&D lifecycle stages for life sciences (i.e., determining the lead and lag time for planning and completing microgravity experiments for applicable pre-clinical phases).
4. Determine the applicability of current ISS facilities to current, emerging, and future life sciences origin types (e.g., chemical, biological, protein, or natural).

If enabled, **Media, Advertising, and Entertainment** requires the least number of humans in space but supports the creation of substantial offsets or subsidies for additional humans on-orbit. The outcome of implementing the recommendations is the potential creation of capital that can be

reinvested into HSF as subsidies or offsets and helps drive demand for consumer space goods. Potential demand, when fully enabled and incentivized, could result in $579M in assumed annual revenue. This use case does not require additional humans in orbit but could fund additional humans in orbit.

We recommend that NASA:

1. Diminish regulatory or policy limitations that preclude additional, and monetized, media, advertising, and entertainment activities.
2. Engage with a branding agency capable of understanding the constraints of a government brand and the challenges of monetizing a storied brand to develop the consumer monetization strategy and guidelines.
3. Charter an industry advisory group composed of both government and media executives to help steer the implementation of monetized media around the NASA brand in space.
4. Support an appropriate entity to accept and reinvest profits into the HSF value chain in the form of subsidies, offsets, or purchases of products or services including consumer goods.
5. Leverage the brand and social media base to drive consumer demand towards the in-space manufacturing of consumer-facing goods by third parties on the ISS to de-risk the overall manufacturing activity.

CONCLUSION

Individually, the recommendations have the potential to stimulate demand and create value in the HSF industry. Collectively, the recommendations support positive feedback loops across the value chain, further stimulating demand. The study developed a roadmap to define the optimal path for implementing the recommendations. This roadmap sequences 15 specific recommendations that focus on developing commercial opportunities and enabling additional HSF demand. While the recommendations are linked together to provide paths and methods for incentivizing demand, these recommendations are meant to be provider agnostic with outcomes applicable to the ISS and future human platforms. While each pathway in the roadmap can be addressed independently, collectively they demonstrate a path towards increased value generation in LEO.

The recommendations and the roadmap provide a path forward for incentivizing demand and creating value generation in LEO. These actions support growth in the market, enable subsequent use cases, prove feasibility of new capabilities, open new markets, support capital for investment, and most importantly, put more humans in orbit. In the absence of action by NASA, the current structure of the industry may not experience the transformation needed to serve NASA as one of many customers.

LOCKHEED MARTIN

Study for the Commercialization of Low Earth Orbit (LEO) Final Report

December 19, 2018

EXECUTIVE SUMMARY

Lockheed Martin (LM) shares the National Aeronautics and Space Administration's (NASA's) vision for a robust Low Earth Orbit (LEO) human spaceflight enterprise in which NASA is one of a number of customers for cost-effective technologies, services, and capabilities offered through innovative public-private partnerships. In order to fully leverage the current political and societal support for deep space exploration in the face of a historically flat NASA budget, it is imperative to reduce the NASA-borne costs in LEO while ensuring the United States remains a leader in the international endeavor of human spaceflight. As part of the study for Commercialization for Low Earth Orbit contract LM has evaluated three aspects of the foundation for a vibrant LEO market: new business approaches and contractual mechanisms for ISS sustainment and operations; an evolution of ISS including new ISS configurations and entirely new free-flying platforms; and a commercial solution for in-space manufacturing and assembly (ISMA) on the International Space Station (ISS) with application to a wide range of customers, both at ISS and for potential use on other free flying platforms.

LM has systematically approached the privatization of ISS by evaluating current ISS elements and capacity that can be used beyond 2025, comparing business model options to privatize selected day-to-day ISS activities by 2025, identifying new customers and markets for products and services, and assessing business case and financial viability to sustain long term ISS operations. The key findings are that in order to retain assured access to LEO, continue International Partnerships, and to maintain world-class lab capabilities the government must act as the anchor tenant. NASA can lower costs of the existing system by leveraging Shuttle experience with USA and recent exploration sustaining/operations RFI activities to move management of existing ISS to private sector to a government services contract. For commercial crew and cargo transfer by privately owned and operated spacecraft and control centers, a single procurement with multiple awards for FY25-FY28 base could be a significant motivator for companies to reduce costs.

In the near term, NASA should be an opportunistic operator/tenant looking at the long-term view for tax-payers, and encouraging businesses to go to LEO through the use of tax incentives and special economic zones (SEZ) with NASA receiving royalties or longer term dividends after early investments or subsidization of commercial demonstrations. From LM's research and collaboration with potential commercial users, several capabilities that enable commercialization have been identified; these include: use of independent projects focused on future needs without redesign of the host vehicle, a fully developed docking mechanism that meets the International Docking System Standard along with the autonomous rendezvous and docking sensor suite and software package, and in-space refueling and servicing through the use of in-space manufacturing and assembly. These enablers along with a reliable launch cadence of US based cargo and crew delivery establish a stable market which lowers the risk for future investors and commercial users. A reliable market with regular revenue streams requires that infrastructure is established with predictable business considerations. Some market considerations LM evaluated include methods to establish standardized space commodities to serve national security and to grow a sustainable space economy, accelerating activity through more transparent and predictable access to LEO, and the balance between risk and reward to give investors the necessary return on investment.

A business model that meets the needs of NASA, DoD, and commercial partners going forward

will be key to a sustainable LEO platform. LM has identified strengths and weaknesses of a variety of business models, and recommends a Government Owned Contractor Operated (GOCO) model that incentivizes the service provider to engage and integrate non-NASA users to accelerate LEO commercialization. This model allows NASA to sustain the International Partnerships established on ISS through multi-lateral government negotiations to extend operations past 2024. It also benefits industry through a single government interface. The GOCO model can also have clauses that give financial incentives to streamline processes and tools, as well as increase transparency in costs will facilitate expansion of commercial users.

LM also looked at ISS vehicle maintenance services contracts and recommends fixed price, condition-based maintenance and spares that incentivize the provider for working systems rather than for time and materials associated with system repairs. Basing financial incentives off working systems can lead to companies investing internal funds to improve prognostics and reduce overall system down time.

Several business case studies were evaluated to compare the costs and possible revenue of several possible evolution concepts of the ISS. LM compared the current continuously crewed operations (180-day increments) with intermittent crewed operations (90-day increments). LM also looked at variations such as two-person crew on a one-year increment, and four-person crew on a one-year increment. Continuous operations by a full crew of four was a much better value than intermittent operations for all LEO vehicle options. Our model showed a potential for 18% EBIT with reduced operating costs and continuous operations with the existing ISS.

LM explored pathways to achieve a smaller, more affordable LEO platform that satisfies NASA's long-term research goals while spurring vibrant commercial activity. Through our first look and first order estimates, viable options for a long-term commercial platform are available. LM looked at a downsized ISS, new free flyer, and hybrid of these options, and found there are advantages and disadvantages to each without a clear winner for operations through 2035. From a flexibility and utility standpoint, the Hybrid approach appears to be the best long-term solution. It takes advantage of Gateway development to use a PPE derived LEO Support Vehicle. The bulk of the pressurized modules used in the design are existing ISS elements. At first look, the elements necessary to assemble a Bravo Station from these new and existing elements looks very feasible. The Hybrid approach provides tremendous flexibility in the options that are possible. For one, it appears to be the optimal approach going forward relative to International involvement. This is the only good solution of the three that easily accommodates continued International involvement while positioning ISS to operate without International partners if necessary. As mentioned, each option in the trade offers its own advantages and drawbacks, and the best solution to meet NASA's long-term needs is highly dependent on NASA's long-term goals, the desired duration of LEO human spaceflight operations, and role of International partners going forward.

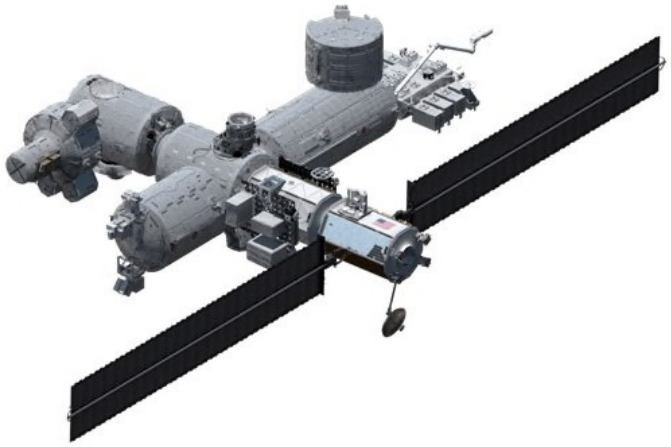


Figure 1.0-1 Hybrid Option for ISS Evolution Utilizing ISS Elements and Gateway Derived Elements

LM's ISMA concept is the Versatile On-Orbit Dual Use Joining and Additive Manufacturing Robot (VOODUJAMR). This concept provides an evolvable platform that has advanced robotics, precise metrology, and cutting-edge artificial intelligence at its core with the ability to expand capabilities through the addition of new modules to perform specific mission objectives such as 3-D printing, welding, and assembly. The VOODUJAMR leverages high-TRL components and operations with innovative joining techniques. While there are many benefits to ISMA, there are some challenges including that this technology is yet to be proven in space, technical constraints exist associated with precision, rigidity, and thermal expansion, and methods for verification of completed in-space builds must be established.

Proving this integrated platform through an in-space demonstration on the ISS, as depicted in Figure 1.0-2, is imperative to buy down risk of this technology. There has been a 50% drop in GEO orders over last year, and the ability to service or upgrade satellites needs to be built in from the beginning. Companies won't spend more for these features when there is no guarantee that the on-orbit servicing, assembly, and manufacturing technologies will be ready in their spacecraft's life time. Risk reduction demonstrations will enable a broader customer base and private investments. LM has evaluated the needs of our extensive customer base to identify the highest value products and services that would benefit from ISMA compared to traditional manufacturing and assembly on Earth, and many synergies have been identified with future NASA needs. DARPA has expressed interest in system development and a ground demonstration of VOODUJAMR. Once the ISMA technology is proven in-space, with the help of humans in the loop to provide oversight of operations, perform telerobotic operations, and process verification and validation; the long term objective is to have a predominantly autonomous robotic operation to minimize manufacturing costs and to enable capabilities in outer orbits (e.g. MEO, GEO, cis-lunar).

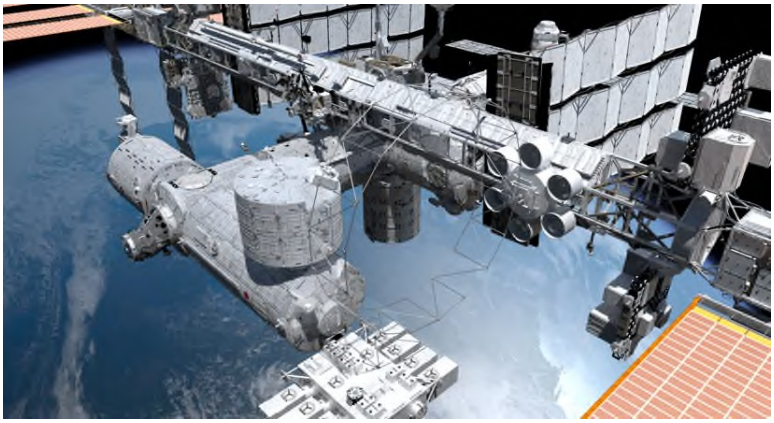


Figure 1.0-2 VOODUJAMR Risk Reduction Demonstration on ISS

LM leveraged our extensive range of capabilities, resources, support systems, and experience to provide detail studies in human spaceflight commercialization concepts business plans, and viability for commercializing LEO and supporting NASA's long-term needs in LEO. In summary, LM believes that NASA must re- main as the anchor tenant for at least one LEO platform to meet national lab, International Part- nership, and assured access requirements; significant annual NASA LEO cost savings can be en- abled through competitive privatized government services contract for operations and sustainment of existing ISS, and evolution of ISS to a reduced footprint with increased autonomy; and use of ISS as a risk reduction platform for emerging technologies such as ISMA will reduce the barrier of entry for new commercial products and users.

EXECUTIVE SUMMARY

KBRwyle examined the qualities and criteria for business applications dependent on a low earth orbiting (LEO) platform for the profitable delivery of a product or service. A successful, sustainable business depends on the demand by customers for a product or service when offered at a fair price. A product requires raw materials, a method of production, and logistics capable of delivering the product to end users. Services likewise require an infrastructure for delivery. The development, manufacturing, and delivery of product must be paid for by the supplier prior to delivery to the customer. The end user, in return, pays some price that covers the costs and operating expenses of the business and rewards those making investments in the business for taking the up-front risks.

We found that there is no shortage of ideas for starting businesses in LEO. Furthermore, as we "followed the money," we found an active, growing, and diverse set of successful space entrepreneurs and established businesses. However, these applications are notably NOT associated with LEO platform-based operations. Our study attempted to understand why this is the case by developing a methodology to analyze and quantify the challenges of business execution on a LEO platform.

A prospective business that depends on the unique environment found in LEO must overcome substantial barriers to entry, most significant of which is the cost of transportation logistics. Once in the environment, significant operations challenges are also evident as demonstrated by the conspicuous lack of commercial success associated with the International Space Station (ISS). **The aging ISS facility was designed to support basic research and was not optimized for commercial operations intended to make a profit. As a result, businesses face a cost basis that requires (to date) unachievable price targets for any business product or service to be profitable.**

Newer, multi-use facilities may become available in the near future, although they may or may not support a specific business venture with its unique requirements. **Based on our analysis, success of any human-tended, orbiting platform-based business depends on NASA participation in 1) early phase risk reduction, 2) payment for facilities and utilities as a user or tenant, and 3) support or some cost offset in the form of launch and/or operations subsidies.**

Ultimately, the environment itself is the enabling element for certain businesses. Microgravity, vacuum, radiation, and space exposure can allow the implementation of a business process that is impossible to replicate on the ground. The resulting products and services are by their nature unique or rare, and therefore highly valued.

For those businesses that have the potential to reach this bar, we applied our "Landlord model" to illustrate the bounds of successful business management from the perspective of the commercialized facility landlord, business tenant. We then quantified the elastic market demand and profitability limits for these businesses. Our Landlord model provides a basis for assessing different business concepts from the perspective of market viability, and the potential requirements for NASA to pursue alternatives associated with transition from a NASA-owned and operated space station to a commercial facility with NASA anchor tenancy.

The Landlord model shows the criticality of viable tenant businesses; **if any of the tenant business models fail, NASA will likely need to cover costs to ensure that the landlord's**

business case does not fail and adversely impact NASA's ability to meet its research objectives.

Each business' demand model is critical to assess the viability of the prospective commercialization effort and ensure that the business is operating at an acceptable profit margin to limit the risk of rent default and jeopardize the space facility's viability.

As NASA considers the potential value for subsidizing nascent industries, it should consider the critical end objectives that will help foster the demand for different business' goods and services:

- **Seek business models that have large, scalable potential demand (large number of provided units) to help maintain reasonable and affordable unit prices that can foster substantial business growth and scalability. This implies subsidizing the research and development of a good (e.g., ZBLAN or medicines) versus a service, like tourism that, with few units sold will likely only be available to the ultra-wealthy.**
- **For those businesses that fly close to the niche market limit, consider the value of rent subsidization versus launch cost subsidization since rent, as a fixed cost, is probably the larger of the business expenses that limit profitability.**
- **For those businesses that require multiple flights per year to operate most profitably, consider subsidizing launch costs since the variable costs drive unit pricing more than the fixed costs due to, for example, space facility rent.**

Thus, while space tourism and nation state "astronaut" flights show the greatest near-term potential for a sustainable business, on the basis of our model and the prevailing barriers to developing a self-sustaining LEO economy, this is not where NASA should spend its money. Rather NASA should be examining ways to stimulate businesses in industries like basic space pharmaceutical research and/or exotic material production. These industries represent potential for producing products with high value back on earth. Additionally, while Space manufacturing is much more difficult, exotic products like ZBLAN (**Z**rF4-**B**aF2-**L**aF3-**A**lF3-**N**aF) optical fibers or the development of highly desirable pharmaceuticals possess the right economics to satisfy the high cost of space-based manufacture and transport.

We also found that space transportation costs are not likely to come down for the foreseeable future. **While launch services operators are achieving significant cost reductions through reusability, prices are not following the downward trend. Instead the operators are retiring development costs and funding future programs with their increasing profit margins.**

Based on historical ISS logistics and operations capacity data, coupled with current pricing for ISS access and operations, we developed "boundary conditions" that must be met by any LEO platform-based business to cover costs and become profitable. **For instance, an evaluation of the tourism market based on current surveys, shows that, with $500 million in fixed costs, maximum profit on forthcoming crew transportation vehicles is obtained when five flights (15 tourists) are flown at a price of $150 million per passenger and break even occurs between $80-105 million per seat.**

In an optimistic model, we show that the cost of the on-orbit manufacture and deployment of an Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA)-class satellite will still cost on the order of tens of millions of dollars, excluding design, development, prototyping, and testing. With the demand characterized at a production limit of four cargo flights a year, the maximum profit pricing occurs at two flights annually.

The manufacturing of pharmaceutical pills comes closest to satisfying the necessary boundary conditions. In the case of a 325 mg (0.01 ounce) tablet-sized product, this equates to around $25 to $120 per pill, which is not unreasonable based on some drug prices today, but these prices do not include development, test, or government approval. Our methodology shows a sound process for business-case evaluation.

A set of assumptions needs to be refined based on the specific market's business case to more realistically assess the market potential for any scenario. First, an estimate of the real demand for the product, including expected sales of quantities across a range of prices must be provided. The business case must also collect all of the fixed costs, including research, development, and test; launch of infrastructure; on-orbit sustainment costs; and space facility rent. Variable costs that change with quantities produced are summed, including materials and operations costs in addition to the launch costs. Finally, volume limitations on the number of units produced per round-trip cargo flight, including the need for upmass and downmass packaging are considered.

With an understanding of viable business case models in hand, we examined a business financing model that combines the need for continued government participation while supporting the establishment of a commercial enterprise. **We looked specifically at the Private Financed Initiative (PFI) form of a Public Private Partnership. Our observations are that the limitations of the ISS platform including operational capacity, necessary equipment upgrades, and cost of operations and maintenance are substantial obstacles and are not consistent with the guiding attributes of a successful PFI. Moreover, when coupled with the associated logistical challenges of sufficient upmass/downmass to support a business model as outlined in our study, we viewed establishment of such an agreement as very unlikely.**

However, a business case that uses the ISS as a transitional platform to maintain a research presence in LEO while a new, more capable platform is designed and constructed does implement many of the key attributes for a successful PFI and is worthy of additional study as a potential PFI partnership between the Government and the private investors. It is noteworthy that, while our study has identified a limited number of market sectors that have high interest in business applications in LEO, we were unable to reconcile the operational cost of using a LEO platform regardless of the use of a PFI.

We conclude from our study that the ISS remains in the critical path for both the establishment of a (ultimately) self-sustaining LEO economy and for the achievement of NASA's exploration goals. Without the ISS there would be no platform to prove out any up and coming business case. Additionally, without a follow-on platform in place at ISS retirement, NASA exploration risk reduction would be significantly jeopardized.

LEO Commercialization Study – McKinsey & Co.

January 2019

EXECUTIVE SUMMARY

This study was undertaken in the context of NASA requesting input on how it can stimulate the economic development of low Earth orbit (LEO) in a manner that supports its LEO human spaceflight requirements. The suggested actions resulting from the study are geared to enable NASA's mission to sustain US leadership and progress human space exploration.

The study is presented in two parts. First, we develop an economic assessment of the market for LEO human spaceflight, accounting for expected sources of commercial demand and the potential commercial habitat supply landscape. Second, we evaluate levers, or actions, that NASA could take to stimulate a commercial LEO economy and improve affordability of LEO human spaceflight access. As part of that process, we identify potential actions that NASA could consider. While this report summarizes the findings of our study, we acknowledge the inherent uncertainty of the LEO human spaceflight ecosystem many years in the future, particularly when the evolution of that ecosystem is partly dependent on the actions of private actors. In tandem with this report, NASA has been provided with a flexible economic model that will allow it to update the findings of this report as conditions change in the future.

Given the immaturity of the commercial market for habitable space today, there is significant uncertainty around potential demand in 2025 and beyond. We evaluate 18 potential demand sources, such as sovereign astronauts (astronauts affiliated with governments of various nations), tourism, manufacturing, pharmaceuticals, media, and asteroid mining. Many of these use cases and technologies remain unproven or in early development stages, and the evolution of such demand will shape what the market ultimately looks like. There is, therefore, a large range between pessimistic and optimistic forecasts. Projected launch costs and capabilities, investment flows, and other factors influence the demand estimates.

About 90 percent of demand for habitable LEO space in 2025 is expected to come from NASA, other sovereign astronauts, and tourism. Commercial demand aside from tourism (for example, from pharmaceuticals) is anticipated to represent less than 10 percent of demand. In addition to those industries requiring habitable space, other commercial industries are expected to mature aboard autonomous (that is, unmanned) satellites, most notably automated manufacturing.

Under most scenarios, total demand for LEO habitable space in 2025 (approximately six people in LEO full-time under the base case) could be served by a single habitat with approximately the capacity of the International Space Station (ISS). The biggest source of variability is the level of demand for tourism in 2025, which will be driven by factors including price, speed of adoption (that is, how quickly space tourism is popularized and demonstrated to be safe), and competition from suborbital tourism, high-altitude

balloons, and other offerings. Even with that variability, it is unlikely that more than one habitat will be commercially sustainable by 2025. To fill an entire (second) ISS-capacity habitat with tourists alone, 20 percent of interested ultrahigh-net-worth individuals would need to pay to travel to LEO for a two-week period every year.

We evaluate the supply of commercial habitat providers that have expressed intent to launch habitats in the 2025 timeframe, factoring in existing funding, technical progress, and industry credibility. We consider the funding landscape and perspectives on capital-raising, as commercial habitat providers most likely will require considerable venture capital funding.

Left to its own devices, the market may develop a mismatch (too many habitats and not enough demand, or vice versa) due to a lack of transparency on commercial and government demand and the number of viable habitats that will be launched both by commercial players and one or more foreign governments. Insufficient viable habitats could result in the inability to maintain a continuous human presence in LEO; too many could result in additional costs to the LEO ecosystem. NASA can play a role in encouraging market transparency to guide the appropriate number of commercial habitats (that is, sufficient habitats to match demand) to be launched.

We propose two programs that NASA could implement to achieve its imperatives for the commercialization of LEO. The programs would stimulate demand for human spaceflight and other LEO industrial applications, encourage the number of habitats launched to match demand through greater transparency, and provide a conducive environment for US commercial activities in LEO.

The first program, the Milk Run Launch Partnership, would be a public–private partnership with commercial launch providers. It would be designed to accelerate the timeline of high-operating-tempo launch services to the ISS, resulting in reduced launch costs and stimulating commercial demand for space tourism and other LEO industries. The second, the Next Generation Habitat Program, would be an industry partnership to evolve commercial habitats through docking port access, technical assistance, and an early commitment for NASA to become the "major customer" of one or more habitats. NASA's commitment would be directed to the habitat or habitats that can demonstrate both commercial viability and ability to meet NASA's technical requirements for human spaceflight. Under most market evolution scenarios, a single habitat would fulfill these criteria.

These programs would act in concert to mature LEO spaceflight and help drive NASA's ability to affordably and reliably access LEO to fulfill its mission and decadal priorities.

1 EXECUTIVE SUMMARY

High Level Recommendations

The most important conclusion to come out of the data gathered through this LEO Commercialization Study is that there is no single point solution for the challenge of creating a commercial marketplace in space. Rather, **an ecosystem of service providers, hardware manufacturers, and consumers (to include government customers) are required to make space a viable location for commercial activity**. Just as the government has stepped in to support other commercial infrastructures, such as airports for aviation and highways for automobiles and trucking, it should work to support the critical infrastructure necessary to make such a space ecosystem thrive. At the same time, it must judiciously limit its role in dictating what activities can take place within such infrastructure—provided that such activities are not hazardous.

Since an ecosystem requires multiple elements functioning together, NanoRacks argues that **upcoming solicitations for commercial elements of the ISS must allow for more than one platform, including 1 attached to the node and 1 or more free flyers in ISS orbit, and nearby enough to be serviceable by commercial resupply and crew missions**. Such commercial space stations, either crewed or uncrewed, if funded by the government, would necessarily serve different markets—for instance one addressing astronaut training and another addressing in-space manufacturing—and should be competed as such. NanoRacks argues that a single-point solution to commercialization, however, is a high-risk endeavor. Imagine, for instance, if the ISS only had one commercial resupply provider. Having more than one platform would help mitigate both technical and commercial market risk, as it would necessarily serve a different enough set of customers. It would also hold significantly elevated technical requirements to an ISS-connected platform given for instance the necessity to be a fully self-contained platform. As such it could well be considered an alternative market regardless of whether or not it performed similar services to a future module attached to Node 2.

The government must also provide the market with necessary signals that investment in commercial LEO actors is financially sound by stating unequivocally that **the ISS is the final government owned and operated space station in Low Earth Orbit.** Commercial ventures are unlikely commit investment to build and operate commercial LEO platforms unless they have some assurance that the government will not compete, even inadvertently, via the government's own platforms serving similar markets—however commercially optimized such platforms are intended to be.

NanoRacks also finds that, within such a domain where government plays an important role in funding infrastructure, and at least in today's ISS-centered market, **investors in ISS hardware must have guaranteed access to their own hardware**. This means that within acceptable parameters of safety and capability, NASA should not reject payloads without perceived merit—a commercial market means that **the government must not step in to decide which commercial**

activities have merit and which do not. If a company, for instance, invests in onboard cameras, then advertisements which generate revenue for non-scientific purposes cannot be sidelined. Ultimately, showing that such hardware can be profitable helps generate commercial incentives to build further infrastructure which ultimately aids in making scientific and other in-space activity more affordable.

In order to facilitate the expansion of the LEO economy via multiple platforms, and also with respect to the recommendation that NASA continue supporting LEO infrastructure, **NASA Commercial Crew Vehicles should visit multiple destinations in LEO, and make additional space available on a commercial basis.** This infrastructure support would allow business cases built around expensive human spaceflight to free-flying platforms to show viability during the nascent phases of market development. Supporting free flying platforms within ISS orbit with infrastructural services such as transportation would not constitute the government choosing commercial winners as it would not directly result in competition or business preference toward one or another platform. That preference would only be an expression of differential services (or value thereof) rather than government support for direct competition.

In order to continue the expansion of the LEO marketplace and secure its sustainability, as well as securing American global leadership in space technology and market innovation, **the U.S. government and commercial sector should aim to bring as many international partners as possible into an agreement modeled after the current IGA in order to promote adherence to certain commercially beneficial *rules of the road* by all actors.** Given the current rapid state of global innovation, as well as the prospect of future foreign competition, isolating American companies from the benefits of foreign innovation would have a negative impact. Such isolation would also limit American access to foreign markets and services. Concurrently, however, such foreign partnerships must be closely monitored for practices such as dumping or government subsidization of competing services. This adds urgency to call for bringing as many international partners as possible into both trade and legal agreements that establish 'rules of the road' for commercial behavior and competition.

Finally, in light of all **this NASA and the U.S. government should consider LEO activity a *Public Private Partnership,* or PPP.** In such partnership, NASA and government agencies like the FCC retain important regulatory roles, as well as basic infrastructure maintenance, while largely leaving open room for commercial activity—of whatever nature—in LEO. The right balance within a PPP would be one where NASA and the government make infrastructural investments that the private sector leverages with private capital, commercial rules, and commercial terms and conditions. NASA and the U.S. government would benefit from the growth of such activity in the same way they benefit from all infrastructure managed in this way: via the taxation of commercial profit and the overall enriching of the American economy. Such support is especially important in this nascent stage of the New Space economy, and the government cannot reasonably expect revenues to directly cover expenses in the near to medium term. In the long term, just as highways facilitate coast-to-coast trade, with repairs not being paid for directly by trucking companies, returns will accrue to the national economy at large. To believe new space

could be profitable without critical government support in the near term, however, is a deeply flawed expectation.

Methodology

This study takes note of ongoing discussions within NASA and the U.S. government on the model for International Space Station (ISS) commercial utilization and is further colored by current debates on the extension of the ISS beyond the 2025 timeframe. However, this study posits that the creation of a sustainable LEO commercial ecosystem is not foregone conclusion, as growing customer utilization of in-space assets is itself not guaranteed. Based on the work conducted herein, NanoRacks believes growth is sustainable given a careful balance of government and commercial investment and support. NanoRacks urges NASA, policy makers, and those in the government as a whole, to carefully consider the results of this and all other LEO Commercialization Studies. This exercise must lead to an opening of channels of communication with industry to reveal the changes that best support the continued growth of a robust LEO marketplace.

This Low Earth Orbit Commercialization (LEOCOM) Study provides a consolidated set of policy and commercial recommendations to NASA focused on facilitating growth in space economies via NanoRacks' *Outpost* system, which uses repurposed upper stages to create habitable or robotically tended, attached or free-flying platforms for use by commercial customers in the near future. Results are gleaned from a combination of research conducted by NanoRacks and its team of 13 industry collaborators. NanoRacks' approach to the business case and financial viability of the Outpost architecture follows a three-pronged strategy: analyzing contributions from commercial partners and NanoRacks experience (Sections 4 to 5.2), developing a detailed financial model relying on NanoRacks' market overview and commercial partner inputs (Section 5.3), and conducting a policy simulation with NASA staff (Section 5.5).

Notably, NanoRacks has requested that 11 of its commercial partners contribute their views on how their technologies may work with the Outpost System or otherwise benefit from the lowered price for in-space volume afforded by a repurposed upper stage. These partners have been grouped into three areas: hardware providers (ULA, Stratolaunch), service providers (Olis Robotics, Kongsberg Satellite Services, Deep Space Industries, Altius, Terminal Velocity), and commercial users (Space BD, Space Adventures, Made In Space, Lunar Resources). These partners' proposed uses of a hypothetical Outpost infrastructure lead to conclusions about ideal policy paths forward to enable such a commercial economy to flourish. Data and results from this work are available throughout Section 4. They also contribute to NanoRacks' business model by providing contributions to assumed future revenue, and providing an understanding of what levels of station operating expenses can be sustained by differing levels of future demand.

Government-Mediated Competition

One of the most important conclusions coming out of the study is the delicate balance that NASA and the U.S. government generally must strike when attempting to influence the direction of future commercial involvement in the sector. The government has an important role to play in this field,

namely in the fact that it can provide the funding and stability to foster infrastructure investments. This must be taken in consideration with NanoRacks' recommendation that the government should aim to expand the market of platforms via a broader procurement for commercial platform additions to the Space Station Program.

Based on the evidence provided in the Study, NanoRacks recommends that NASA carefully evaluate the current state of hardware on the ISS and not fund redundant capabilities. Rather, NASA should fund pioneering infrastructure, and let the market decide if demand can support further infrastructure of the same type (for instance a second, or third microscope with similar capabilities)—to be built by commercial means. Once built, neither NASA nor any government sponsored NGO should step in to decide toward which commercial actor business is directed. Building two centrifuges aboard the ISS constitutes the creation of non-useful competition, because these are specific pieces of hardware—individual services—which fulfil an identical purpose. Supporting the construction of two separate platforms, however—for instance one serving tourists and another serving hyper-sensitive ZBLAN manufacture—would almost be a requirement, given the pristine conditions required in one (no unwarranted movement due to crew disturbances, as an obvious example)., and the movement required in the other (for instance by crew exercise and general movement around the platform).

That said, while the government should *not* support multiple identical capabilities, again, **NASA must endeavor to support multiple platforms within (and eventually outside of) the ISS orbit, both attached and free-flying, crewed and uncrewed, in order to support the broad range of activities in LEO.** A single-point solution to all commercial activity is counterproductive to the facilitation of a true ecosystem, while at the same time, multiple pieces of hardware providing identical services does not foster competition—it rather stymies investment interest., unless demand grows to the point where demand exceeds the capability of the first facility—a real possibility, but one which this Study does not model While there would doubtless be some overlap between platforms, the critical point is that they would also constitute part of the infrastructure of the LEO ecosystem, rather than rack and sub-rack level services.

Policy Simulation

As part of this Study, NanoRacks proposed to NASA to conduct a Policy Simulation. This simulation would be based around three hypothetical scenarios that NanoRacks wrote in consultation with NASA, and that were composed with NanoRacks' best assumptions about what form future real-world policy challenges might take. These scenarios were composed based both on NanoRacks' past experience and views of what issues might arise over the duration of managing a commercial space station in LEO, as related to both NASA and the market generally. NanoRacks also drew on the expertise of its team members to propose the associated scenarios and questions. In summary, they are intended to capture three cases in which NASA's guidance on policy would help to shape commercial outcomes in the LEO economy. The purpose of this exercise was not necessarily to receive a response from NASA regarding the particular question, but rather to exercise and analyze the process that NASA undertook in order to answer that question.

Three illustrative policy scenarios were crafted based on NanoRacks' assumptions of what future commercial space platforms may confront. These raised questions on the scope and future of the Space Station Intergovernmental Agreement (IGA), the use of NASA resources for attached versus free-flying platforms, and allowable nationalities on commercial platforms.

The most important conclusion resulting from the policy simulation was that no codified, well-trodden channel of communication exists within NASA internally, or between NASA and external agencies, with respect to broad policy considerations. Additionally, NASA takes a broadly consultative approach to resolving all policy related questions, seeking input and opinions from both government and industry groups. Finally, the mechanism for consultation under the IGA—a critical factor in the policy simulations presented—is very sensibly centered within the ISS program office at JSC.

Financial Model

A major portion of this study involved showing how the NanoRacks Outpost would become a financially feasible platform, and how much NASA involvement would be required in order to make it sustainable. This model combined factors including assumptions about future revenues and investments based on commercial partner research and NanoRacks historical data. This assisted the Study in determining how assumed costs would line up with future revenues, thereby allowing for probabilistic conclusions on 1) how much a future Outpost could cost in terms of non-recurring and recurring investment, 2) how much funding would be required from NASA and the U.S. government to close the business case, and 3) how much future revenue would be required to close a business case for Outpost.

Within this methodology, NanoRacks considered a map of all Outpost subsystems as described first in the NASA NextSTEP Study. Assumed subsystem costs were modeled on the basis of a probability of distributions across observed minimum and maximum costs, and amortized costs assuming specified amounts of NASA investments—all pointing to certain Internal Rates of Return (IRR) plotted against those rates which would be acceptable to venture investors. NanoRacks then conducted an industry survey of available ranges for these subsystems. Where ranges were not available, NanoRacks used the NASA Project Cost Estimating Capability (PCEC) across a range of relevant inputs, as well as LEOCOM Partners' industry estimates. A uniform distribution of cost probabilities was then applied across the price range as this was the most conservative assumption to make given sparse data. The technology readiness level (TRL) of each subsystem was considered in setting the width of the price range, with higher TRLs being associated with more certainties in terms of price, and the potential for lowered future prices.

5,000 scenarios for pricing were subsequently run in Excel in order for the Study, with non-recurring engineering (NRE) and recurring engineering (RE) costs left as independent, uncorrelated processes to determine the probability of each of the Non-Recurring and Recurring costs for the Outpost falling below a certain level. These numbers were then used to detail a "heat map" showing the probability the NRE and RE Cost were equal to or less than a certain pair of those NRE and RE costs. They were also color coded to show bands of probability, and this color

coding was transported to a table of IRRs representing the IRR for each combination of NRE and recurring investment using the same costs buckets as the first table. This "key chart" is shown below, and represents the template for financeable investments against which the following scenarios are mapped.

Table 1.1: Probability of NRE and Unit Costs being Below Values – Per Station – Color Key

	Recurring Investment per Station Module (i.e. one-time costs per station module)								
	$200.0	**$225.0**	**$250.0**	**$275.0**	**$300.0**	**$325.0**	**$350.0**	**$375.0**	**$400.0**
$300.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
$325.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
$350.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
$375.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
$400.0	0.0%	0.1%	0.6%	1.9%	3.9%	6.3%	8.0%	8.3%	8.3%
$425.0	0.0%	0.5%	2.8%	8.5%	18.22%	28.70%	46.36%	47.64%	47.72%
$450.0	0.0%	0.8%	5.3%	16.80%	34.78%	55.10%	78.52%	80.88%	81.08%
$475.0	0.0%	0.9%	6.7%	21.34%	43.86%	69.80%	96.68%	99.78%	99.98%
$500.0	0.0%	0.9%	6.7%	21.34%	43.86%	69.82%	96.70%	99.80%	100.00%

Key
0.00%
0 % to 10%
11% to 20%
21% to30%
31% to 40%
41% to 50%
51% to 60%
61% to70%
71% to80%
81% to 100

This allowed the team to determine if Outpost costs would successfully fall into an investment-worthy range. These ranges (20% to 30% or greater) were based on the team's knowledge of commonly required IRR's for private equity and venture capital transactions, and represent the percentage figures in the following charts.

In the base plan, which assumes just one instantiation of an Outpost and that is tailored to NASA's need for a continuously crewed free flying platform as well as marginal pricing for crew transport, the analysis showed such a plan had an IRR below what would be considered a financeable range for venture and other investors. In such a case, acceptable rates of return would be yielded only where costs would be unrealistically low given the earlier cost analysis. For instance, a station yielding a 20.2% IRR would require $300M RE and $400M RE—but such a cost would only have a 4.3% probability of actually occurring. However, a station with a higher probability of feasibility according to the Model, say for instance at 61.3%, would yield a 17.6% IRR and cost $325M in RE and $450M in NRE. The illustrative chart and correspondence is shown below.

Table 1.2: 10-Year IRR Sensitivity for Scenario 1: Base Assumptions (Use Color Key in Table 1.1)

10-Year IRR Sensitivity for Scenario 1: Base Case Assumptions

Non-Recurring Investment (NRE) \ Recurring Investment per Station Module (i.e. one-time costs per station module)	$200.0	$225.0	$250.0	$275.0	$300.0	$325.0	$350.0	$375.0	$400.0
$300.0	42.6%	40.5%	38.6%	36.9%	35.3%	33.8%	32.4%	31.2%	30.0%
$325.0	40.4%	38.5%	36.8%	35.2%	33.7%	32.3%	31.1%	29.9%	28.8%
$350.0	38.4%	36.7%	35.1%	33.6%	32.3%	31.0%	29.8%	28.7%	27.6%
$375.0	36.6%	35.0%	33.5%	32.2%	30.9%	29.7%	28.6%	27.6%	26.6%
$400.0	34.9%	33.5%	32.1%	30.8%	29.6%	28.5%	27.5%	26.5%	25.6%
$425.0	33.4%	32.0%	30.7%	29.6%	28.46%	27.41%	26.43%	25.50%	24.62%
$450.0	31.9%	30.7%	29.5%	28.38%	27.34%	26.36%	25.43%	24.55%	23.71%
$475.0	30.6%	29.4%	28.3%	27.27%	26.29%	25.36%	24.48%	23.65%	22.85%
$500.0	29.3%	28.2%	27.2%	26.21%	25.29%	24.41%	23.58%	22.79%	22.03%

Key
0.00%
0 % to 10%
11% to 20%
21% to30%
31% to 40%
41% to 50%
51% to 60%
61% to70%
71% to80%
81% to 100

The team then considered two alternative plans. The fist examines the type of pre-payments for services to which NASA would need to commit in order to raise the IRR. The second looks at allowing the probable assumption that multiple instantiations of Outpost platforms with shared NRE expenses would lower the NRE allocated to the NASA free flying LEO Outpost to make it financeable.

For the first alternative, the team assumed that NASA paid two years of R&D up front. Results showed that at the 61.3% probability range mentioned above yields 25.7% IRR, making it significantly more financeable than in a base-case. The resulting table is provided below, with the coloration corresponding to NRE and Unit Costs both being below given values, per the Key Table above. The baseline assumptions for two years of NASA-derived up-front R&D costs is also provided (figures in 1,000s).

Table 1.3: 10-Year IRR Sensitivity for Scenario 2: Assuming NASA Pre-Payment (Use Color Key in Table 1.1)

Scenario 2: IRR Sensitivity under base case assumptions with NASA partial prepayment (includes 100% NRE allocation to single crew-tended station to NASA specs)

10-Year IRR Sensitivity for Scenario 2: Prepayment

Non-Recurring Investment (NRE) \ Recurring Investment per Station Module (i.e. one-time costs per station module)	$200.0	$225.0	$250.0	$275.0	$300.0	$325.0	$350.0	$375.0	$400.0
$300.0	75.4%	68.8%	63.3%	58.7%	54.8%	51.4%	48.4%	45.7%	43.3%
$325.0	68.6%	63.1%	58.5%	54.6%	51.2%	48.2%	45.6%	43.2%	41.1%
$350.0	62.9%	58.4%	54.5%	51.1%	48.1%	45.5%	43.1%	41.0%	39.0%
$375.0	58.2%	54.3%	51.0%	48.0%	45.4%	43.0%	40.9%	38.9%	37.2%
$400.0	54.2%	50.8%	47.9%	45.2%	42.9%	40.8%	38.8%	37.1%	35.4%
$425.0	50.7%	47.7%	45.1%	42.8%	40.65%	38.72%	36.96%	35.34%	33.84%
$450.0	47.6%	45.0%	42.7%	40.55%	38.62%	36.87%	35.25%	33.75%	32.37%
$475.0	44.9%	42.6%	40.4%	38.53%	36.77%	35.16%	33.67%	32.28%	31.00%
$500.0	42.4%	40.3%	38.4%	36.67%	35.07%	33.58%	32.20%	30.91%	29.71%

Key
0.00%
0 % to 10%
11% to 20%
21% to30%
31% to 40%
41% to 50%
51% to 60%
61% to70%
71% to80%
81% to 100

Figure 1.1: NASA Pre-Payment Assumptions for Scenario 2 (Table 1.3)

NASA Prepayment Calculation:	Year									
	1	2	3	4	5	6	7	8	9	10
Research & Development										
Total NASA R&D Revenue	$103,113	$105,175	$107,279	$109,424	$111,613	$113,845	$116,122	$118,444	$120,813	$123,230
Number of Years Prepaid:	2									
NASA Prepayments on R&D Revenue	$103,113	$105,175	$0	$0	$0	$0	$0	$0	$0	$0
Total Prepayment on R&D Revenue	**$208,288**									
Total Initial Investment per Unit (i.e. station)	**$338,925**									
Investment Offset for NASA Prepayment	**-$208,288**									
Adjusted Initiial Investment per Unit	**$130,637**									

For the second plan, NanoRacks assumed that NRE costs were amortized across four instantiations of Outpost, including two autonomous and two crewed platforms. To remain conservative, the analysis assumed those other programs were able to pay for 60% of the NRE cost (rather than a more aggressive 75% as might be assumed with an even split across 4 platforms). As background, demand for two autonomous, robotically operated platforms was assumed to result from one technology demonstration platform for non-NASA U.S. government purposes, and another for in-space manufacturing, based on findings in the commercial partner contributions. Demand for crewed platforms was assumed to derive from one sovereign free-flyer (either for Deep Space Gateway or for a non-US sovereign space agency) and a LEO continuously crewed free-flyer in ISS orbit for NASA accommodation. To make the model apposite to a LEO continuously crewed free flyer and in order to limit the scope of the financial model presented in this work, the financial model focuses exclusively on the continuously crewed free-flyer rather than the whole of four platforms. Amortizing the cost to NASA of procurement of this platform also conforms with NanoRacks' conclusion that single-point hardware solutions incur extensive risk, and are impractical due to the multiple requirements that would need to be imposed upon a single platform. In the team's analysis, the cases that occurred at least 61.3% of the time had IRR's that were even more financeable, with an IRR of 30.4%. The resulting chart is shown below.

Table 1.4: 10-Year IRR Sensitivity for Scenario 3: 40% Allocation of NRE (Use Color Key in Table 1.1)

Scenario 3: IRR Sensitivity under base case assumptions (includes 40% NRE allocation to single crew-tended station to NASA specs)

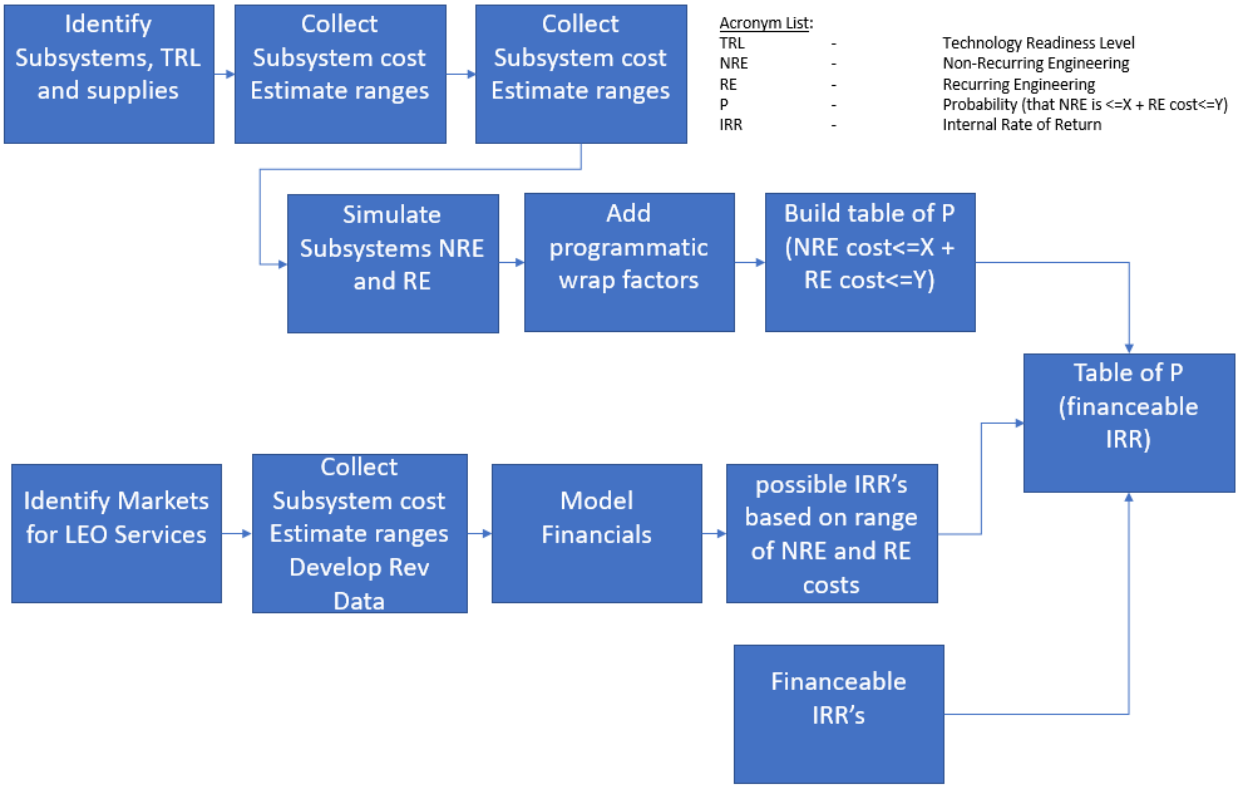
10-Year IRR Sensitivity for Scenario 3: 40% Allocation of NRE

Non-Recurring Investment (NRE)	Recurring Investment per Station Module (i.e. one-time costs per station module)								
	$200.0	$225.0	$250.0	$275.0	$300.0	$325.0	$350.0	$375.0	$400.0
$120.0	69.3%	63.8%	59.2%	55.3%	51.9%	48.9%	46.2%	43.8%	41.7%
$130.0	66.9%	61.8%	57.5%	53.8%	50.6%	47.7%	45.2%	42.9%	40.8%
$140.0	64.7%	60.0%	55.9%	52.4%	49.4%	46.6%	44.2%	42.0%	40.0%
$150.0	62.7%	58.2%	54.4%	51.1%	48.2%	45.6%	43.2%	41.1%	39.2%
$160.0	60.7%	56.6%	53.0%	49.8%	47.1%	44.6%	42.3%	40.3%	38.4%
$170.0	58.9%	55.0%	51.6%	48.6%	45.98%	43.60%	41.45%	39.50%	37.71%
$180.0	57.2%	53.6%	50.3%	47.49%	44.95%	42.67%	40.61%	38.72%	37.00%
$190.0	55.6%	52.2%	49.1%	46.39%	43.97%	41.78%	39.79%	37.98%	36.31%
$200.0	54.1%	50.8%	47.9%	45.35%	43.02%	40.92%	39.01%	37.26%	35.64%

Key
0.00%
0 % to 10%
11% to 20%
21% to30%
31% to 40%
41% to 50%
51% to 60%
61% to70%
71% to80%
81% to 100

Ultimately, the NanoRacks team concluded that building a single platform with standard contracting payments would not be easily commercially financeable. However, if certain amounts of pre-payment could be provided, such a limited scope program becomes more financeable. Of course, if the Outpost team were successful in amortizing the NRE for Outposts over multiple instances (and where not all have to be crewed) then the program becomes even more financeable. Some combination of the two will allow the program to become even more easily financeable, but this analysis did not take such a best case scenario into account. A summary chart detailing the logical flow of data used to derive these charts is provided below.

Figure 1.2: Financial Model Logical Flow



INTRODUCTION

1.1 History

NanoRacks, LLC was formed in 2009 to provide commercial hardware and services for the U.S. National Laboratory on board the International Space Station (ISS) via a Space Act Agreement with NASA. NanoRacks is a market leader for in-space services, providing modular facilities and platforms derived from existing industry standards, such as the CubeSat form factor. Services include access to state-of-the-art microgravity research platforms, both internal and external to the ISS; small satellite deployment; and overall end-to-end payload integration services. In addition to facilitating research and CubeSat deployment on the ISS, NanoRacks also facilitates research on Blue Origin's *New Shepard* suborbital vehicle, SmallSat deployment on non-ISS launch ehicles, and is constructing the Bishop commercial airlock for the ISS.

The NanoRacks ISS customer base includes leading pharmaceutical companies, research organizations, Earth observation companies, educational organizations from over 160 congressional districts, and both domestic and international governmental organizations, such as DLR (the German Space Agency), the European Space Agency, and the European Union. Domestic government customer organizations include NASA, the U.S. Army, the National Reconnaissance Office, and many others.

The NanoRacks team has transformed the marketplace by establishing an international foundation of customers from 32 nations, thereby gaining a unique understanding of price points, customer objectives, and future projections. NanoRacks has to date shepherded over 700 payloads through the ISS safety and payload review process to utilize the company's own self-funded hardware, including having deployed over 200 satellites from the ISS.

Important to the company's business philosophy is the fact NanoRacks has achieved this level of utilization relying solely on financial resources from investors or self-funding via company revenue. NanoRacks was formed to create a non-governmental, commercial pathway to ISS utilization. From the beginning, the company chose a business development model that heavily favored private capital investments, investor risk, and private sector marketing to leverage the existing Congressional investment in the ISS, all to a degree that even today has hardly been replicated by other companies.

1.2 Reasons for Study

NanoRacks has always strongly held that private sector-funded orbital platform development is not only possible, but essential in creating an economically viable low Earth orbit commercial community. NanoRacks therefore enthusiastically embraced the opportunity to collaborate not only with NASA, but also with a group of commercial partners, to explore the economic feasibility of developing an orbital commercial community.

NanoRacks agrees with NASA that now is the time for dialogue on the development of a LEO commercial community. NanoRacks firmly believes that the ISS launch vehicle ecosystem has developed to the point where a mature and robust commercial community in low Earth orbit is on the horizon, with privately owned and operated Outposts filling sustainable market niches for a variety of customers.

With this in mind, the motivations NanoRacks has for conducting this study include:

- Investigating the commercial case for the repurposing of in-space hardware via the NanoRacks Outpost program.
- Entering into partnerships with space hardware providers to start building a collaborative network toward fostering growth in the new space economy.
- Working with commercial partners to explore how business collaborations with hardware providers, investment partners, and customers can facilitate economic activity in LEO, opening pathways to new opportunities for commercial customers and for NASA.
- Defining the commercial, technical, and contractual means for making free-flying space platforms a critical component in growing a LEO economy.
- Opening a discourse on the current policy approaches to LEO commercialization, including the continued use of NASA resources by commercial companies.
- Gaining an understanding of the current regulatory environment around space and how it might be changed to create the ideal conditions for commercialization.
- Working to document the kinds of investment opportunities available for LEO platforms, who the likeliest investors would be, and how the new space economy could be structured to attract them.
- Documenting the historical context of commercialization efforts generally across the U.S. economy that have succeeded in developing robust and sustainable markets.
- Conveying that the space industry is united in not wanting to have a gap in space station presence in LEO, akin to the gap in crew capabilities resulting from the years between the retiring of the Space Shuttle program and availability of American commercial crew vehicles.

NanoRacks recognizes that the development of a mature LEO commercial community requires guidance for all parties involved: service providers, commercial customers, and the government. NanoRacks envisions this study, and those of the other teams selected by NASA, as a means of providing a viable, realistic roadmap for all LEO stakeholders.

1.3 Scope of Study

In accordance with NASA's stated goals for the study, NanoRacks conducted the study to consider these overall questions and issues:

- **Structure of a proposed orbital platform** – NanoRacks' technical concept for an Outpost system to address NASA's needs, including technical specifications of an Outpost system.

- **Function of an Outpost system** – what role Outposts would serve in a LEO commercial community.
- **Funding** – what model of public-private funding NanoRacks identifies as being most cost-effective in creating a viable LEO community.
- **Market demand** – uses for Outposts, as identified by several commercial partners who are most likely to be involved in developing and utilizing a LEO commercial community.
- **Role of the ISS** – how the continuing presence of the ISS, its evolution, and eventual decommissioning are projected to impact the development of a LEO commercial community.
- **Role of NASA** – what participation from NASA would be needed to make a LEO community financially viable, and the effects of NASA policies today on the overall commercial case.
- **Moving from government-led investment to private funding** – paths to follow that would lead from a primarily government-funded LEO community to an economic model that is sustainable through commercial, private-party funding with government support for overall infrastructural investments.

1. EXECUTIVE SUMMARY

Northrop Grumman Innovation Systems (NGIS) is an industry leader in commercial space systems and proven innovator in the commercialization of low Earth orbit (LEO). With the Cygnus spacecraft, shown in Figure 1, developed in a Public-Private Partnership (PPP) with the National Aeronautics and Space Administration (NASA) to deliver commercial cargo services to the International Space Station (ISS), commercialization in LEO has already begun. Building off of the highly successful Cygnus vehicle, NGIS has the current systems, and future systems already in formulation that will revolutionize the industrial use of space, and enable synergy across NASA's human spaceflight enterprise.

Figure 1. NGIS Cygnus Commercial Spacecraft.

NGIS is pleased to present this final report of the *Study for Commercialization of LEO*, to inform the commercialization efforts that can be implemented today, planned for tomorrow, and pursued in the future toward creating a sustainable LEO economy. The results of this study enable a comprehensive picture of the commercial market in LEO today, its potential for the future, the systems that can enable it, and the path to get there.

Through this study, NGIS developed a sound, feasible, and implementable roadmap that lowers costs, increases utilization, and ultimately provides a path to transitioning the lead in LEO from the U.S. Government (USG) to industry. To develop a complete picture of the LEO economy, its potential, and the systems and roadmap that can enable its most-effective utilization, NGIS and its partners Alpha Space, Engility, and SpaceWorks, performed five component studies to:

- Evaluate the commercial LEO market and perform forecasting and financial analysis based on an incremental, modular, and scalable technical concept toward creating a sustainable commercial economy.
- Assess the use of Cygnus, its variants, and the Cygnus-derived Augmentation Module (AM), shown in Figure 2, to support other commercial providers toward development of ISS-attached and free-flying commercial platforms.
- Analyze the Cygnus-derived technical concept to develop a future NGIS commercial platform, with a business case that closes, that meets NASA requirements and provides access for many different users.

Figure 2. NGIS Augmentation Module in LEO.

- Examine the configuration, operation, and utilization of the ISS to determine potential reconfiguration, down-sizing, and cost-optimization options to create a more affordable solution, increase commercial activity, and enable USG/commercial cost sharing.
- Investigate current commercial use of the ISS and partnerships between NASA and industry toward maximizing effective use of the platform.

Cygnus, its Long-Duration variant, and the Cygnus-derived AM provide the building blocks for the NGIS roadmap. NGIS is currently utilizing Cygnus as an active commercial platform to stimulate the LEO economy as a research and technology testbed, in addition to its ISS commercial cargo resupply services. The Long-Duration Cygnus, planned for first flight on NG-11 in 2019, will extend Cygnus capabilities with flights of one year or more, providing a valuable platform for pristine microgravity research and testbed for technology development and demonstration.

As NASA looks beyond-Earth, the systems that will enable our return to cislunar space will provide synergy with the Agency's efforts to transition LEO to industry leadership. The AM, currently in formulation as part of NASA's Next Space Technologies for Exploration Partnerships (NextSTEP) Program, is a Cygnus-derived vehicle with modular capabilities for habitation, logistics, science, and a wide-range of mission-specific variants.

Figure 3. NGIS Conceptual Commercial LEO Platforms.

With first flight in 2022, the AM provides a synergy between LEO commercialization and cislunar exploration that decreases costs and provides an unparalleled multi-mission platform. The AM can be used for a variety of missions in LEO, including augmenting ISS habitation and laboratory capabilities, providing enhanced logistics support to the ISS, and being the building blocks for future LEO platforms, such as shown in Figure 3.

As leadership in LEO is transitioned from the USG to industry, the maintenance and continuation of the ISS is imperative to creating and expanding future commercial markets. As an integrated system, the capabilities that the ISS provides are unmatched, and likely not to be matched by any near-term future platforms through 2030. The AM provides a capability to augment the ISS and provides a foundation for future, complementary platforms.

The future operation of the ISS until a commercial market can be sufficiently matured is imperative to the goal of true commercialization. Building off of the initial commercial steps manifested in Cygnus, there now exists a path with its evolution, and building off of the ISS platform, to stimulate the demand side of the market to non-USG users.

Cygnus, its variants, and the Cygnus-derived AM provide the current and future platforms that can enable creation of a sustainable commercial market to become a reality. The roadmap to creating a sustainable commercial LEO market starts today with Cygnus. With its future variants and Cygnus-derived vehicles, NGIS can decrease costs, increase synergy across NASA, and maximize the commercial potential of LEO. NGIS is poised to lead into the future as we continue to partner with NASA toward creation of a sustainable commercial market in LEO, and advancement of American leadership in space.

Sierra Nevada Corporation (SNC) is an experienced leader in the commercial space industry, developing key human and cargo logistics capabilities for the International Space Station (ISS) and low-Earth orbit (LEO) operations through our *Dream Chaser*® spacecraft (DC), a reusable lifting-body vehicle. While the ISS continues to deliver significant and critical capabilities, a new approach is required to increase commercial economic participation, thus, decreasing NASA's costs to support LEO operations and freeing up funds to advance NASA's exploration campaign. We propose an innovative approach based on our investments in Dream Chaser and our next generation spacecraft, to provide a flexible, scalable architecture that supports NASA's LEO objectives while reducing costs to grow commercial economic activity. SNC's flexible architecture utilizes LEO as a central hub of commercial activity, providing up and downmass, free-flying services, ISS attached services, and long-term reuse of viable ISS modules to create a self-sustaining LEO capability, as well as a connection to lunar activities.

Our Dream Chaser vehicle can continue to provide logistics services in the future commercial environment just as it is for the Commercial Resupply Services (CRS-2) contract. With modifications, using non-invasive kits and modules, Dream Chaser is able to support over 40 payloads in-orbit for short duration science missions of up to 30 days on-orbit. Our next generation spacecraft provides additional capabilities to support long-duration applications including human habitation. Furthermore, the SNC LEO architecture enables future commercial activity by creating a system that allows for a variety of operations including, but not limited to, human habitation and transportation, satellite support, hosted payloads, cargo and logistics, and in-space manufacturing and assembly.

SNC has worked with industry leaders and performed extensive market analysis using publicly available and privately attained data to develop a broad understanding of the current space markets as well as the burgeoning future space markets. Through our comprehensive business evaluation techniques, we researched and developed multiple business scenarios for the commercial viability of our LEO architecture and looked at both upside and downside potential of each case. The output of the analysis showed commercially viable scenarios where NASA is a buyer of services and capitalizes on the growing global interest in LEO operations.

Our unique approach leverages significant previous private industry and government investments to enable a vibrant LEO commercial economy. This flexible, modular architecture provides a cost-effective approach that fully supports current LEO activities, provides a graceful transition from ISS to commercial services, and gives enhanced capabilities that support the evolving future space commercial markets while ensuring a sustained human presence.

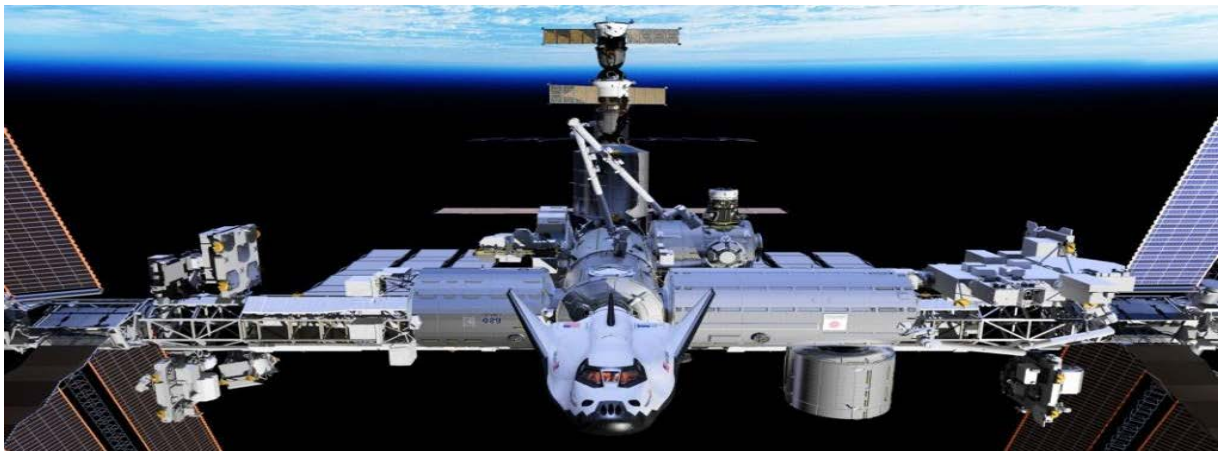


Figure 1-1. SNC's innovative commercial approach uses Dream Chaser in conjunction with re-use of ISS modules to provide the future of commercial space.

SECTION 1: Executive Summary

This Final Report is submitted by Space Adventures (SA) in conclusion of its four-month study of transition of the International Space Station (ISS) and commercialization of low-Earth orbit (LEO). With the business case as the central tenet, SA's study sought to identify a solution that satisfies NASA's transition goals at the intersection of the commercial market opportunity, the technical concept for sustainable low-cost habitation, and available private investment. The specific objectives were as follows:

Objective 1: Quantify Market Opportunity
Objective 2: Evaluate Technical Concepts for Low-Cost Habitation
Objective 3: Determine Viable and Sustainable Business Case
Objective 4: Synthesize Conclusions and Recommendations

This executive summary highlights conclusions and recommendations resulting from the study and summarizes the supporting research and analysis.

1.1. Market Opportunity

SA identified the following market segments as possible sources of revenue for a self-sustaining commercial human spaceflight enterprise in LEO:

- **Human Spaceflight: Government** – Established and Emerging Agencies
- **Human Spaceflight: Private** – Private Citizens and Media Projects
- **Research & Development** – R&D, Technology Testing, and Hosted Payloads
- **Satellite Services** – Deployment, Assembly, and On-orbit Servicing
- **Space Manufacturing** – Optical Fibers, Industrial Parts, and Others
- **Media and Public Relations** – Film and TV, Advertising and Sponsorship, and Education

Having conducted a thorough assessment of the potential size of these market segments based on ongoing primary-source interviews and secondary research, SA concluded:

- **Human Spaceflight: Private, and Media and Public Relations,** both show clear and current demand, but the dollar value of these markets are limited even in the long-term.
- **Space Manufacturing and Satellite Services** show significant long-term potential, but predictions for these marketplaces cannot be made with any degree of confidence given the present barriers and uncertainties.
- **Human Spaceflight: Government, and Research & Development,** are intrinsically linked as markets and account for most of the demand in both the near and long term.

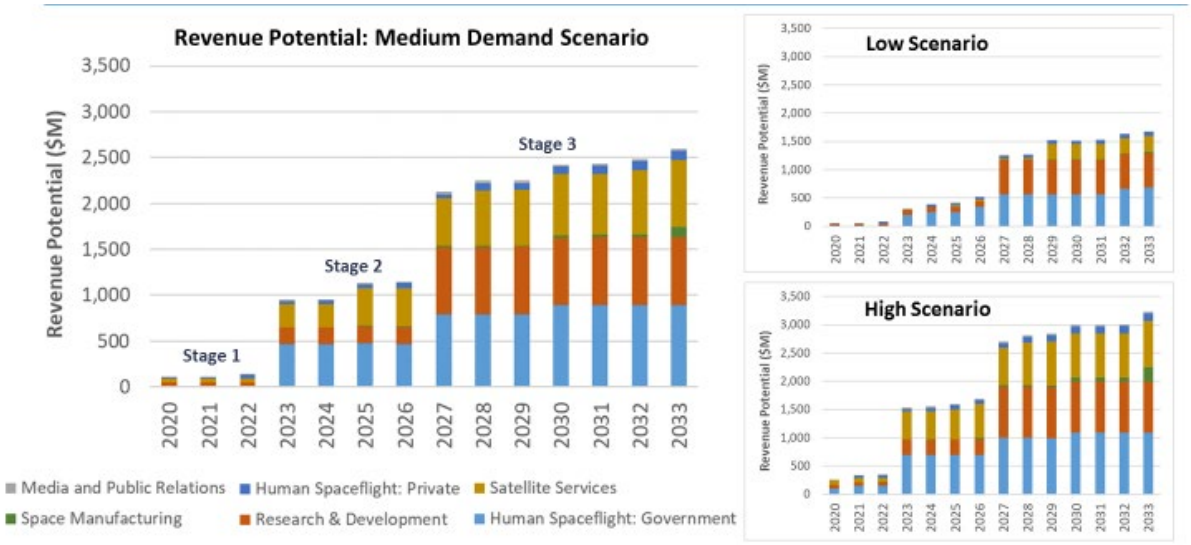


Figure 1: Commercial Space Station Revenue Potential

SA's conclusion, reflected in the revenue potential estimate of Figure 1, is that by necessity, multiple government sources of revenue are required to support a commercial LEO station, but commercial markets should not be ignored. In addition, market research illuminated that the satellite services applications with the most potential require a station in an orbital inclination other than 51.6 degrees where the ISS resides.

1.2. Technical Concept

SA's assessment of the market resulted in the recommendation of a staged approach with the goal of completing ISS Transition to an entirely independent commercial station by 2028. Each of the stages involves the transfer of successively greater responsibility from the government to the private station operator. The three stages of transition are:

- **Stage 1- Commercial Startup (2019 – 2023)** - NASA and the private station operator work together to define a detailed transition plan and demonstrate models for transfer of responsibility. This includes low-risk pathfinder activities that deliver value to ISS and commercial return on investment.
- **Stage 2 – Commercial Phase-in (2024 – 2026)** - greater responsibility is transferred as NASA becomes a customer to the private station operator at a significant level, such as habitation services for one to two NASA astronauts.
- **Stage 3 – Commercial Growth (2027 and beyond)** - NASA becomes fully a customer of the private station services and the ISS is retired.

SA conducted a robust review of station hardware options to develop a low-cost reference design and deployment schedule that adds incremental capability to meet the transferred government demand and incubate the emerging commercial markets. The reference design

builds from a single repurposed Cygnus cargo vehicle attached to ISS to a station centered on a six-port node with three Cygnus modules, an expandable habitat, external pallet with robotic arm, and a multipurpose module. The Stage 3 configuration is capable of accommodating up to eight permanent astronauts, 23 experiment racks; and supplying ~60 kW of power.

1.3. Business Case

The business case for a private space station appears feasible within the constraints of private investment expectations and government budgets. As illustrated in Figure 2, the reference design can be developed at a cost of $2.2 billion plus module launch cost of $1.1 billion. Assuming government (all governments, not just NASA) development contribution of $1.2 billion, $1.5 billion per year by 2030 in government-sourced recurring revenue and private investment of $1 billion, a commercial space station can achieve an IRR of 25%.

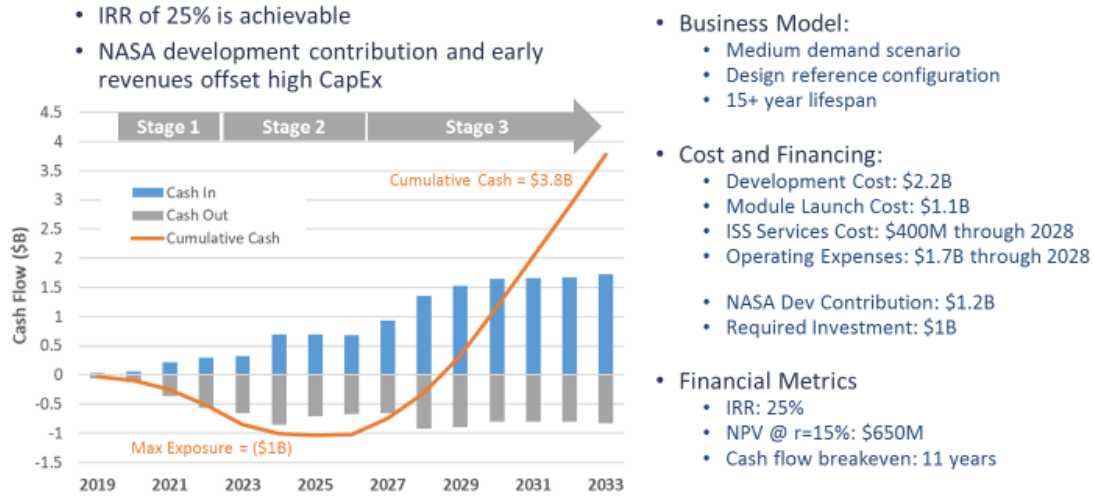


Figure 2: Baseline Business case for Multi-purpose station

SA identified several financial levers available to NASA to balance control of government expenses with commercial viability. The financial levers include target Internal Rate of Return (IRR) for investors; what NASA invests in advance versus pays later for services; the rate of transition of services from the ISS; other government funding sources (including ISS Partners); and the rate of charges for ISS services (such as power) during the transition. Figure illustrates the relationship between IRR, and what NASA (or governments) pay in advance and pay later for services.

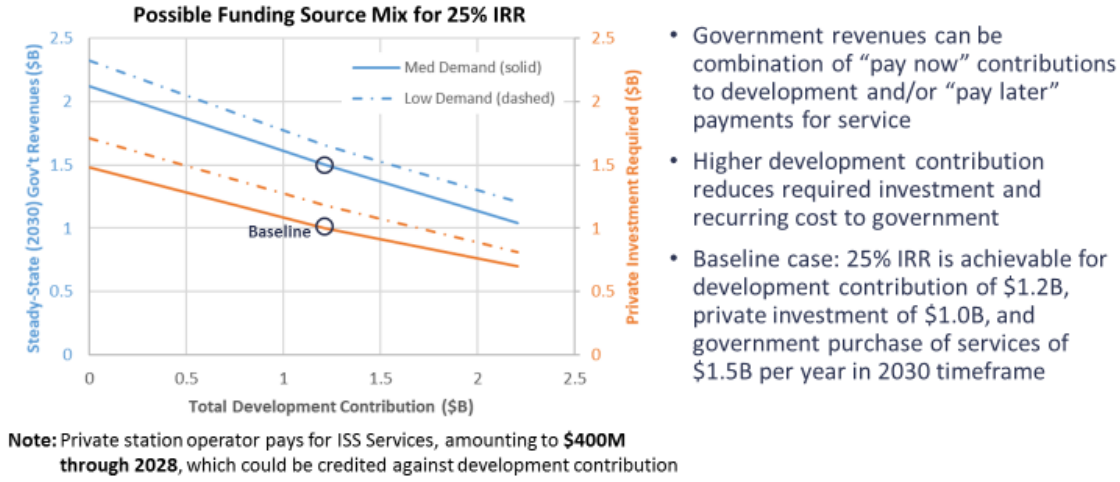


Figure 3: Funding station options for Government

Early opportunities

The proposed evolutionary roadmap for ISS transition involves beginning new commercial activities at ISS on a small scale in the near-term. Chief amongst the possible early opportunities is the concept of repurposing a Cygnus cargo carrier to provide storage or habitation at ISS. By verifying lifetime extension of the Cygnus to five years and disposing of trash through an alternate means (e.g. Bishop airlock), the Cygnus could be put to useful work attached to the ISS. Two specific business cases were developed based on this technical concept, the best of which was to outfit the Cygnus for use as a habitat for private and sovereign government astronauts. This case required a $122 million investment and returned a 25 percent IRR with breakeven in 6 years.

1.4. Legal and Regulatory Review

A legal and regulatory review determined there are no issues that substantively prevent the operation of a commercial space station in LEO. However, SA identified a number of improvements to the domestic legal and regulatory environment that would help encourage investment and commercial growth.

- **Regulatory Recommendation – Export Control:** Expand the ITAR exclusions enjoyed by the ISS to include commercial space stations;
- **Regulatory Recommendation – Intellectual Property:** NASA should waive IP rights to commercial activities in SAA and FAR contracts, and Congress should ensure that NASA can choose to waive IP rights for all Federal Agencies;
- **Regulatory Recommendation – Outer Space Treaty:** Congress and the Administration should provide a Federal Agency with clear authority to meet Article VI "authorization and continuing supervision" requirements;

- **Regulatory Recommendation – Liability / IGA:** Extend Intergovernmental Agreement (IGA) Cross Waivers to protect companies from any liability to NASA and extend the ISS IGA future free-flying commercial space stations.

1.5. Investor Feedback

Following discussion with over 20 investors, SA concluded that the short-term business case is appealing, and the long-term case more challenging but feasible. The primary feedback from investors was:

1. **Market risk is greater than technical risk** – the technology involved in operating a private space station is well developed, and it is the marketplace that presents greater risk.
2. **Limited revenue growth and no exit** – venture capital has expectations of "hockey stick" like revenue growth and high-value exit in a 5 to 7 year timeframe. Neither of these conditions exist, making the project less appealing.
3. **Revenue guarantees** – given the previous two points, the project's primary appeal comes from assured returns to investors, which requires revenue guarantees, primarily from government sources.

Given the feedback received, it is possible to raise the financing required to complete development by employing a phased approach with a mix of investor types. Therefore, SA recommends focusing on demonstrating a near-term business case that delivers a reasonable return on investment (IRR: 25 percent), nurtures the immature commercial market, proves the concepts of operations, and builds demand for a more significant follow-on step.

1.6. Conclusions

A gap exists between short-term and long-term revenue opportunities due to the emerging nature of the commercial market, system development timelines, and investor expectations. SA's proposed transition approach and associated technical solution spans this gap with a successful business case that builds from a single module to an independent station that fully serves the market. Government demand is transferred over time, and several financial levers are available to the government to customize its funding allocation. In support of this approach, SA provides the following conclusions:

Market

- Long-term market potential is good with government being the dominant source of demand as transition from ISS unfolds;
- Tourism and media / advertising present good, but relatively small, short-term revenue opportunities;

- Satellite services and space manufacturing present larger long-term commercial opportunities but require continued nurturing to become significant revenue sources.
- Satellite services market can evolve as part of a multi-purpose platform but requires a separate platform at an inclination other than 51.6 degrees in the long-term.

Technical

- SA developed viable low-cost configurations to meet current needs for the multi-purpose and satellite market segments. The SA station facility configurations are flexible to meet future market segment demands as they evolve;
- ISS provides an excellent springboard for risk reduction and evolution aligned with demand;
- Creative approaches executed through focused public-private partnership may enable significant cost reduction in the development of a multi-purpose platform.

Business Case / Investment Opportunity

- Business case appears feasible within the constraints of private investment expectations and government budgets;
- Limited commercial demand makes moving directly to the establishment of a free-flying station impractical within the constraints of financial markets;
- Financial markets are ready to support a short-term low-cost approach to 'get their feet wet' in this industry;
- A long-term multi-purpose platform is financeable dependent on customer commitments from the government; and
- No legal or regulatory show-stoppers exist, but improvements could help bolster investment and commercial activities.

1.7. Recommendations

SA makes the following Recommendations to NASA aimed at ensuring the viability and success of transition to a commercial space station:

Market

- Clearly quantify requirements and commit funds;
- Enable regular, scheduled access to the ISS for space tourism, as demand is clear;
- Adopt an 'incubator' approach to support and nurture the market (such as space manufacturing) and to take advantage of low hanging fruit; and
- Relax the rules of engagement (e.g. create a 'free enterprise zone') to aid all markets.

Technical

- Fund multiple providers in non-competing markets;

- Provide ISS services (communications, power) at subsidized levels;
- Clarify the availability of existing on-orbit assets for use by a private station operator.

Business Case/ Investment Opportunity

- Stability and clarity of intent from NASA and governments as a whole is key:
  - Commitment as a customer;
  - Encourage ISS partners to make similar commitments;
  - Allow participation from diverse commercial users.
- Support SA's proposed Stage 1 – Cygnus Locker or Habitat proposal to allow investors to "get their feet wet" and enable long-term participation; and
- Advocate for modest regulatory reforms to remove barriers and reduce risk.

SSL Executive Summary for Study of the Commercialization of Low Earth Orbit: Sustain business utilizing human/robotic LEO platforms

Purpose: Develop/Evaluate business cases and financial viability of habitable platforms in low-Earth orbit (LEO) to manufacture and assemble commercial satellites.

Scope of the study: "Partial study" to leverage SSL work in robotics amd om-orbit habitats, with SSL customer knowledge and feedback (include support from Telesat) to come up with potential commercial business plans. Technical concepts are not part of this study scope. Focus on the business case and recommended role of government and international partners.

Prospective Program Description

Lead: Space Systems Loral (SSL) Palo Alto, CA

Expected Partners/Subcontractors: SSL Robotics (Pasadena & Houston), Existing Commercial Satellite Supply Chain, Existing commercial launch systems, Habitat Developers (**Nanoracks** and **Space Adventures**), existing satellite owner / operators (**Telesat**)

Expected Customers: Satellite Owner / Operators: **Telesat**, Intelsat, SES, Eutelsat, Optus, Echostar, Asiasat, + ~30 others

Key Investors: Private Equity, Commercial Financing, with U.S. Gov. support **(CASIS)**

- Manufacture of Communication Satellites in LEO is a viable business model
  - Structures of increased / unconstrained size and/or payload capacity
  - In-space fabrication technologies and robotics are available now for complex assembly
  - Private stations (like Independence-1 or other) will be used for robotic space manufacture
  - Tugs (i.e., Orbital Transfer Vehicle (OTV)) will be utilized for orbit-raising from manufacture at LEO to GEO
- Data segments (managed networks, enterprise and consumer broadband) highest potential growth sectors of satellite communications market
- ISS is the foundation to conduct development & demonstrations to burn down risk and encourage investment
  - ISS crew will be needed to assist/setup demonstrations, address anomalies, and efficiently adapt platform
  - Demonstrations recommended for:
    - Platform Guided Rendezvous and Proximity Operations (RPO)
    - Truss Generation
    - Satellite Assembly
- Trades drove the approach to the space Assembly Platform, the product and the business plan:
  - Satellite payload technological approach driving the capabilities that can be supplied
  - Space Assembly Platform concept of operation driving the requirements for platform, launch and earth-based support factory
  - Orbit and inclination of the space Assembly Platform driving accessibility and fuel for GEO transfers
  - Space Assembly Platform as either a hosted platform or a free-flyer platform
- Alternate business models/solutions will increase opportunities for space-based satellite services
- Fiscal, Legal and Regulatory are recommended to encourage future development and market growth

Business Plan: ISS as Tech Demonstrator, with follow-on off-ISS 51.6 deg manufacture