Outpost: An In-Orbit Commercial Space Station Habitat Development Enabling Cost-Effective and Sustainable U.S. Presence in Low-Earth Orbit

January 14, 2019
A Study for the Commercialization of Low Earth Orbit
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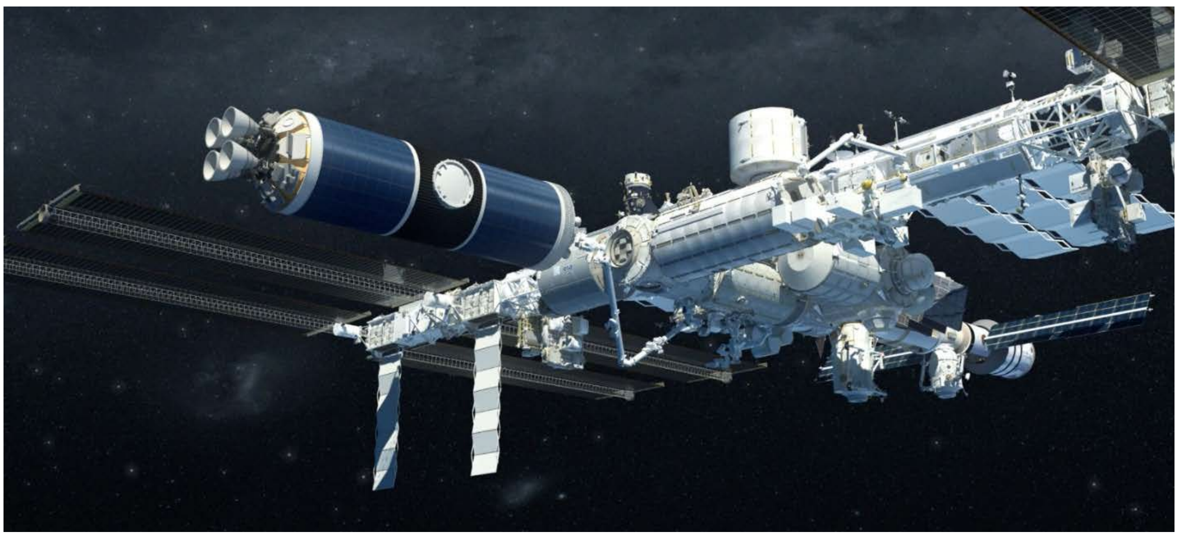

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1 EXECUTIVE SUMMARY

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 29.2% IRR in a base case assumption (Table 1.2) would require $300M RE and $400M NRE—but such a cost would only have a 3.9% probability of actually occurring. However, a station with a higher probability of feasibility according to the Model, say for instance at 55.1%, would yield a 26.36% IRR and cost $325M in RE and $450M in NRE. The illustrative chart and correspondence is shown below in Table 1.2.

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 in Table 1.3, the team assumed that NASA paid two years of R&D up front. Results showed that at the 55.1% probability range mentioned above yields 36.87% 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 55.1 % of the time had IRRs that were even more financeable, with an IRR of 42.67%. 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)

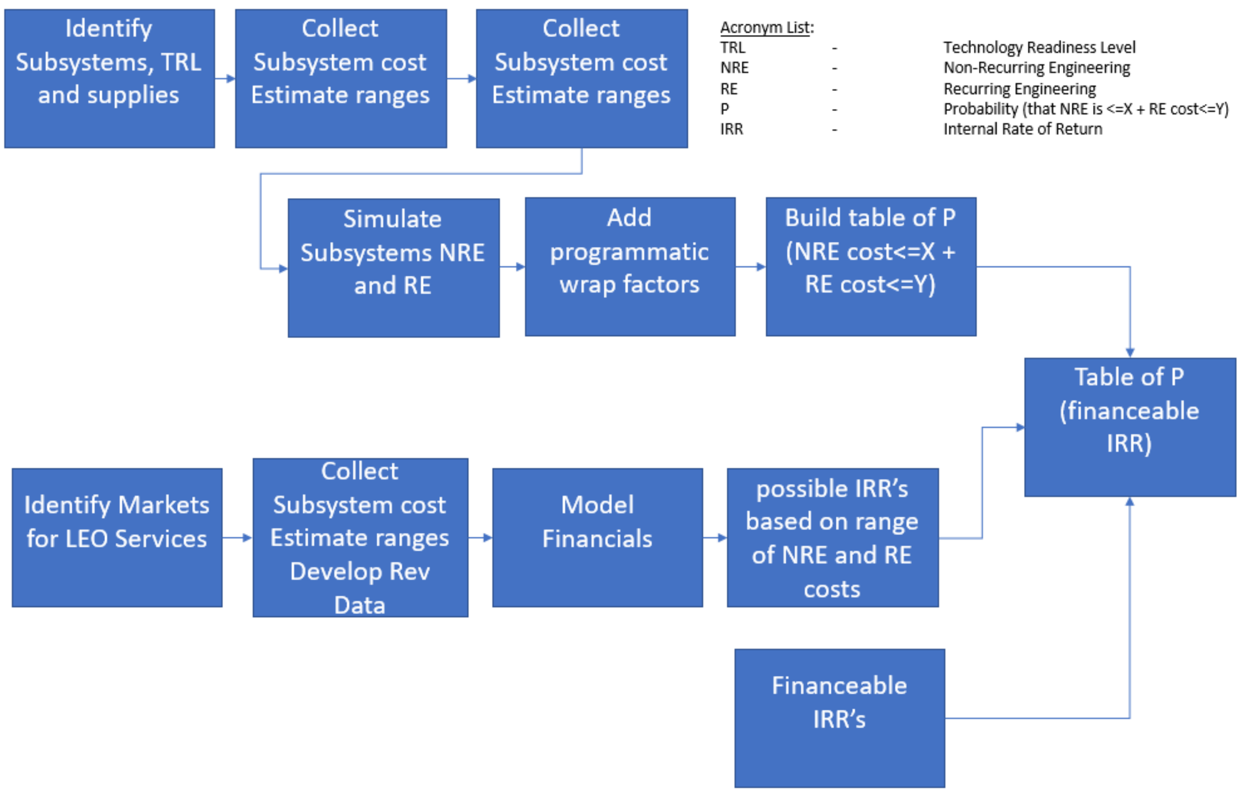
Scenario 3: IRR Sensitivity under base case assumptions (includes 40% NRE allocation to single crew-tended station to NASA specs)

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)**									Key
	$200.0	**$225.0**	**$250.0**	**$275.0**	**$300.0**	**$325.0**	**$350.0**	**$375.0**	**$400.0**	0.00%
$120.0	69.3%	63.8%	59.2%	55.3%	51.9%	48.9%	46.2%	43.8%	41.7%	0 % to 10%
$130.0	66.9%	61.8%	57.5%	53.8%	50.6%	47.7%	45.2%	42.9%	40.8%	11% to 20
$140.0	64.7%	60.0%	55.9%	52.4%	49.4%	46.6%	44.2%	42.0%	40.0%	21% to30%
$150.0	62.7%	58.2%	54.4%	51.1%	48.2%	45.6%	43.2%	41.1%	39.2%	31% to 40
$160.0	60.7%	56.6%	53.0%	49.8%	47.1%	44.6%	42.3%	40.3%	38.4%	41% to 50
$170.0	58.9%	55.0%	51.6%	48.6%	45.98%	43.60%	41.45%	39.50%	37.71%	51% to 60
$180.0	57.2%	53.6%	50.3%	47.49%	44.95%	42.67%	40.61%	38.72%	37.00%	61% to70%
$190.0	55.6%	52.2%	49.1%	46.39%	43.97%	41.78%	39.79%	37.98%	36.31%	71% to80%
$200.0	54.1%	50.8%	47.9%	45.35%	43.02%	40.92%	39.01%	37.26%	35.64%	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



2 INTRODUCTION

2.1 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.

2.2 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.

2.3 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.

2.4 List of Abbreviations

ABS	-	Acrylonitrile Butadiene Styrene (Polymer)
ACL	-	(India) Antrix Corporation Limited
ADCS	-	Attitude Determination and Control System
AEB	-	Agencia Especial Brasilerira (Brazil National Space Agency)
AFRL	-	Air Force Research Laboratory
AIT	-	Integration and Testing
AMF	-	Additive Manufacturing Facility
ARPO	-	Autonomous Rendezvous and Proximity Operations
ASI	-	Italian Space Agency
ASM	-	Altius Space Machines
BEAM	-	Bigelow Expandable Activity Module
CAGR	-	Compound Annual Growth Rate
CASIS	-	Center for the Advancement of Science in Space
CCDEV	-	(NASA) Commercial Crew Development Program
CERN	-	European Organization for Nuclear Research
CLIN	-	Contract Line Item Number
CNES	-	(France) National Centre for Space Studies
CoC	-	Cash-on-Cash
COMSTAC	-	(FAA) Commercial Space Transportation Advisory Committee
COTS	-	Commercial Off-The-Shelf / Commercial Orbital Transportation Services
CRS	-	Commercial Resupply Services
CSA	-	Canadian Space Agency
CSLA	-	Commercial Space Launch Act (1984)

CST	-	Crew Space Transportation
DARPA	-	Defense Advanced Research Projects Agency
DDT&E	-	Design, Development, Test, and Evaluation
DHS	-	Department of Homeland Security
DIO	-	Delivery in Orbit
DNS	-	Domain Name System
DOD	-	Department of Defense
DOF	-	Degrees of Freedom
DOG	-	Delivery on Ground
DOS	-	(India) Department of Space
DOT	-	Department of Transportation
DSI	-	Deep Space Industries
DSU	-	Delay in Start-Up
EAR	-	Export Administration Regulations
EBITDA	-	Earnings before Interest, Tax, Depreciation, and Amortization
ECCN	-	Export Control Classification Number
ECLSS	-	Environmental Control and Life Support Systems
ELaNa	-	(NASA) Educational Launch of NanoSatellites
ELV	-	Expendable Launch Vehicle
EMBARC	-	Electropermanent Magnetic Boom Assisted Rendezvous and Capture
EML	-	Earth-Moon Lagrange
EPM	-	Electropermanent Magnet
ESA	-	European Space Agency
ESL	-	Earth-Sun Lagrange
EVA	-	Extravehicular Activity
EXPRESS	-	Expedite the Processing of Experiments for Space Station (Racks)
FAA	-	Federal Aviation Administration
FARS	-	Federal Acquisition Regulations System
FCC	-	Federal Communications Commission
FFP	-	Free Flying Platform / Firm Fixed Price (Contract)
FOC	-	Future Operating Capability
FY	-	Fiscal Year
GDP	-	Gross Domestic Product
GN&C	-	Guidance Navigation and Control
GSA	-	General Services Administration (U.S. government)
GSO	-	Geostationary Orbit
GW	-	Gigawatt
HDPE	-	High-Density Polyethylene (Polymer)
IDIQ	-	Indefinite Delivery Indefinite Quantity (Contract)
IDSS	-	International Docking System Standard
IGA	-	Intergovernmental Agreement (on the ISS)
IOC	-	Initial Operating Capability
IP	-	Intellectual property

IR	-	Infrared
IRR	-	Internal Rate of Return
ISRO	-	Indian Space Research Organization
ISRU	-	In Situ Resource Utilization
ISS	-	International Space Station
ITAR	-	International Traffic in Arms Regulation
JAXA	-	Japanese Aerospace Exploration Agency
KSAT	-	Kongsberg Satellite Services
LEO	-	Low Earth Orbit
LEOCOM	-	(NASA) Study for the Commercialization of Low Earth Orbit
LoA	-	Level of Autonomy
LoTA	-	Level of Task Autonomy
LRI	-	Lunar Resources, Inc
LRG	-	Launch Risk Guarantees
LV	-	Launch Vehicle
LVFO	-	Launch Vehicle Flight Only
MFF	-	Material Fabrication Facility
MIS	-	Made In Space (Company)
MISSE	-	Materials on International Space Station Experiment
MLI	-	Multilayer Insulation
MLV	-	(Stratolaunch) Medium Expendable Launch Vehicle
MMOD	-	Micrometeoroid and Orbital Debris (Environment)
MPL	-	Maximum Probably Loss
NASA	-	National Aeronautical and Space Administration
NDA	-	Nondisclosure Agreement
NOAA	-	National Oceanographic and Atmospheric Administration
NRA	-	NASA Research Announcement
NRE	-	Non-Recurring Expense
NextSTEP	-	Next Space Technologies for Exploration Partnerships
ODAR	-	Orbital Debris Assessment Report
OIG	-	(NASA) Office of the Inspector General
OMV	-	Orbital Maneuvering Vehicle
OPEX	-	Operational Expenses
ORA	-	(Orbital) Robotic Arm
PCB	-	Printed Circuit Board
PPP	-	Public Private Partnership
PRC	-	People's Republic of China
ProxOps	-	Proximity Operations
R&D	-	Research and Development
RFP	-	Request for Proposal
RLV	-	Reusable Launch Vehicle
ROI	-	Return on Investment
SAA	-	(NASA) Space Act Agreement / (Australia) Space Activities Act

SLASO	-	(Australia) Space Licensing and Safety Office
SBIR	-	Small Business Innovation Research
SiC	-	Silicon Carbide
SINDAE	-	(Brazil) National System for the Development of Space Activities
Space BD	-	Space Business Development (Japan)
SSPD	-	Satellite Servicing Projects Division
STS	-	Space Transportation System (Space Shuttle)
STPI	-	Science and Technology Policy Institute
T&C	-	Telemetry and Command
TAA	-	Technical Assistance Agreement
TDRSS	-	Tracking and Data Relay Satellites
TPL	-	Third Party Liability (Insurance)
TRIA	-	Terrorism Risk Insurance Act
TRL	-	Technology Readiness Level
TRW	-	Thompson Ramo Wooldridge, Acquired by Northrop Grumman 2002
TSA	-	Transportation Security Administration
UHLV	-	Ultra-Heavy Launch Vehicle
USD	-	United States Dollar
ULA	-	United Launch Alliance
UNHWI	-	Ultra-High Net Worth Individuals
VC	-	Venture Captial
WSF	-	Wake Shield Facility
WTO	-	World Trade Organization
Xhab	-	(NASA) Exploration Habitats
ZBLAN	-	ZrF4-BaF2-LaF3-AlF3-NaF

3 METHODOLOGY

3.1 Summary of Technical Concept

As part of the 2017 NextSTEP study, the NanoRacks Outpost team determined that a Centaur upper stage could be repurposed to become an Outpost Space Station and used for a variety of missions. The Centaur Outpost design comprises three primary components: *XHab*, i.e., the converted Centaur V upper stage hydrogen tank; an integrated *Mission Module* based on upper stage hardware; and a *Node* connecting the modules. This configuration provides significant interior pressurized volume of 265 m3 at minimal cost. The cost efficiencies and scalability are the core advantages of the Outpost program, through which NanoRacks believes a LEO economy based on orbiting platforms would be made most feasible.

In the 2017 study, the Mission Module and Node are envisioned to launch atop the ULA Centaur V upper stage on a Vulcan rocket. Once the upper stage, Mission Module, and Node have reached their desired orbit, the Centaur tanks are vented of hydrogen and oxygen. Robotic systems stored in the Node are used to remove the top of the hydrogen tank for interior access to the eventual XHab module. A combination of isolation valves and robotically installed plugs seal the tank of the XHab, which is then pressurized along with the Node modules using air stored in the Node. When pressure is equalized across all three segments, the Mission Module hatch is opened to the Node and XHab. Robotic manipulators move packaged interior structures and subsystems from the Mission Module into the empty XHab for deployment and assembly.

The technical concept, associated requirements, and corresponding risks are explained in more detail in section 5.1.1, "Technical Concept."

3.2 Involvement of Commercial Partners

NanoRacks strongly believes that any commercial marketplace must be driven by the needs of the customers, and that listening to the customer is the most powerful survey possible. Customers know best what it is they need from commercial orbital platforms. NanoRacks seeks to be responsive to what actual customers, future customers, and end-users of the LEO community want to see the community provide for them.

With this fundamental philosophy in mind, NanoRacks approached this study of LEO commercialization from the viewpoint that customer input would be an essential component of the study. NanoRacks therefore collaborated with multiple commercial partners to gather data detailing the demand for habitable and automated platforms in LEO, as well as the role of government in such a broad-based commercial venture. These customers, service providers, and suppliers contributed invaluable data about the current state of the LEO market and its possible future; where demand may come from; and what policy issues and other obstacles lie in the way of stimulating that demand.

Figure 3.2-1 shows one possible arrangement of services across an Outpost-enabled LEO ecosystem, and how a concept of operations may look once Outposts are functioning as active crewed and uncrewed orbital platforms.

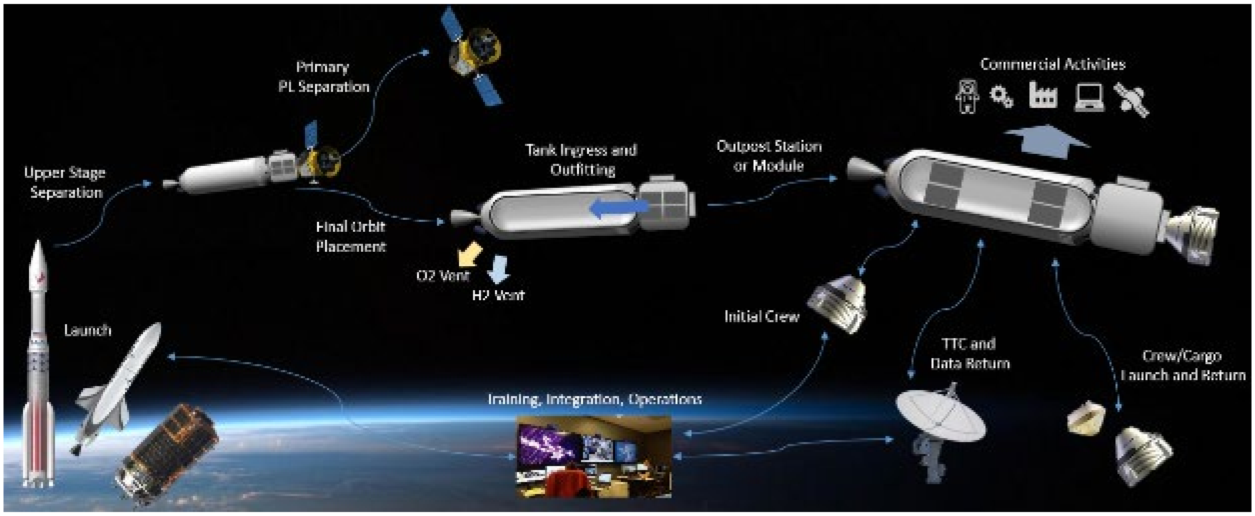


Figure 3.2-1: Services across an Outpost-enabled LEO ecosystem

3.3 References to Requirements

The noted intent of this study is, "to inform NASA and its stakeholders on the space industry's commercialization concepts, business plans, and viability for habitable platforms in LEO, whether using the ISS or free-flying, that would enable a commercial marketplace in LEO where NASA is one of many customers."[1] The structure of this study responds to the CLIN line items in the initial solicitation individually, in the order that they were originally posed in the NASA Research Announcement (NRA). NanoRacks additionally has employed the assistance of 13 commercial partners to add color to its own view of the industry commercialization concept and demonstrate the capability of its proposed Outpost architecture to function as an enabling platform for LEO commercialization.

This NRA specifically requested habitable platforms in LEO, and NanoRacks does answer to those in this study. That said, NanoRacks also believes firmly that in order to commercialize effectively, LEO requires both crewed and uncrewed, robotically tended (and therefore less cost-intensive) platforms. NanoRacks has also put specific emphasis on the benefits of free-flying commercial

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[1] NASA, *Study for the Commercialization of Low Earth Orbit,* 2018, pp. 7

space platforms, independent of the ISS, and the market and policy assumptions that would need to be in place to support their development.

3.4 Study Structure

NanoRacks approached the NASA study by leveraging the strength of its partnerships and legacy on the International Space Station. NanoRacks' core values derive from the work initially conducted on the Space Station—work that demonstrates that growing commercial profits are fostered when commercially funded hardware meets the needs of customers in as commercially effective an environment as possible. These are the essential ingredients to the overall success of any economy and will carry over with the growth of a LEO Commercial Sector.

NanoRacks' approach is a qualitative, milestone-based analysis that feeds into a quantitative output for technical cost models. Additional elements are quantitative and fit into revenue and cost side of the financial models. Work derived from NanoRacks commercial partners, outlining their utilization of Outpost, provides additional qualitative insights into future LEO economies. Focus on policy issues involving NanoRacks' proposed Policy Simulation resulted in out-briefs and a report consisting of concerns and lessons-learned.

Figure 3.4.1 describes how information flows throughout this study and how it used to draw corresponding conclusions, as well as the chapters (numbered above each respective box) where information is made available.

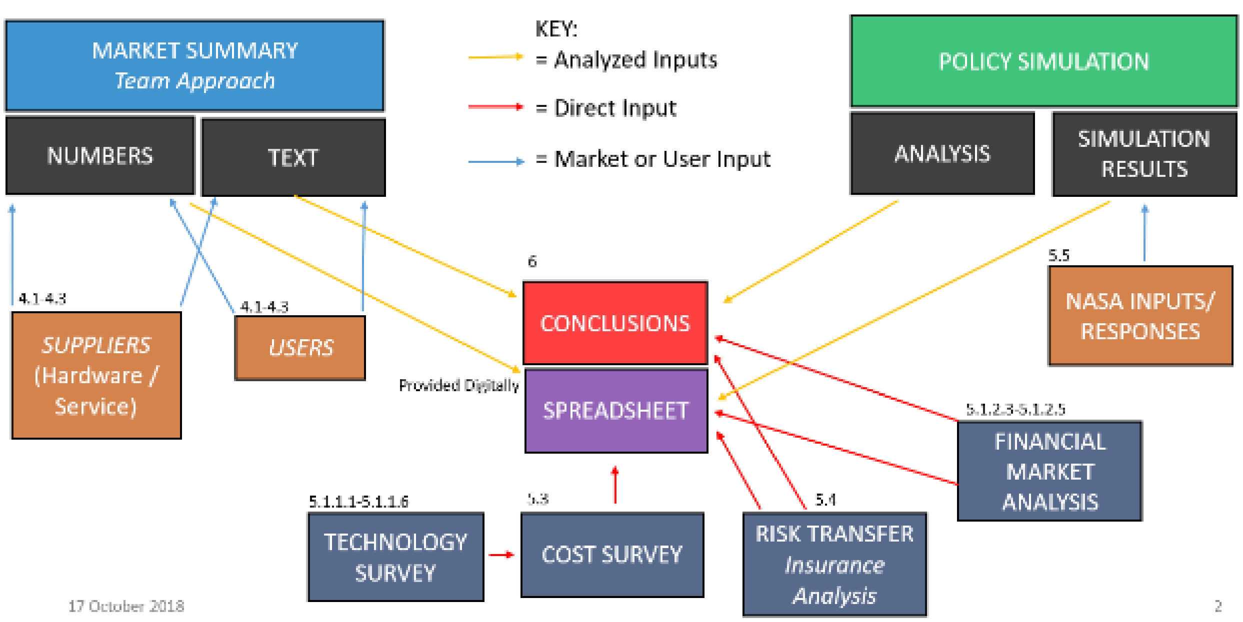

Figure 3.4-1: Information Flow for LEO Commercialization Study

3.4.1 Commercial Partner Input

The structure of the study is based on NanoRacks' core belief that the development of a low Earth orbit commercial community is most efficiently driven by commercial demand. To that end, NanoRacks engaged a group of commercial partners to contribute their insights and experience with space commercialization. Section 4 of this study presents the data and conclusions from these commercial partners.

These commercial partners are grouped into three distinct market sections, including Hardware Providers, Service Providers, and Users. NanoRacks therefore aims to address both the supply side of the commercial equation via hardware and services, and the demand side via users. Inputs form these partners provides critical insights into the viability of the ISS and Outpost for commercial activity, and the potential for future growth via multiple scenarios. These insights are incorporated extensively throughout the study, in particular within section 5.1.2 on the Business Case and Financial Viability, as well as within the Financial Model itself.

Figure 3.4.1-1 below shows the organization of commercial partners' input into the Study based on their stated use cases for (and resulting from) the Outpost infrastructure, and their respective division by category. Note that Kongsberg Satellite Services (KSAT) is shown with multiple Earth-pointing arrows due to their role in coordinating ground stations, rather than actual role in-space as part of the Outpost infrastructure.

Figure 3.4.1-1: Organization of Commercial Partners

3.4.2 Study Topics and Responses

NanoRacks has extracted the commercial partner information necessary to respond directly to each of the study topics NASA identified as goals of this study. In many cases, multiple commercial partners were able to contribute to a study topic, providing a more varied perspective. NanoRacks has combined that commercial partner information with NanoRacks' own industry experience to prepare responses to each of the identified study topics. This information is provided in Section 5 of this study.

3.4.3 Financial Model

In addition to contributions from its commercial partners, NanoRacks has developed a financial model in spreadsheet format. This tool enables NanoRacks to quantify the investment and revenue required to make LEO platforms commercially viable, as well as documenting the projected cost and revenue arising from deployment of such a platform across multiple use cases, and as informed by the partners' contributions in Section 4. This model generally describes "min-max" scenarios where various configurations and assumptions within the Outpost system may lead to potentially different price results. Among the more striking examples of this can be seen where commercial astronauts are concerned, as certain variables are found to profoundly affect the end cost-per-seat.

More information about this financial model and its results is presented in Section 5 of this study.

3.4.4 Policy Simulations

As part of this study, NanoRacks conduct a series of simulations to investigate the impact that NASA policies might be expected to have on the development of a low Earth orbit commercial community. NanoRacks structured these simulations based on hypothetical scenarios that might arise between NanoRacks, NASA, and other commercial partners during the development and deployment of orbital platforms. NanoRacks conducted these simulations in direct collaboration with NASA staff. The results and recommendations of the scenarios are presented in Section 5 of this study.

3.4.5 Overall Conclusions

In Section 6 of the study, NanoRacks synthesizes the data provided by its commercial partners, along with NanoRacks' own conclusions, to present a set of comprehensive conclusions and recommendations representing the overall results of the study.

4 PARTNER CONTRIBUTIONS

PARTNER FINDINGS NOT AVAILABLE FOR RELEASE

5 DATA AND ANALYSIS

This section contains NanoRacks' responses to the CLINs that NASA asked for in the LEO Commercialization Study RFP. Each subsection draws on information from the commercial partners as applicable, as well as NanoRacks' own data and experience, to address each specific CLIN.

5.1 Roadmap to Establish Enterprise in LEO

Outposts are destinations and platforms—not a definitive roadmap, but fundamental building blocks for a LEO economy. NanoRacks has experience in public-private partnerships to enable experience-based assumptions about commercially run platforms can enable the LEO economy.

Sustainable LEO development needs:

- Affordable access to LEO
- An ecosystem of commercially desirable activities to undertake on arrival

Rather than one-time solutions, NanoRacks is looking for roadmap elements as building blocks.

NanoRacks envisions initial launches of human-rated and robotic Outpost platforms in the early 2020s, with exploratory partners on board those first missions, proving out their business concepts. As commercial concepts are proven and begin providing benefits for the Earth economy, and the technology to make commercial human spaceflight viable matures, Outposts are envisioned to become platforms to host tomorrow's astronauts—whether professional, private-sector researchers, or tourists and others to host dangerous manufacturing and research.

5.1.1 Technical Concept

5.1.1.1 NanoRacks Outpost

Concept of Operations

The technical concept of operations begins with Outpost integration with the launch vehicle at the launch site. This process for the mission module follows the same process that the launch providers uses for secondary payloads and payload attach fittings. The primary payload also is integrated above the mission module. During launch, the upper stage separates with both the Outpost mission module and primary payload attached. Once attaining the appropriate orbit for the primary, it is separated from the mission module and upper stage Outpost stack. The upper stage may then be able to move the Outpost to its final operational orbit. Once there, the tanks can be vented of propellant. The tank is then opened robotically using robotic manipulators within the mission module to provide a large interior habitable volume. The flexible robotic systems are able to install and assemble mission-specific interior outfitting within the vehicle. Once complete, commercial operations can begin, including crew and cargo delivery, interior and exterior payload hosting and operating, and data and payload return. Crew and payload operator training, ground control operations, and communications are managed from the Outpost mission control center.

Flight Elements

The Outpost architecture can be decomposed into two primary flight elements, the Mission Module and the XHab. A node element can be used to provide additional docking interfaces on the Outpost and a translation path and interfaces between the Mission Module and Xhab. The Mission Module houses the core subsystems, stowage, and crew accommodations that support the Outpost. These systems are preintegrated before launch to minimize the operations required within the Xhab on orbit. It also provides a location for stowage of robotic systems needed to convert the upper stage to a working Xhab. The Xhab provides a large pressurized volume that is supported by the Mission module systems.

Outfitting stored in the mission module is used to transform the interior into a useful volume. It includes secondary structure and mechanical interfaces for payloads and equipment as well as air, power, data, and fluid distribution lines. The robotic arms used on the Outpost are designed to perform a wide range of tasks both inside and outside of the vehicle. The arms can install their own low-profile grapple fixtures to allow for translation across the Outpost. External to the Outpost, body mounted radiators, MLI, MMOD protection, and solar array blanks are installed before launch and are protected by a fabric shroud during launch.

Docking of visiting vehicles is enabled by IDSS compatible interfaces. Airlock capability can be provided either by an integrated airlock pressure vessel or via a NanoRacks Bishop-derived bell jar-style airlock operated by the robotic arm. Spacecraft control is provided by multiple control moment gyros and hydrazine thrusters. Communication systems are provided for S, X, and Ka band uplink and downlink.

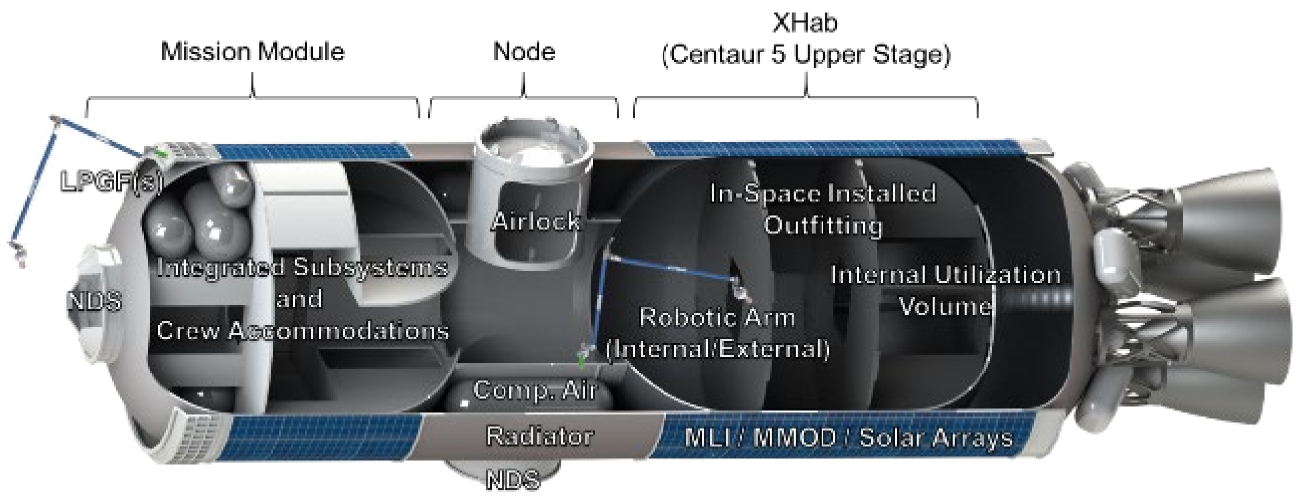

Figure 5.1.1.1-2: Outpost Flight Elements

5.1.1.2 Schedule

NanoRacks will launch the first Outpost demonstration in 2020. The aft-bulkhead-carrier based mission will demonstrate critical robotic operations on the upper stage, including cutting and tank sealing. The first operational robotic Outpost will launch in 2022 with location to be determined by primary payload and specific needs of commercial customer applications. An ISS-vicinity robotic Outpost also will be comanifested to LEO with an ISS cargo or crew launch. Payload return capsules may be launched with this version to bring valuable payloads back to Earth over approximately five years of lifetime.

The first crew-supporting Outpost will launch to the ISS in 2023 to take advantage of the Node 2 forward port and also will be comanifested with an ISS crew or cargo launch. It also will provide two additional docking and berthing interfaces to allow for further commercial expansion. Subsequent launches to the ISS will provide both Outpost-specific crew and cargo needs as well as return capabilities over an approximately 10-year lifetime. The first crewed Outpost free-flying station will be launched in 2024 to ISS vicinity. Crew and cargo will be brought to the station through transfer from the ISS or through dedicated launches. Additional instantiations of all of these Outposts will be launched based on market needs and are discussed further in the overall business case sections.

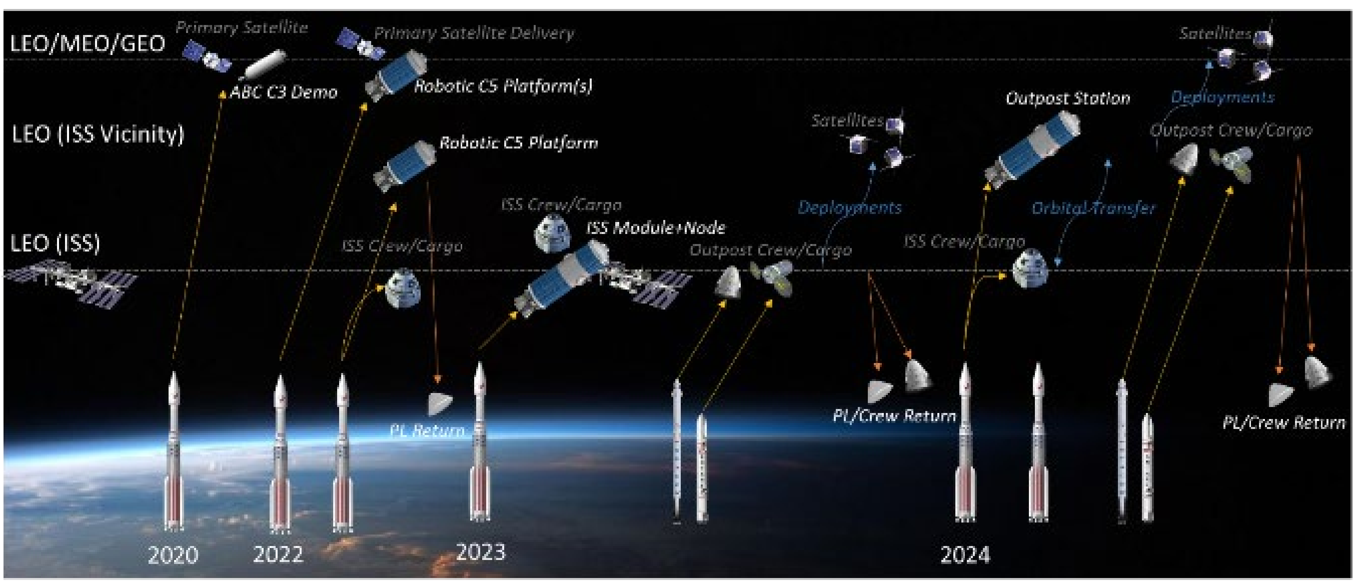

Figure 5.1.1.2-1: Outpost Schedule and Traffic Model

5.1.1.3 Crew concept

The Outpost is designed specifically to minimize any crew activities required to reconfigure the upper stage to a habitable station; most of that work is completed by the robotic systems before any crew arrives. The nominal crewed Outpost supports up to four crew at any one time. Two of the four spots are reserved for trained Outpost crew. Having two dedicated Outpost crew allows for crew function redundancy and provides the ability to work on partner tasks such as maintenance and EVA. These Outpost crew members are able to operate and maintain the entire station, leaving two remaining spots for paying customers, who are able to use their time for tourism, research, entertainment, and sovereign activities.

It is estimated that the commercial crew will have almost six hours per day of utilization time on average, plus the ability to prepare for and perform EVAs if desired. The Outpost crew will have a limited utilization time of around 1.5 hours per day on average to perform activities for customers without another crew member to assist. The customer crew members also may be Outpost personnel trained as mission specialists to perform on board activities on a per-service basis. Training will take place at a NanoRacks facility to provide access to system experts, mock-ups, and simulators. Customer crew and mission specialists must train on a subset of systems as well as prepare for on-orbit operations of the specific customer payloads.

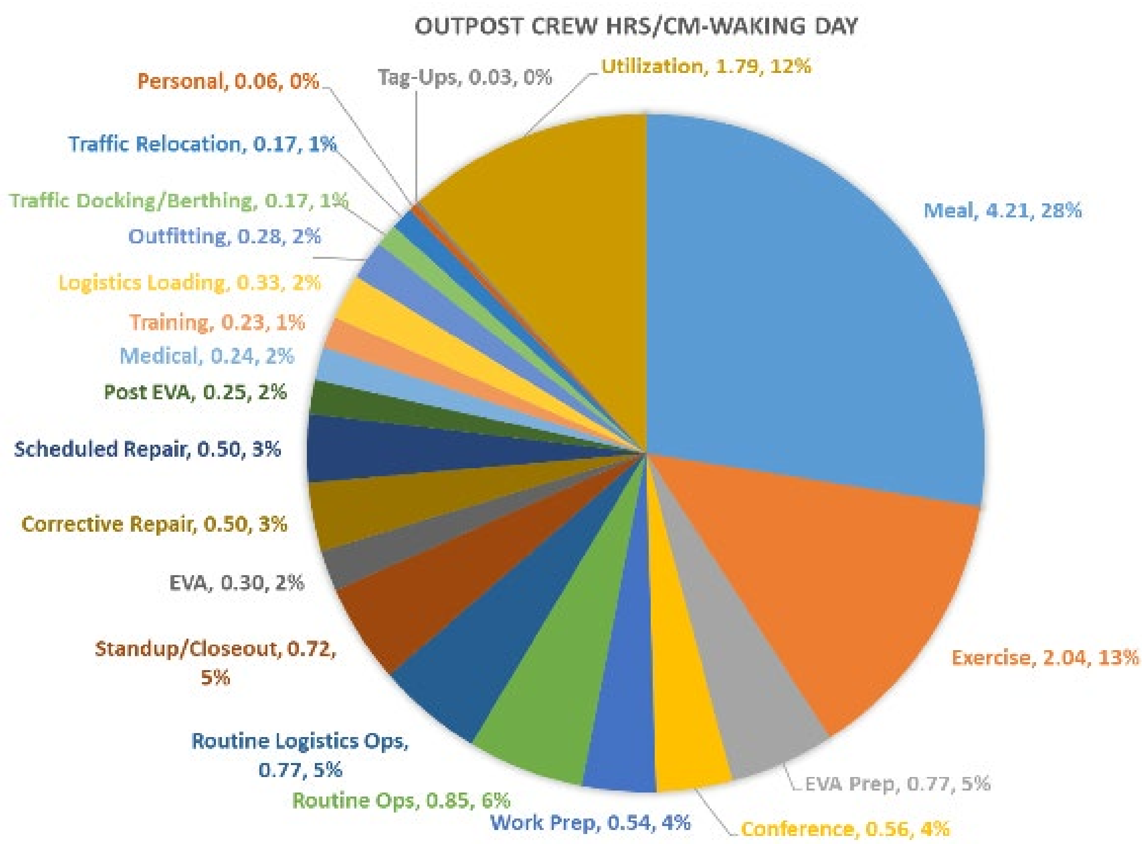

Figure 5.1.1.3-1: Outpost Crew Hrs/CM-Waking Day

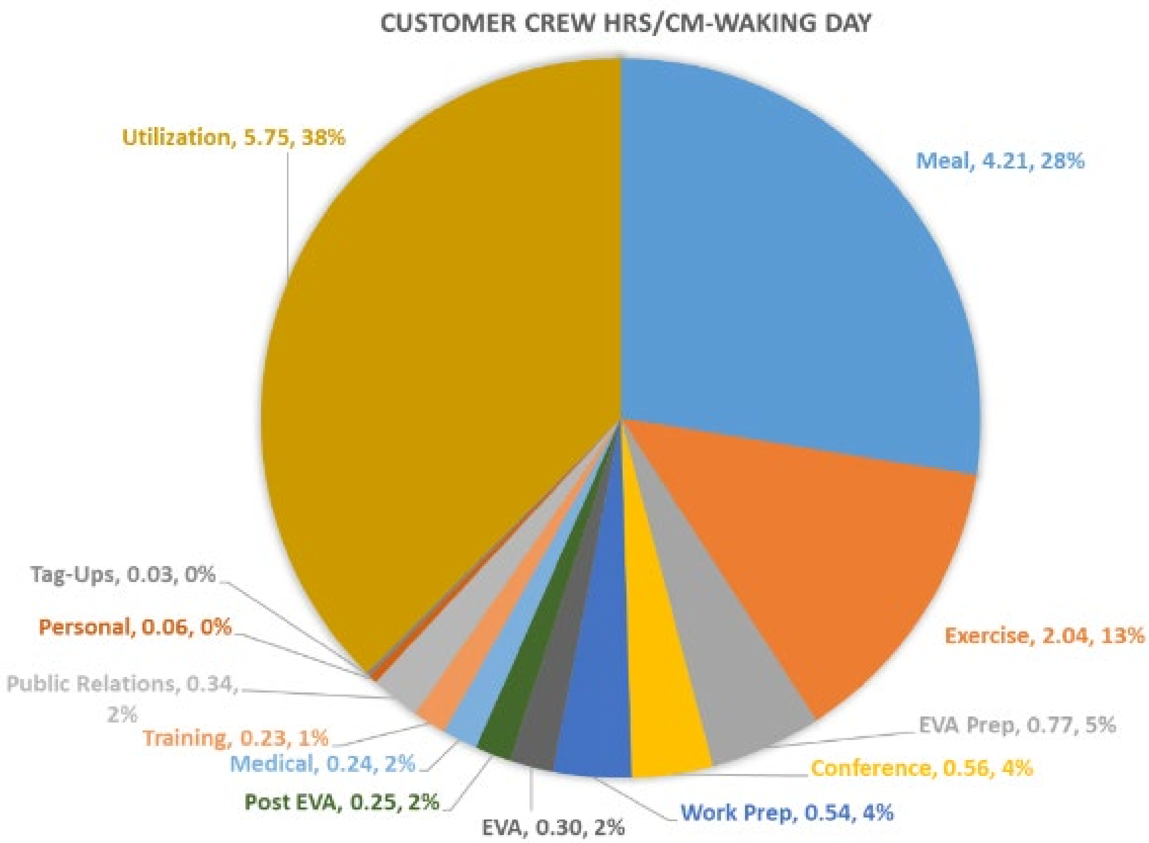

Figure 5.1.1.3-2: Customer Crew Hrs/CM-Waking Day

5.1.1.4 Ground systems

The Outposts will be operated via the Outpost Mission Control Center. The mission control center provides workstations for 16 flight controllers and is based on NanoRacks' experience with their own payload control center in Webster, TX currently supporting 4 controllers maximum. Flight controllers will be in contact with the crew at all times, with a reduced ground personnel team during the night.

The crew will train at a dedicated Outpost training facility. This facility will contain full scale mock-ups of each flight element, as well as system experts for the entire Outpost to prepare crew for the mission. A neutral buoyancy facility will be provided for preparation and training for EVAs on the Outposts. The expected time for customer crew to prepare for a 30-day Outpost mission is between 3 and 6 months based on areas of expertise required. Reductions in this required time will be sought in order to align with the commercial necessity of lowering the amount of training necessary to engage in space tourism activities especially. [2] The NanoRacks Outpost crew will have a much deeper familiarity with the Outpost systems, and will train for one to two years before their first mission based on their area of required expertise. NanoRacks also expects that the dedicated crew will have spaceflight experience on the ISS and can take advantage of much of this knowledge on heritage systems and procedures aboard Outpost as well. Crews will be able to train together with the mission control center flight controllers and an Outpost simulator in the three months before the mission to prepare for nominal and contingency procedures.

The Outpost will communicate from orbit with the Outpost mission control center via the Kongsberg global ground station network. This network will provide near-constant coverage, with occasional loss of signal for up to five minutes, and provides data uplink and downlink for both payloads, commanding and control, and crew voice communications. The Outpost team also is investigating options for leveraging satellite constellation communication networks, including TDRS.

[2] More information on the issue of reductions in training required for increasing space tourism demand are available in Space Adventures' contribution, Section 4.3.3

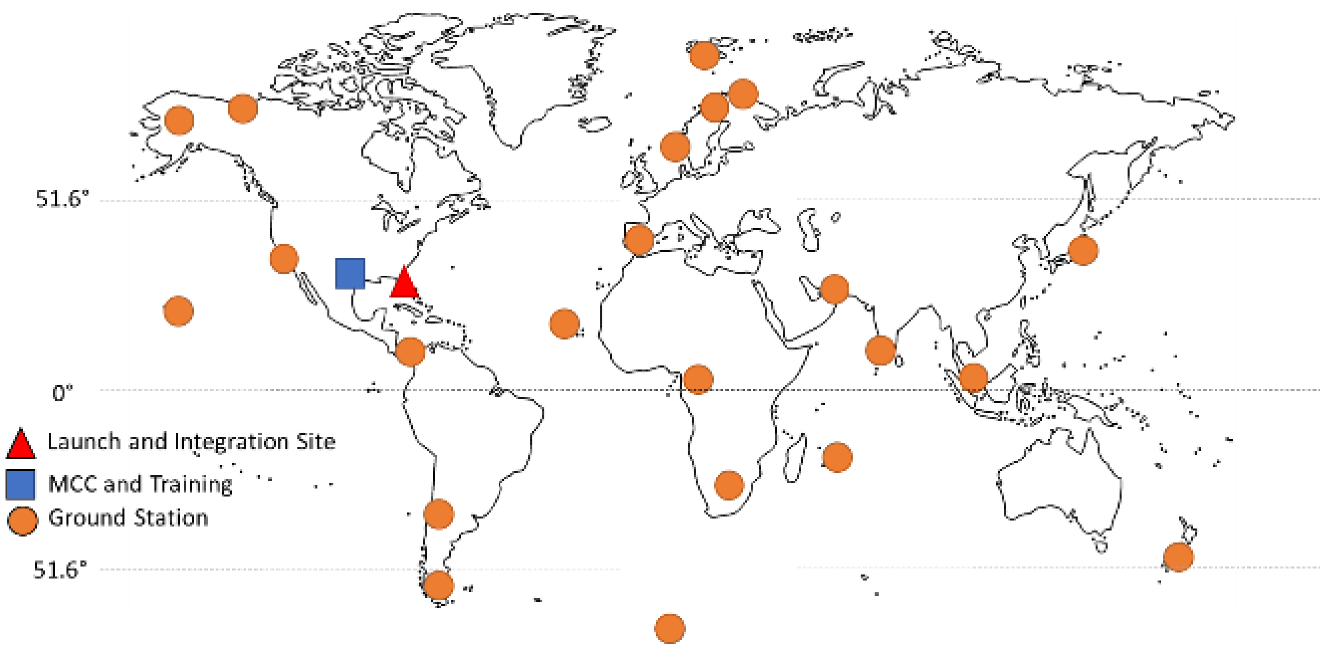

Figure 5.1.1.4-1: Outpost Ground Systems Map

5.1.1.5 Use of NASA resources

NASA resources have been and will continue to be invaluable to the Outpost program if they are available. NASA has already invested in the Outpost architecture through the NextSTEP public-private partnership program. This has allowed NanoRacks and partners to complete a feasibility study of the Outpost and to continue development of the key enabling technologies such as tank modifications, robotics, and outfitting. NASA's continued support of this development through NextSTEP Phase 2 is critical to making affordable crewed Outposts a reality.

NASA's commercial crew and cargo services programs have created an opportunity for other companies to develop their own space station supply vehicles. These logistics capabilities are essential to the Outpost as well, and NanoRacks will rely on them to launch and return crew and cargo. The Outpost program will benefit greatly from the continuation of these programs, increasing the number of providers, and the ability to share launches with NASA to the ISS and the Outpost. The discussion of assumptions on availability of mass and seats as well as launch pricing are left for the business case sections.

Access to NASA's communication networks would be highly valuable for future Outposts. NASA has built the Space Network and Near-Earth Network to support its Earth orbiting assets, including the ISS. Having this infrastructure available for telemetry, tracking, and communication on a commercial basis would be highly valuable to both the ISS Outpost module and free-flying stations in the future to increase achievable data rates, ensure greater service availability, and provide redundant communications capacity to reduce risk.

NASA has been instrumental in defining interface standards for elements both unique and critical to human space flight systems. Continuing to develop, maintain, and update these standards will help the burgeoning industry to grow more effectively by ensuring compatibility between providers and customers alike.

The Outpost program will benefit from the availability of the Node 2 forward port (or others) on the ISS to host an Outpost module. This will provide Outpost with the ability to checkout and evaluate the architecture on orbit, provide NanoRacks a faster schedule to get to orbit, provide NASA with habitable volume for use on the ISS, provide NanoRacks with access to marginal crew and cargo launch and return capabilities, and provide customers with access to commercial space station services. NanoRacks has included the possibility of additional docking ports in the node section to provide other commercial companies with the ability to add their own modules as well and has worked with NASA to show feasibility of berthing a Centaur-5 based Outpost.

NASA has spent over half a century developing the facilities and expertise needed to prepare for and operate crewed space systems. Access to this infrastructure and expertise over the coming years will help NanoRacks bring Outpost to flight more quickly without requiring the time and capital to recreate these facilities. Possible examples include NASA's Christopher C. Kraft Jr. Mission Control Center Mission Control Center facility, the Neutral Buoyancy Laboratory, and the Space Vehicle Mock-Up Facility. The ability for NanoRacks to access NASA's experienced teams in the areas of operations and training also would be valuable to increase the pace of development for Outpost.

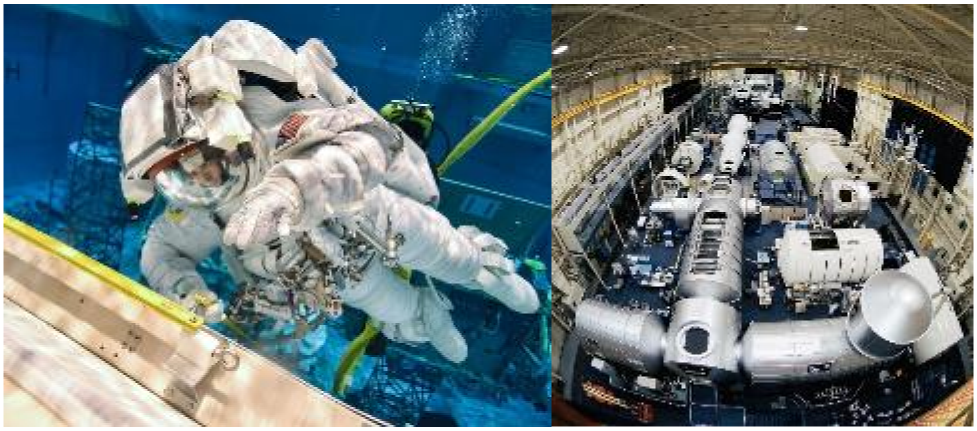

Figure 5.1.1.5-1: NASA's NBL (left) and SVMF (right) located in Houston, TX

5.1.1.6 EVA and robotics

Robotics

The Outpost will launch with two robotic arms designed to be lightweight, flexible, and mobile. Developed by SSL for the Dragonfly in-space assembly project and based on the Mars rover and Phoenix lander robotic arms, the two manipulators provide a low-cost, low-complexity solution to performing the necessary tasks for conversion of the upper stage hydrogen tank into a fully functional habitat. The arms are approximately 3.5m long with a positional resolution of 5mm and tip speed of 10cm/s. Power will be provided to the arm either by a tether or power and data grapple fixtures. Grapple are preinstalled on the Outpost except for within the hydrogen tank of the upper stage, where the manipulators will install their own grapple fixtures to the walls. The arms are able to be used for both IVA and EVA tasks and are able to move between modules through the airlock. Ground operators will teleoperate the arms from the ground mission control center to allow for crewless outfitting and around-the-clock payload operations if necessary.

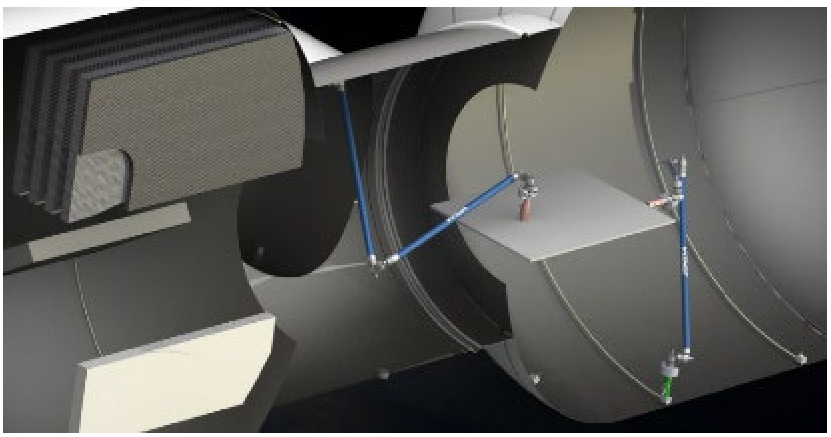

Figure 5.1.1.6-1: Two robotic arms shown passing a rigid outfitting panel from the Mission Module into the Xhab upper stage tank

EVA

While the Outpost will rely on robotic systems to the maximum extent possible, EVA is a necessary capability to keep the station systems maintained over time, manage exterior payloads, and react to contingency scenarios. EVA also may prove to be a highly valuable activity for customers of all kinds. For these reasons the notional Outpost configuration includes an airlock capability based on the Bishop cargo airlock that NanoRacks will launch to the ISS at the end of 2019. By modifying this airlock for future Outpost use, it can be augmented to allow both crew and cargo ingress and egress. In the case where no EVA is desired, a smaller IDSS-based airlock also is available. The crew will need to rely on heritage suits and prebreath procedures used by NASA for the ISS program to limit new development costs for the program.

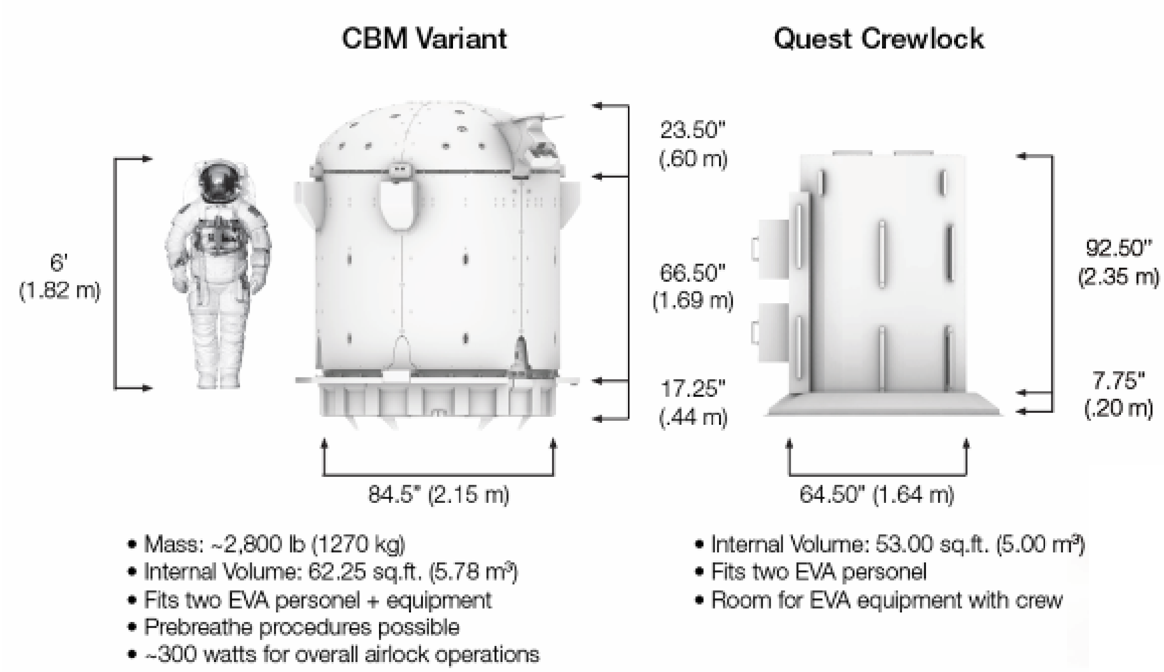

Figure 5.1.1.6-2: Crew airlock option for Outpost based on Bishop (left) compared to ISS Quest crewlock

5.1.1.7 Commercial approaches

A fully realized, economically viable and robust LEO ecosystem is a complex and ambitious undertaking. In addition to the logistics of creating and deploying usable volume in space, and conducting commercial activities to use that space, there are foundational infrastructure concerns that must be addressed.

NanoRacks is relying on a network of commercial partners, as well as a collaborative partnership with NASA, to build and develop the LEO ecosystem. Components of infrastructure development include major functional areas such as design and construction standards, human systems standards, operations, logistics, safety and mission assurance, and interoperability. It is not realistic to expect any one company to have expert proficiency in all of these areas. No company by itself can develop all of the infrastructure and hardware needed to create and sustain a viable LEO economy.

NanoRacks is leveraging knowledge and experience from its commercial partners not only to provide information for this study, but also to start exploring collaborative relationships that can form the basis for the matrix of interconnected goods, services, and hardware that will be needed to make the LEO ecosystem a reality.

NanoRacks has engaged companies that expect to be customers of the LEO community, in order to gain insight into what those customers will need from the Outpost platform and the LEO community in general. NanoRacks is also collaborating with companies that expect to be service providers in the LEO ecosystem, to get a better idea of what customer demand they anticipate for their goods and services. NanoRacks does not expect to be the only customer or the only provider in the LEO market, so it is in the Company's best interest to gain perspective on the LEO ecosystem in its entirety.

The Outpost platform is designed to serve as a nexus for LEO development, an intersection point where various streams of technology, hardware, goods, services, and revenue streams come together. A commercial Outpost system could, by its very existence, provide the foundation for many other industrial actors to begin their work in earnest. As such, NanoRacks needs to maintain awareness of the current and projected trends for LEO development.

Section 4 of this study provides information from the commercial partners NanoRacks engaged for this study. This information includes:

- Economic projections of market demand for various goods and services
- Ways in which various commercial partners anticipate collaborating with each other
- Ways in which commercial partners see their own corporate offerings meshing with NanoRacks' Outpost platform and the LEO ecosystem in general
- Questions and considerations the commercial partners have regarding interaction with NASA

Partner Proposed Capabilities

Stratolaunch notes that the strength of the LEO economic opportunity is in the combination of potential revenue sources it offers. For example, sovereign crew and visitors paying an Outpost operator for crew time on orbit while providing added value to the Outpost operator by performing R&D or monitoring and loading/unloading manufacturing materials and products. These R&D and manufacturing ventures conducted on the Outpost provide additional revenue streams to the Outpost, but also lead to further innovations and product development and manufacturing that create revenue streams for the companies developing those products. Stratolaunch identifies these as "value overlaps" that can generate additional revenue margins for the LEO economy beyond the direct revenue streams from Outpost operation.

United Launch Alliance (ULA) is a major provider of launch services with which NanoRacks is consulting to explore multiple approaches to providing commercial services as part of the LEO community. These approaches include arranging launch services to get hardware, materials, and crew into space; providing Centaur second-stage launch vehicles for refitting into Outpost platforms; and developing an orbital maneuvering vehicle (OMV) to facilitate transport of crew and materials between orbital platforms. NanoRacks does not anticipate ULA being a major consumer in the space market, but rather a service provider, working alongside other providers to enable the development of the infrastructure needed to make the LEO community a reality.

Altius is developing a small space tug, the BullDog, that can expedite inter-platform transport of materials and products, perform orbital platform and satellite maintenance services, and move satellites and platforms from one orbit to another. But since ISS is the only current orbital platform, there are limited use-cases for the BullDog at present. Altius can provide the transport capability on orbit, but does not have the capability to generate the goods and services to utilize that transportation.

Deep Space Industries is working to bring to reality a concept for a LEO transportation depot. DSI's depot will serve as a transportation hub for the LEO community where free-flying modules can dock, small orbital vehicles such as space tugs can refuel, and where space-based manufactured materials can be warehoused. This makes DSI both a consumer and a provider in the LEO community, basically converting usable volume in space into an array of services to enable other consumers in the space community.

Kongsberg Satellite Services has a worldwide network of ground stations to facilitate a comprehensive communication network. KSATs network provides almost non-stop coverage for satellites (and eventually platforms) in a variety of orbits. KSAT already is managing communications for the ISS, so adapting the existing network to accommodate free-flying modules and platforms will be easier. The overall goal is to leverage the existing network as much as possible. KSAT also is exploring opportunities to coordinate robotic installation of communication equipment on orbital platforms, reducing the amount of crew time that would be needed.

Olis Robotics is developing revolutionary space-based robotics capability that is adaptable to various operational regimes ranging from crew-tended projects needing robotic assistance to fully-automated processes in which functions are driven by robotics with little or no crew intervention. But obviously, these robotics applications are dependent on other companies developing processes and applications to utilize the robotics capability. And while Olis Robotics can produce customized robotics applications for projects with varying degrees of crew intervention, Olis does not have the capability to provide crew to conduct those projects.

Terminal Velocity (TVA) currently is developing a new generation of reentry vehicles that can be transported to orbit, docked with an orbital platform, and then loaded with manufactured products, test samples, etc., for return to Earth. TVA has the capability to launch and land these REDs (re-entry devices), but does not have a direct use for them; instead, TVA is dependent on other companies conducting activities in orbit that require materials to be returned to Earth. TVA also notes that NanoRacks' eventual deployment of the Bishop Airlock will enable operation of substantially more re-entry devices to be deployed from the ISS or any other orbital platform—but the ISS is the only current platform, and does not generate sufficient commercial demand to justify TVA deploying a larger number of re-entry devices. TVA therefore is dependent on other private-sector space companies to develop manufacturing or R&D or testing projects that will create a demand for TVA's services.

Lunar Resources is developing in-space vacuum deposition technology to fabricate functional coatings and thin film materials in the vacuum of space for applications on Earth and in-space. Lunar Resources faces the same project implementation needs as other space-based manufacturing companies: requirement of robotic infrastructure; and launch and tug services to transport raw materials and finished products.

Made In Space currently operates a manufacturing facility on the ISS, and is exploring further capability to fabricate ZBLAN fiber in space. The manufacturing process will depend on launch vehicle service providers to transport raw materials to the fabrication module, and re-entry vehicles to return finished product to Earth. The process also features several crew intervention points, from removing finished products from the fabrication unit, to loading products into re-entry vehicles for return to Earth, to performing maintenance and repairs on the fabrication equipment. On a more fundamental level, Made In Space needs usable volume in space to accommodate the manufacturing equipment, and to warehouse raw materials and finished product until the next launch and re-entry cycles.

Space Adventures has arranged space tourism flights to the International Space Station, but has faced logistics challenges building this market significantly. SA is interested in partnering with NanoRacks to provide opportunities for SA's private spaceflight clients to fly to space and stay on board a private space habitat. Controls and limitations placed by NASA on ISS-related operations have made it desirable for SA to explore space tourism possibilities on free-flying platforms.

Space BD is a general service provider for the space industry. It provides various services and solutions for overcoming obstacles to the industrialization of space, and to contribute to developing space even further. Space BD sees space as a commercial industry, and seeks to develop it further by implementing a commercial, market-driven approach to manage projects ranging from satellite deployment to getting hardware into space. Space BD has a working arrangement with JAXA, which operates the Japanese module on the ISS. Space BD would like to expand this opportunity by entering into collaborative relationships on free-flying platforms that are not subject to NASA restrictions on international collaboration.

5.1.1.8 Conceptual enterprise

Contractual Mechanisms - Public

NanoRacks is in the unique position of having delivered nearly a decade of commercial services to the American and partner governments on a crewed space station. This experience will shape the company's transition as the ISS and LEO moves forward into commercialization, and NanoRacks itself evolves its services into the Outpost program. In part, this will be aided by continuing to develop robust contractual mechanisms that sustain the public-private partnerships that have allowed NASA and the U.S. government to procure services, as well as maintaining existing contracting mechanisms like the GSA schedule.

To deliver commercial space station services, NanoRacks does not believe that currently existing provisions or mechanisms require much adapting, except for the possibility that procurements could be conducted under Other Transaction Authorities (OTAs)[3]. This, however, would need to be a closely managed process; contractual oversight should not be allowed to lapse, but contractual mechanisms should be simplified and requirements clarified or standardized, especially given certain scenarios for commercialization.

There could, for instance, be the requirement for a more aggressive change in the current contractual environment if future free-flying or attached Outpost platforms would be considered outside the IGA. In such a case, there would have to be more careful focus on risks, liabilities and the corresponding extra costs of risk mitigation. Such risk mitigation may result in commensurately increased costs.

NanoRacks has a robust and proven history of contracts between vendors and customers that are in compliance with, and take into account, NASA programmatic, safety, and legal requirements. NanoRacks has always been appreciative of the trust that NASA has placed in the Company, as a private sector actor entering into agreements that are based in part on ensuring NASA fulfil certain commercial responsibilities. When the Company was still new, this was a novel and uncharted undertaking. NanoRacks' contracts and ability to enter into commercial commitments today represent an ongoing give-and-take relationship, requiring constant communication between NanoRacks and NASA space station program officials. Contracts that NanoRacks has signed with NASA have also been evolutionary, with multiple clauses added or edited over time, on the basis of experience, and from suggestions from NASA and other space agencies to assure compliance with program and regulatory requirements. Within this context, much has been learned.

[3] According to *The Procurement Playbook,* "Other Transaction Authority ("OTA") describes the streamlined procedures that federal agencies may use to procure innovative research or prototypes, without the constraints of a typical contract, grant, or cooperative agreement. This flexibility has made OTA an increasingly popular choice for federal acquisitions in recent years. OTA helps open the door for contractors to partner with the government in new and exciting areas. OTA allows for much greater speed, flexibility, and accessibility in performing research and prototype projects." Radthorne, *An Overview of Other Transaction Authority*, 2018

Based on existing experience working commercially with NASA on, for instance, the SBIR-III Services Contract, NanoRacks does not envision any conflict arising from the integration of vendors and customers, whether commercial or governmental, into future commercial programs. That said, and within this context and even within the context of the IGA, the commercial operation of the Outpost would benefit from an understanding of how much international collaboration would affect NASA's willingness to conduct activity aboard a commercial space station, even as the Company works to ensure legal and programmatic compliance from its international partners.

Contractual Mechanisms - Private

NanoRacks not only expects, but actively encourages, multiple independent contractual relationships with different customers and service providers. This fosters a diverse LEO economy and builds a marketplace that has the capability to move in different directions with respect to available services and pricing. A flexible contracting matrix of customers and service providers creates adaptability that enables the market to respond as needs change.

External partnerships also drive the exchange of cash and services among companies, which builds a true economic network, as well as necessitates the proliferation of multiple contracting mechanisms between commercial actors; there is no one monolithic contractual source of private cash. Funds will come from commercial enterprises exchanging goods and services; the market will determine how funds flows. NanoRacks cannot expect to be the single recipient, nor the single payer, in the LEOCOM economy.

For example, an in-space manufacturing facility would have multiple cash flows. The manufacturer would need to pay for use of the Outpost space; transportation of raw materials to the Outpost and the return of finished product; robotic grappling capability to minimize the need for crewed operations; ground communications to manage remote grappling operations; transportation of astronauts to the Outpost from other platforms when needed for maintenance; and so on. In exchange, the manufacturer will sell its product, in many cases to some of the same companies the manufacturer is paying to acquire the ability to do in-space manufacturing. This simple scenario generates multiple cash flows between multiple service providers and customers, each operating independently of the others, but working together to create an economic matrix that sustains, and causing multiplier effects that additionally encourage a fully developed space economy.[4]

NanoRacks envisions that like today, future commercial space station services will involve both commercial transactions for a given fee, and barter arrangements with services being provided in return for in-space resources as appropriate. Indeed, the barter arrangements first envisioned as part of the IGA are a root assumption behind why NanoRacks believes that the price of a

[4] For more information on planned interactions of transportation and robotic servicing requirements especially, please reference Altius and ULA contributions in Section 4 of this Study.

commercial astronaut seat can remain relatively low compared to NASA's stated estimates of approximately $50-60 million[5]. In addition, NanoRacks envisions that at some point in the future, cross-ownership of space assets will take place. In such a scenario, launch vehicle operators and destination owners will co-invest in one another, thereby allowing lower costs as both benefit from the increased use of both pieces of hardware.

Enterprise Setup for Government versus Commercial

NanoRacks observes several key findings in establishing commercial relationships with either the government or industry. Generally, these findings may be summarized as follows:

1) Both government and industry partners prefer well-defined contracting forms, like Firm Fixed Price (FFP) contracts, because they reduce time between order, execution, and payment.
2) Government partners, while also in some cases preferring FFP contracts, often experience changing contractual requirements, pushing their contracts more toward Cost-Plus and Time & Materials formats.
3) NanoRacks gains many efficiencies by being able to sell services as FFP, but the industry may not yet be in a state to support such contracts given how often services change, and commercial providers cycle in and out. Simpler contracting forms (like GSA) have legacy and TRL requirements, which are often difficult to attain for new entrants into the market.

FFP contracts are preferable because they set clear expectations and allow service providers like NanoRacks to standardize processes across multiple customers, gaining efficiencies in responsiveness to requirements along the way. As a case in point: it is the set and predictable integration schedule, practiced over the past nine years, that has largely led to NanoRacks' success as the leading integrator of ISS-bound commercial payloads and CubeSats. The initial decision to standardize form-factors around the 1U NanoLab represents the critical insight that began this trend. Non-baseline services offered as part of the baseline Services Contract with NASA, like a week of additional hosting within the NanoLab enclosures, or additional power supply requirements, or non-standard safety work, ideally also would be rolled up into an FFP model.

That said, FFP pricing models are premised on a stable product and requirements infrastructures. NanoRacks has experienced a large slip-rate[6] due to customer inability to meet requirements by NASA-mandated handover dates. This is consistent across the type of customer, whether new or experienced, and increases financial liabilities for all payload contracts. Additional work required to de-and re-manifest payloads onto future flights incurs significant costs for NanoRacks. Such uncertainties, particularly in more traditional NASA markets like technical demonstrations where payloads are less likely to be standardized, make FFP contracts less attractive options.

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[5] Stating an estimated cost of $58 Million: NASA, *Commercial Crew Transportation*, 2015

[6] Based on October 2018 interviews conducted with NanoRacks Mission Management Team and historical NanoRacks ISS deployment data.

Nonetheless, within the conceptual enterprise of the Outpost program, and within the context of ISS commercialization, NanoRacks believes that some of these hurdles potentially could be overcome by splitting the business between a government-dedicated component, and one built to deal exclusively with the commercial sector. Determining an ideal balance between these contracting structures requires further study.

5.1.1.9 Related capabilities and services

Uncrewed Outposts

One idea of particular interest to NanoRacks' commercial partners is the concept of orbital platforms that are mostly or even completely automated, relying on robotics to perform operational functions with minimal crew tending required.[7] Such platforms would be customizable for various commercial demands, capable of operating in various orbits, and rely heavily on robotics to reduce the need for crew-tended operations with their higher operational costs.

Many of the commercial partners NanoRacks engaged for this study identified a free-flying platform, with extensive use of robotics to reduce the need for crew tending, as one of the optimal models for furthering LEO development. Deploying multiple platforms following this model would resolve several current challenges to expanding the LEO ecosystem:

- They would provide more usable volume on orbit.
- They would provide the capability to put usable volume in different orbits at different altitudes to address varying customer needs.
- They would provide customizable and modularized capacity that can be tailored to meet various customer use-cases.
- They could interface as modules on the ISS as well as free-flying capability for independent operation.
- They would provide operational cost reductions by automating many functions through the use of robotics, which would eliminate some or all crew tending requirements, along with the associated costs of crew support (ECLSS, accommodation space, and so on).

Such a model for usable volume in space is not, of course, without its risks. Some of the more easily identifiable risks, as well as their potential cost impacts, include:

- **Risk of loss of platform.** Extensive use of robotics reduces the need for crew tending, but also reduces the number of crewed hours. The chances of a catastrophic system failure resulting in the loss of the platform as an operational element is increased when astronauts are not present to perform remediation. On the other hand, free-flying platforms such as NanoRacks' Outpost are significantly less expensive to deploy than traditional "dry lab" platforms that are partially assembled on the ground and finished in space. An Outpost or other similar platform would be more cost-effective to construct and put into operation. This results in more platforms being in orbit, which reduces the impact of any one of those platforms being lost through accident or malfunction. And since the Outpost platform has as its basis an expended second-stage launch vehicle, every launch is a potential opportunity to put another Outpost into operation, with a much faster launch cadence than

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[7] For further information on the orbital platform concepts explored by NanoRacks' commercial partners, the contributions these partners envision making to such an uncrewed platform, and the benefits the commercial partners anticipate drawing from an uncrewed platform, please make reference to the commercial partner contributions in Section 4 of this study.

a dry lab with multiple modules that would need to be built, transported to space over a series of launches, and assembled into a platform. Each step in this process incurs risk, and therefore mitigation and insurance cost.

- **Potential cost of compatibility with ISS.** Under NASA's current operational model, LEO commercial development is focused primarily around the ISS. Any independent platform or module that could have any interaction with NASA crew is subject to a regulatory regime that is in many cases so restrictive that compliance with NASA requirements is cost-prohibitive for these independent platforms. While NanoRacks hopes that this regulatory environment will change over time, in the meantime it is vital to the development of a LEO economy for customers to have access to affordable usable volume in space. Extensive use of robotics will reduce the need for astronauts to perform crew tending functions, which will bring down the overall cost of the platform.
- **Risk of market saturation.** Just as overbuilding can cause saturation in a terrestrial real estate market, there is a risk of overbuilding of space platforms without customer demand to utilize those platforms. This would depress the market and could lead to inefficiencies in the LEO ecosystem. NanoRacks and many of its commercial partners have planned for this risk by designing their business models to be customer-responsive; that is, they plan to build only to meet specific customer demands, not engage in "speculative building" in the hope that customer demand will develop. This will ensure that not only orbital platforms, but also other goods and services that comprise the LEO ecosystem, will have full business justification from the moment they become operational.
- **Limitation of use-cases.** Despite the current and ever-expanding functionality provided by robotics, there are some space operations that currently, and always will, require crew tending. A LEO platform model that relies too heavily on robotics necessarily will limit the potential uses of that platform. The ISS does not have the usable volume to support all anticipated customer demand for crew-tended space operations that are projected to come into existence. As the ISS approaches the end of its operational life, any crew-tended commercial operations currently supported by the ISS will need to be transitioned to independent orbital platforms. Therefore, it is vital that any orbital platform such as NanoRacks' Outpost be adaptable to operational scenarios with a variety of crewed/robotic ratios. Another crucial component in the further development of the LEO ecosystem is an emphasis on recruiting and training a cadre of astronauts capable of conducting crew-tended operations on multiple orbital platforms that are functioning in various orbits, with a variety of missions, for diverse customers.[8]

Inter-Related Commercial Development

In the process of exploring the concept of deploying multiple customizable orbital platforms, NanoRacks and its commercial partners also identified another collateral benefit to the

[8] Section 3.1.2.2 on Cash Flow Summary provides further details on the nature of financial relationships that may be facilitated aboard an orbiting platform.

development of such platforms: the strength of collaboration between commercial space providers to create an interdependent network that is the basis for a robust, financially viable LEO economy.

Some space companies provide foundational space operational components, such as orbital platforms, launch and re-entry vehicles and services, payload deployment capabilities, and inter-platform transportation vehicles. These foundational "building block" products and services enable a second tier of companies that provide supplemental products and services—for example, companies that produce satellites, conduct space-based research, and provide materials and technology for in-orbit maintenance and repairs, as well as companies that manufacture products with space applications (such as Lunar Resources functional coatings and thin film materials) or that are produced in space for use on Earth (such as Made In Space's ZBLAN optical fiber). These are companies whose product and service offerings are directly dependent on the products and services of the foundational companies. They function as customers for the first-tier foundational companies; in turn, the first-tier companies act as customers of the goods and services provided by these second-tier companies.

It is in these multiple tiers of inter-related private-sector space providers and customers that NanoRacks sees the development of an economic matrix of LEO activity. And it is this matrix of interrelated product and service offerings that will produce a viable, healthy, diverse LEO ecosystem. This is the core reason why NanoRacks engaged multiple commercial partners in the development of this study: because NanoRacks sees a collaborative model between multiple private-sector space companies as the only viable model for a LEO ecosystem.

All of the commercial partners NanoRacks engaged for this study have hardware, services, or manufacturing processes that will contribute to a robust, diverse, and stable LEO economy. However, all of these commercial partners also have noted that they cannot operate independently; all of them are dependent on hardware and services provided by other companies. [9]

- Companies providing launch and re-entry services need other companies to conduct activities on orbit that generate demand for launch and re-entry services.
- Companies that manufacture satellites have a need for launch providers to get those satellites into space, as well as companies to monitor and tend those satellites.
- Companies that are exploring manufacturing opportunities in space need a means of getting raw materials up to an orbital platform, a means of returning finished product to Earth or warehousing it for use in space-based applications, and a means of performing maintenance and repairs on manufacturing equipment on orbit.
- Companies that provide space tug or transport shuttle services need to have multiple space platforms to create demand for their transport services.

[9] For further information on the goods and services offerings of the various commercial partners NanoRacks engaged for this study, please make reference to the commercial partner contributions in Section 4 of this study.

- Companies that manufacture usable volume in space need launch services to get the modules up to orbit, as well as customers to utilize that volume, both astronaut and robotic maintenance services, and so on.

As an extension of this idea, all of the commercial partners working with NanoRacks on this study have been able to identify product or service offerings of other commercial partners that provide collaboration opportunities. In short, every commercial partner has something to offer with the potential to stimulate more commercial demand and build a space economy, not only centered on the ISS but also creating a demand for more orbital platforms that are adaptable to various uses.

This concept of a network of commercial providers in space, where multiple companies provide goods and services to other companies, who also provide goods and services in return, is one of the key concepts to emerge from this study. It cannot be overemphasized: no one piece of hardware, and no one company, will ever be capable of driving, much less sustaining, a robust and economically viable LEO community. No one player can, nor should, be the “single solution” for LEO development. NanoRacks, NASA, and every other commercial space venture must be prepared to work toward a LEO ecosystem in which all participants act as providers and customers in a collaborative economy.

5.1.1.10 Benefits to U.S. human spaceflight

Pathways to and Effects of Lowering Human Spaceflight Costs
Understanding the benefits of United States human spaceflight is more than a philosophical exercise, given the extraordinary expense of human exploration.

Whether in factories on Earth, or those soon to be in Earth's orbit, the role of humans is less necessary than ever before. Science and automation have evolved significantly from the early days of the space program, where space officials and dreamers assumed that the first space stations would be staffed by soldiers, using the orbital station to observe adversaries[10]. That task now belongs to satellites, but these could just as easily be called orbiting robotic platforms.

The orbiting factories, warehouses, and fuel depots soon to come via Outposts and other commercial platforms will be operated robotically, with humans perhaps necessary for dropping off and picking up cargo—though given the high costs associated with keeping humans alive and safe, a human role is unlikely to be justified within several decades, unless that role would be revenue generating, as in the case of sovereign astronauts and tourists. Having said this robotic operation is an important component of lowering the cost of human spaceflight.[11] Over the next several decades, astronaut time will be increasingly liberated from dangerous or repetitive support activities in hostile environments, allowing the focus of the spaceflight experience itself, and ultimate costs of human missions, to decouple from station maintenance or other operational requirements[12].

Across NanoRacks' Outpost platform, robotics are critical in the pathway for development, construction, and in some cases operation—especially maintenance and reconfiguration—of space habitats while humans are not present. Regardless, such systems, even when human-tended for only a fraction of their lifetimes, are expected to remain significantly more cost-intensive than fully automated systems. From a commercial perspective, this is an important point.

As on Earth, the extraordinary advances in robotics, artificial intelligence, and virtual reality systems, to name just three advances, are causing profound changes in how we conduct ourselves, from driving cars, to shopping, to self-awareness. This change will soon enough sweep through NASA and the conduct of space exploration. One is therefore left with pondering the role of humans in space in a society where robots are capable of performing most operations.

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[10] See Manned Orbital Research Lab (MORL) study for early concepts of repurposed upper stages for defense and research purposes: Pisciotta, *Report on the Development of the Manned Orbital Research Laboratory (MORL) System Utilization Potential*, 1966 - <http://www.astronautix.com/m/morl.html>
[11] For more information on robotics applications in space, please make reference to the commercial partner contribution of Olis Robotics in Section 4.2.4 of this study.
[12] For more information on how roles of astronauts and space visitors are anticipated to change as the LEO ecosystem evolves, please make reference to the commercial partner contribution of Space Adventures in Section 4.3.3 of this study, as well as the financial model provided as part of this study.

That said, however, NanoRacks does support the human role for three historic roles it has taken: tourism, national exploration, and human expansion. These powerful justifications lead NanoRacks to the conclusion that, in order to maintain and expand our capability to meet their requirements, the costs of humans' presence in space must be reduced. Reducing these costs requires either a breakthrough in technology or greater cadence of commercial vehicles, to name two of the primary drivers in cost.

Benefits of Expanded Infrastructure

NanoRacks believes that the fundamental benefits of a more robust orbiting infrastructure would be reduced cost and increased cadence of required services. This would occur whether or not the destination requires humans. An evolution of the Outpost ecosystem as described in the partnerships presented herein means that NanoRacks would have multiple modes of transportation, return, and servicing in the critical pathway, enabling a more efficient meeting of demand for customer needs. In addition, as more commercial space service providers enter the market, the increased competition will motivate those providers to reduce their per-service costs to attract more business—whether or not the immediate mission is human-rated. The result will be decreased costs for space transportation, whether human-rated or not. Ultimately, however, NanoRacks argues that the benefits would accrue to human transportation and habitability costs, ultimately securing the ability of the three human spaceflight elements above to evolve sustainable.

This interface or cross-dependency between human spaceflight and robotics deserves close examination. As LEO Outposts become available for manufacturing, commercial manufacturing companies will more efficiently fabricate materials in space. This will produce a significant cost savings over transporting construction materials from the ground.[13] As demand for human accommodations in space increases, in-space manufacturing will allow commercial providers to respond more quickly and inexpensively to the demand for habitats and other required infrastructure.[14]

Put more simply, the key to decreasing launch costs in the absence of a technological breakthrough is to have increased reasons to fly to and from and within space. In the human sector, the demand for space tourism must first increase to allow scaling. NanoRacks' financial model shows that, within increased availability in crew-capable platforms, such scaling becomes possible. But this scaling is a function of space tourism driving an increased need for goods and services, and these goods and services will need to be supported by uncrewed vehicles to drive lower costs for human-rated systems.

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[13] According to Made in Space, commercial business cases for space-based manufacturing, however, cannot close without significant decreases.

[14] For more information on in-space manufacturing and its ability to reduce spaceflight costs, please reference the Lunar Resources contribution in Section 4.3.1 of this study.

Space tourism development therefore is a key part of the evolution of the LEO ecosystem, because space tourism will generate increased demand for the goods and services needed to support human spaceflight. This circularly-increased demand for goods and services will then increase the cadence of flights, which will enable service providers to reduce per-flight costs and make crewed space flight more affordable.[15]

Despite the overlap described above, the market for human spaceflight requires demand, vendors, and supporting services that are unique. This would include ECLSS, consumables, and a far more sophisticated safety system from start to finish. No matter the uniqueness, the fundamental truth holds: more reasons for transportation result in lowered human spaceflight costs.

Expanding Demand for Human Spaceflight - Challenges
Another important potential avenue to generating more interest in space tourism would be a renewed focus on the experience customers have on the ground. In current regimes, training is conducted in Russia—a country where most potential tourists would be kept far from loved ones, in dorms, to conduct six to nine months of laborious training.[16] Customers also have expressed extensive hesitation about launching on a foreign vehicle.[17] The process to launch tourists to space at this time is almost a non-starter when considering the possibility of increasing demand.

A whimsical analogy for such a process may be found in today's airline industry. Were it to operate under the same assumptions as human spaceflight, there would only be one flight per week between Washington, DC and London. Passengers would be required to take weeks of swimming lessons, while undergoing psychological training to build their endurance for spending hours in a cramped space without available exits while operational. Emotional evaluations would naturally have to be conducted prior to flight. The cost of tickets would logically rise to $20,000 apiece, and the notion that ticket prices could be lowered by not conducting the required evaluations and testing prior to transatlantic flights would be met with disbelief and ridicule.

Making predictions on the future commercial human space economy is difficult, because in order for human spaceflight to be scalable and therefore commercially attractive, a greater understanding of its role in the entire ecosystem must be attained. Put another way, it would have been difficult for government officials and investors of the 1950s to have anticipated the growth of European hotels for American tourists—businesses which at their core rely on adequate transportation. The hotels of the early jet age could well become analogues for tomorrow's space communities, attracting artists, writers, and visionaries that create unanticipated commercial markets of space

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[15] For more information on scaling and how it impacts spaceflight costs per mission, please reference the ULA contribution in Section 4.1.2 of this study.
[16] Work provided by Space Adventures, based on interviews with potential customers, indicates that a lowering of training regime requirements would yield a corresponding increase in the total available market of space tourists willing to both pay the cost of a space mission and spend the time required to prepare for this mission. More information available in the Proprietary Annex.
[18] NASA, "Forecasting Future NASA Demand in Low Earth Orbit," October 26, 2018

music, art, and multimedia fueled by lowering costs of space transportation. Worth noting is that there were then, and continue to be, robust partnerships between the airlines and the hotel chains, much the like the cross-ownership between launch operators and destination companies that NanoRacks envisions.

Role of NASA Astronauts in Outpost Development

NanoRacks is not able to adequately predict the role that NASA astronauts would take in the development of commercial space stations, especially in the context of the Outpost program. This very much depends on the requirements that the use of NASA astronauts would impose on the design of a platform intended for commercial use.

In any case, NanoRacks does see two possibilities. In one case, NASA astronauts could play an important role in setting ISS-connected platforms up, and conducting required upkeep. In the second case, astronauts would undertake operations, perform research, and conduct services aboard the platform. If NASA were to leverage Outpost platforms for activities outside the scope of the commercial sector, such as preparation for Mars or Deep Space journeys, the specific design requirements needed for these non-commercial activities would trigger additional cost. As with other activities, NanoRacks believes that the most effective way to conduct such activities would be through individual activity-based FFP contracts.

NanoRacks anticipates that Outpost will be modifiable to meet the NASA's stated need for a "LEO platform intending to host NASA human research… to support crew health and safety, access to and from LEO, and the research capabilities needed to enable the activities identified in [Human Research Program] risk reduction plans."[18] These platforms feasibly could provide comparatively low-cost solutions to validate technologies for NASA missions beyond LEO, and NanoRacks notes that such potential requirements would be baselined into a set of possible additions for future crewed platforms.

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[18] NASA, "Forecasting Future NASA Demand in Low Earth Orbit," October 26, 2018

5.1.1.11 Technical Risks

This section addresses technical risk for the Outpost station program. This risk is distinct from cost risk, schedule risk, and programmatic risk. Technical risk "is the risk associated with the evolution of the design and the production of the system of interest affecting the level of performance necessary to meet the stakeholder expectations and technical requirements. The design, test, and production processes (process risk) influence the technical risk and the nature of the product as depicted in the various levels of the PBS (product risk)." – NASA/SP-2016-6105 Rev 2 NASA Systems Engineering Handbook

The Outpost Program uses a process of Risk-Informed Decision Making and Continuous Risk Management to increase likelihood of program success based on the NASA/SP-2011-3422 Risk Management Handbook. The processes address the risk-informed selection of decision alternatives to assure effective approaches to achieving objectives and implementation of the selected alternative to assure that requirements are met throughout all program phases. At this early stage, technical risks have been identified for the Outpost architecture as it is presented in this study and are presented below. The risks have been evaluated based on both their likelihood and consequence, with mitigation strategies defined to reduce one or both.

Table 5.1.1.11-1: Likelihood values (1 through 5) defined per NASA S3001 Revision G

Likelihood		
Score	Likelihood of Occurrence (p)	
5	Near certainty	p > 80%
4	Highly likely	60% < p < 80%
3	Likely	40% < p <60%
2	Low likelihood	20% < p < 40%
1	Not likely	p ≤ 20%

Table 5.1.1.11-2: Consequence values (1 through 5) defined per NASA S3001 Revision G

CONSEQUENCE					
	1	2	3	4	5
Performance	Minimal consequence to objectives/goals	Minor consequence to objectives/goals	Unable to achieve a particular objective/goal, but remaining objectives/goals represent better than minimum success or outcome	Unable to achieve multiple objectives/goals but minimum success can still be achieved or claimed	Unable to achieve objectives/goals such that minimum success cannot be achieved or claimed
Safety Human	Discomfort or nuisance	First aid event per OSHA criteria	No lost time injury or illness per OSH criteria	Lost time injury or illness per OSHA criteria	Loss of life
Asset	Minimal consequence: asset has no sign of physical damage	Minor consequence: asset has cosmetic damage and is repairable	Minor consequence: asset is damaged but repairable	Major consequence: asset is substantially damaged but repairable	Destroyed: asset is compromised, and unrepairable; a total loss
Schedule	Minimal consequence	Critical path is not slipped; total slack of slipped tasks will not impact critical path in less than 10 days	Critical path is not slipped; total slack of slipped tasks is within 10 days of impacting the critical path	Critical path slips	Critical path slips and one or more critical milestones or events cannot be met
Cost	Minimal consequence	Minor cost consequence. Cost variance ≤ 5% of total approved FY baseline	Cost consequence. Cost variance > 5% but ≤ 10% of total approved FY baseline	Cost consequence. Cost variance > 10% but ≤ 15% of total approved FY baseline	Major cost consequence. Cost variance > 15% of total approved FY baseline

Table 5.1.1.11-3: Risk Matrix with priority values (1 through 25) defined per NASA S3001 Revision G

LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	10	15	19	21
2	2	8	11	14	17
1	1	3	5	9	12
	1	2	3	4	5
	CONSEQUENCE				

Table 5.1.1.11-4: Outpost Risk Ratings and Mitigation Strategies

Priority	Technical Risk Title	Consequence	Likelihood	Mitigation Strategy
17	Visiting Vehicle Collision	5	2	Outpost flight rules for rendezvous and proximity operations based on ISS due to historical success and availability of crew and cargo vehicles designed to those requirements. Includes 4km x 2km approach ellipsoid, 200m spherical keep-out zone, and use of passively safe trajectories.
17	Fire in Station Cabin	5	2	Portable fire extinguishers available in all habitable volumes of the Outpost designed with 101.3 kPa, 21% oxygen atmosphere.
17	Outpost Launch Failure	5	2	Outpost designed with 101.3 kPa, 21% oxygen atmosphere.
17	Tank Sealing Failure	5	2	Ground development and testing for reliability. Redundant applicators and robotic manipulators available on orbit.
17	Tank Cutting Failure	5	2	Ground development and testing for reliability. Redundant cutting tools and robotic manipulators available on orbit.
17	Cabin Contamination	5	2	Internal working fluids Safety process in place for customer payloads based on material toxicity levels.
14	Robotic Manipulator Failure	4	2	Manipulators based on heritage hardware. Redundant manipulators available on station. Interior hardware and operations designed to be crew compatible.
14	Solar Array Deployment Failure	4	2	Co-designed with robotics for repair capability. Development and testing for reliability. Orbital deployment prior to crew or payload operations.
14	MMOD Shield Deployment Failure	4	2	Co-designed with robotics for repair capability. Development and testing for reliability. Orbital deployment prior to crew or payload operations.
14	MLI Deployment Failure	4	2	Co-designed with robotics for repair capability. Development and testing for reliability. Orbital deployment prior to crew or payload operations.
14	Crew Medical Condition or Injury Untreatable on Orbit	4	2	Crewed Outposts will require abort capability via docked crew vehicles (return or orbital transfer type) during all crewed durations.
12	Loss of Crew Due to Lack of Abort Option	5	1	Crewed Outposts will require abort capability via docked crew vehicles (return or orbital transfer type) during all crewed durations.
12	Visiting Vehicles Unable to Dock to Station	5	1	Redundant docking interfaces provided on all free-flying Outposts to assure docking ability even if one interface is blocked or non-functional.
11	Airlock Failure	3	2	Airlock based on Bishop system with ISS heritage for cargo transfer. Development resources dedicated to crew version upgrade. Modular design allows for replacement if necessary.
10	Loss of Communication	2	3	Use of proven, global commercial ground station network for constant communication with top priority for Outpost needs. Development of crew training program to improve crew independence. Outpost designed to maximize autonomous robotic operations.
10	Resupply Launch or Docking Failure or Delay	2	3	Contingency supplies stored on-board. Abort capability available for crew.
10	Crew Launch Delay	2	3	Station designed to operate autonomously when no crew is present.

5.1.2 Business Case and Financial Viability

5.1.2.1 Commercial offerings and future markets

General Overview of Future Markets

Fundamentally, NanoRacks finds no single partner able to close a full business case alone, without either significant outside support or access to an existing commercial in-space infrastructure. Since the LEO economy is still in its infancy, NanoRacks sees a matrix of financially and commercially interconnected goods and services providers as the only feasible path to developing a robust, mature space market. Research in conjunction with NanoRacks' commercial partners indicates multiple avenues for product and service development in manufacturing, space tourism, scientific research, and point-to-point transportation between space platforms. In all of these cases, however, commercial partners have indicated that none of their offerings can develop in isolation; what is needed is collaborative development effort, including the participation of government entities.[19]

While access to additional platforms would help foster new markets, study indicates that three additional conditions must also be met in order for them to be commercially useful:

- First, they must be able to function within a fairly commercially permissive regulatory framework that reduces delays to payload processing and provides clarity on the ownership of materials either produced in space or refined from ISRU processes.
- Second, an infrastructure must already be present on-hand to meet some of the assumptions that aim to make LEO commercial activity profitable.
- Third, as a component of the above infrastructure, launch and transportation costs must be decreased by multiple orders of magnitude.

Investor Interest and Development

Several of NanoRacks' commercial partners have indicated that one of their biggest current obstacles to developing a space economy is reluctance on the part of investors to enter the market. Because the market is so new, there is a high level of perceived risk that is currently discouraging investors due to uncertainties such as lack of current demand for space manufacturing and assembly services. As a result, in some cases, economic development funding has turned out to be lower than originally forecast. Businesses interested in developing a viable space economy must identify ways to leverage the existing market and infrastructure as much as possible to increase customer demand, so that investors will see the economy grow and develop and will be more likely to invest in its continued development.[20] Government support represents a critical component of facilitating that viability.

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[19] For more information on the various product and service offerings of NanoRacks' commercial partners, and their analyses of the benefits of collaborative development with government participation, please make reference to the commercial partner contributions of ULA, Stratolaunch, Terminal Velocity, Made In Space, Lunar Resources, Altius, and Deep Space Industries in Section 4 of this study.

[20] For more information regarding investor funding issues in the LEO economy, please make reference to the commercial partner contributions provided in Section 4 of this study.

NanoRacks has some experience with such issues aboard the ISS, where for nearly a decade the biopharmaceutical industry—the gold standard of commercial customers—largely has not invested the levels of funding initially (and optimistically) predicted at the inception of the Station.[21] While the zero-gravity environment offers conditions to discover potentially groundbreaking applications of current pharmaceutical and other science, the full laboratory environment—among other things, one capable of doing many thousands of test cases—does not exist.[22] Indeed, many experiments done in space are one-offs, sometimes conducted for their novelty, otherwise because of the singular long-duration zero-gravity conditions that the ISS permits. In either case, they are extremely expensive for most researchers, and therefore likely not repeatable barring a stable funding source.

Market Requirements

NanoRacks concludes that researchers, scientists, and commercial actors must have access to ready-built equipment that can scale their production quickly, while not having to pay costs for the actual manufacturing of that equipment. Space systems as-a-service are the only commercially viable pathway forward in order for operations to scale to a pace where they become valuable. Such an environment would have the following conditions:

1) **Accessible** – the cost of reaching the station must not be prohibitive, and must not require the purchase of an entire commercial flight. Rideshare models are critical to ferrying users to their hardware. Saying otherwise would be like saying that the first rider of any bus must pay for every seat on the bus, attaining a cost reduction only when (and if) additional riders travel on the same route.
2) **Affordable** – The cost of transportation, servicing, and in the case of goods production, downmass must be within the scope of startup companies, to the extent they can finance all these steps within the current funding available to them, and where the value generated in space is greater than the cost of production.
3) **Repeatable** – Equipment aboard any orbiting platform must be capable of quickly repeating experiments and activities; it must be optimized to be used multiple times and for multiple use-cases, similar to typical Earth-based lab environments.
4) **Dependable** – From both a policy and hardware standpoint, users and service providers must know unequivocally that their activities are subject to regulations similar to those they would encounter on Earth.

NanoRacks finds that, within the context of LEO commercialization, no specific hardware solution can itself create a market opportunity, but there are cases in which modification of hardware could prove potentially extremely beneficial for certain means. One particular case that was outlined by NanoRacks partner Space Adventures is the inclusion of a window for commercial tourists on free-flying Outpost platforms. Indeed, the absence of a window would make such platforms

[21] An interesting study reveals how early ideas for the opportunities for Microgravity Research initially developed to great fanfare: National Research Council, *Microgravity Research Opportunities for the 1990s*, 1995
[22] Hyde, *Space Lab 3.0: Imagining the future of science in* space, 2018

commercially untenable for tourism unless they were docked simply as crew quarters aboard the ISS.[23] Another illustrative example is the manufacture of ZBLAN in space which, while valuable, would not necessarily be exploitable unless returned to Earth and sold, therefore requiring the existence of some capsule to return such a payload.

A varied approach to the Outpost architecture could do much to resolve especially the second case, and this is described further in Section 5.1.2.4 on Major Suppliers. Adding in more platforms for varied purposes, however, would not necessarily be useful to an ecosystem unless it could somehow be linked with an inter-station network of vehicles as proposed with the NanoRacks LEO Village concept supported by ULA. Sharing services across platforms and across multiple orbits could provide a cost reduction for the overall architecture.

Concept within ISS Context

Based on available experience, NanoRacks believes that a major detractor from the ability to commercialize LEO is the architecture of the ISS itself. While the Station represents perhaps among humankind's greatest engineering feats, it is counterproductive for the purposes of the LEO market, as it offers a single platform in one single location and orbit. No such analogue may be found in the terrestrial environment, where a multiplicity of markets and facilities exist in differing geographies and under differing conditions.

A commercial station in sun-synchronous polar orbit, for instance, would serve a very different set of markets from one in a lower inclination. Additionally, a robotic platform serving space manufacturing would be a very different market than a space hotel where manufacturing facilities and their associated operations could be unwelcome near a tourist's quarters (consider the highly motion-sensitive process of ZBLAN manufacture). Further experiential data is necessary to add depth to this understanding—a process that will require direct trial-and-error engagement with existing orbital hardware. Regardless, NanoRacks believes that different stations, in various locations and serving multiple orbits, are the only viable solution for creating a truly sustainable marketplace that can address multiple demand scenarios and reach a scale capable of providing commercial viability.

Multiple Orbital Configurations

From a policy angle, NanoRacks finds that from the perspective of the U.S. government, it is no longer viable statement of policy to say merely that a human presence in LEO is sufficient. To wit—if a Chinese space station were to be built orbiting at 43 degrees and 600km, servicing a separate range of customers, the U.S policy community could not conceivably state that a 51.6

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[23] Please see Space Adventures contribution in Section 4.3.3, additionally gleaned from conversations and interviews with Space Adventures staff, based on commercially conducted market surveys. Further information on demand increases scaling based on lowering prices is available in the Proprietary Annex, not for public release. A graph showing demand parameters, and changes in demand corresponding to changes in the policy and regulatory environments, also is available in the Proprietary Annex.

degree inclination would adequately represent a LEO presence. These different configurations serve entirely differing markets and purposes, and therefore should not be construed as equivalent.

Presuming such markets do exist in multiple orbits, NanoRacks also assumes that additional cash flow could be generated by ensuring that flight safety requirements are kept equivalent to the purpose of the given LEO presence. In general, it is true that the more open the terms and conditions for the use of the platform, the greater the margin of profit for both the customer and the operator, as profit is not just cost driven, but rather resource-commitment driven. Within these offerings however, NanoRacks must reiterate that ultimate cash flow is not the only metric that should be used to judge the health of an orbiting platform.

Role of NASA and the U.S. Government

Given the vast scale of infrastructure in consideration, such platforms may themselves not be profitable for a decade, but if they result in a robust ecosystem of services that depend on their function, that represents the best possible outcome for the competitiveness of American industry at large. NanoRacks' ideal investors would not take a narrow view of cash flow being the singular determinant of value, but rather focus on three factors. First, whether there is an identified government or commercial need for proposed platforms; second, how diverse (and therefore sustainable) the customer base for such platforms would be; and third, what civil and strategic purposes such platforms would serve.

The ISS architecture, while technically sophisticated, does not provide the necessary diversity of use-cases, hardware, or commercially-tailored capability to make it attractive to private capital as an investment opportunity. In spite of this, NASA and the U.S. government have a critical role to play as both initial investors and long-term members of a robust PPP where the respective agencies engage in monitoring and rulemaking activities, while creating required financial stability in the economy by investing in such initial infrastructure.

Take, for example, the relationship between the U.S. government and automotive manufacturers. Ford, GM, and Tesla do not pay for the privilege of allowing their vehicles to drive on taxpayer-funded roads. They themselves build a product that facilitates the robustness of an overall economy, while generating revenues (and in turn paying taxes) that continue to support that economy in order to build more roads and maintain existing infrastructure—all while responding to the needs and desires of their customers, the drivers. The government also works to supply the necessary legal regulations, at both the national and state level, such as emissions and safety standards, which make conditions on such infrastructure safer and more economically efficient for all actors—both public and private.

Taking this analogy, it is clear why no single market can be addressed without having a full commercial ecosystem and the multiple platforms to support it, as well as targeted government support. In most cases, there would be extreme overlap of services across such platforms, including legal, financial, risk mitigation, regulatory, and developmental.

It also is clear from NanoRacks' research with its commercial partners that one of the most effective methods of reducing perceived market risk, and therefore encouraging investors to participate in market development, is for the U.S. government to be an active participant in the development of a space economy. According to this research, NASA's current space development paradigm appears to focus heavily on government applications. While it is not expected that NASA, or any government agency, would take on the full financial burden of developing a space economy, NASA could contribute to the space market by stimulating research and development of technologies. By sponsoring infrastructure development that benefits not only NASA and other government projects, NASA would support the critical infrastructure needed to sustain a commercial market.

This is similar in principle to the U.S. government helping to stimulate the growth of the automobile industry by providing funding for construction of the U.S. interstate highway system, and providing regulatory oversight and structure to give automobile manufacturers a framework within which to develop the industry.

Existing Ecosystem to Future Markets

For NanoRacks, among the most exciting aspects of working at the heart of the new space market is facilitating the transfer of technology from terrestrial to space markets in a manner that occurs with greater seamlessness, efficiency, and speed than has heretofore been the case. Taken in contrast with the ISS, which today flies with multiple elements that were first described 35 years ago, the conflict between market requirements and available infrastructure presents a critical challenge to further commercial development.

Today, and specifically within the scope of the LEO Commercialization study, NanoRacks cooperates with industry leaders advancing robotics, software, communications AI, and human interface systems. This underlines the point that innovation is difficult to accomplish in environments where NASA or the government chooses hardware specifications, puts out solicitations, makes evaluations, endures protests, and then awards hardware to contractors that move forward on lengthy development cycles. This must not be considered a commercially viable method for innovation by simple virtue of the fact that such cycles are not reactive—they are prescriptive from the outset; market development cannot be guided by such a cycle.

This is precisely the reason that NanoRacks did not, in the early phase of its development, patent the original NanoLab hardware: to create an effective ecosystem that yields new and innovative solutions to potential problems, competition is necessary. NanoRacks sees a three-pronged question of supply, demand, and investment liquidity at play, where certain risks come when an engineering agency like NASA, or a government-sponsored NGO such as CASIS, creates artificial demand for hardware like centrifuges, or satellite deployers. Where markets exist, competition—and resulting innovation—will follow. Surely NASA, and ultimately taxpayers, would benefit from competition—not as facilitated forcibly by the government, but rather enabled by government investment in required infrastructure.

Speed is, indeed, of the essence, as exemplified by the rapid development of new technologies. NanoRacks believes that, much like the increase in computing power resulting from miniaturization, as exemplified by Moore's Law, the space industry is rapidly reaching a point in time where the state of in-space equipment no longer accurately reflects available capabilities. One illustrative public example of this tendency would be the state of the Space Shuttle in 2002, with reports of NASA engineers scouring eBay for parts that were no longer being manufactured.[24] As the *Times* article states, even in 2002, "Civilian electronic markets now move so fast, and the shuttles are so old, that NASA and its contractors must scramble to find substitutes." In ecosystems of the future, platforms will need to keep changing in an evolution as constant and predictable as the yearly cycle of cell phone upgrades. Only in such a manner will they reach a state of technological advancement and low cost that makes them commercially scalable and attractive from a user perspective.

Another significant market factor is that the current operational plan promoted by NASA and other space agencies does not take into account how government-sponsored missions could be leveraged to jump-start the development of a space economy. As one example of this, United Launch Alliance has identified multiple NASA missions on Starliner and Dragon where the NASA crew does not occupy all of the launch vehicle's seven-member capacity. Making the empty seats available for space tourism would create a market for tourists even before launch vehicles specifically dedicated to tourism are developed. The demand would trigger the commercial space market to respond. [25]

United Launch Alliance also has identified a need for space agencies to take into account how government-sponsored platforms could transition to commercial use after their government missions are completed. Under the current design and engineering regime, the ISS was constructed and expanded solely in response to the needs of NASA, without any consideration being given to how complex and costly the process of refitting ISS components for commercial use might be. As a result, the current U.S. space presence is not well-suited to adaptation in ways that would encourage the growth of a commercial space market. This is also shown by input from Made In Space, which has identified a potentially explosive market for the manufacturing of ZBLAN fiber, but which currently is limited in terms of production because of the available space on ISS that could be utilized for manufacturing, and because of the size of the ISS airlock, which limits the amount of produced ZBLAN that could be offloaded at one time and therefore would require increased cadence of reentry vehicles.[26] This, in parallel with the need to return large volumes of fiber in order to reach profitability, as well as the difficulty of maintaining fiber production in an

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[24] Broad, *For Parts, NASA Boldly Goes… on eBay,* New York Times, 2002
[25] For more information on ULA's research regarding the need for NASA involvement in the establishment and expansion of the space market, please make reference to the ULA commercial partner contribution in Section 4.1.2 of this study.
[26] For more information on Made In Space's analysis of ZBLAN production potential, as well as limitations, please make reference to the Made In Space commercial partner contribution in Section 4.3.2 of this study.

environment where Astronauts regularly disturb the manufacturing process with motions caused by required exercise for instance.

Market Engagement and Research

NanoRacks maintains an open and robust dialogue with current and potential customers and critically, does not compete with them in any manner, such as building CubeSats or constellations. This dialogue, built almost entirely by word-of-mouth and reputation-based recommendations, has allowed NanoRacks a unique vantage point on the possible evolution of space systems in directions not currently predicted in even the most optimistic reports. NanoRacks therefore does not believe that a useful avenue of research will be extrapolating current trends out by potentially decades, as the October 2017 Bank of America report[27] did, stating for instance that by 2045, the industry would be worth $2.7 trillion.

NanoRacks firmly believes that such an exercise would be as useful as predicting explosive growth in the market for horse carriages due to a burgeoning middle class on the year prior to the invention of the automobile. Both trends being enabled by the industrial revolution and well-built infrastructure, the rise of the car would have been wholly unpredictable even after the automobile's invention in the late 19th century, much the less the heights it would reach when refined by Henry Ford and standardized with the Model T.

When NanoRacks conducts market research as such, the possibility that groundbreaking inventions capable of transforming in-space markets could be duplicated (if not improved) terrestrially, is kept open. If improved, cheaper methods for producing ZBLAN eventually materialize on Earth, for instance, there is no conceivable reason why commercial customers would endure the increases in price necessitated by an in-space transportation infrastructure to attain that product—except perhaps the novelty of space-manufactured material. The optimism surrounding the manufacture of gallium arsenide (GaAs) crystals in space in the mid-1980s[28] provides a useful analogue, where a market was expected to grow exponentially and fuel demand for space-based manufacturing capacity, only to fizzle due to improved terrestrial methods.

[27] Bank of America Merrill Lynch, *To Infinity and Beyond – Global Space Primer,* 2017
[28] Randolph, *Producing Gallium Arsenide Crystals in Space*

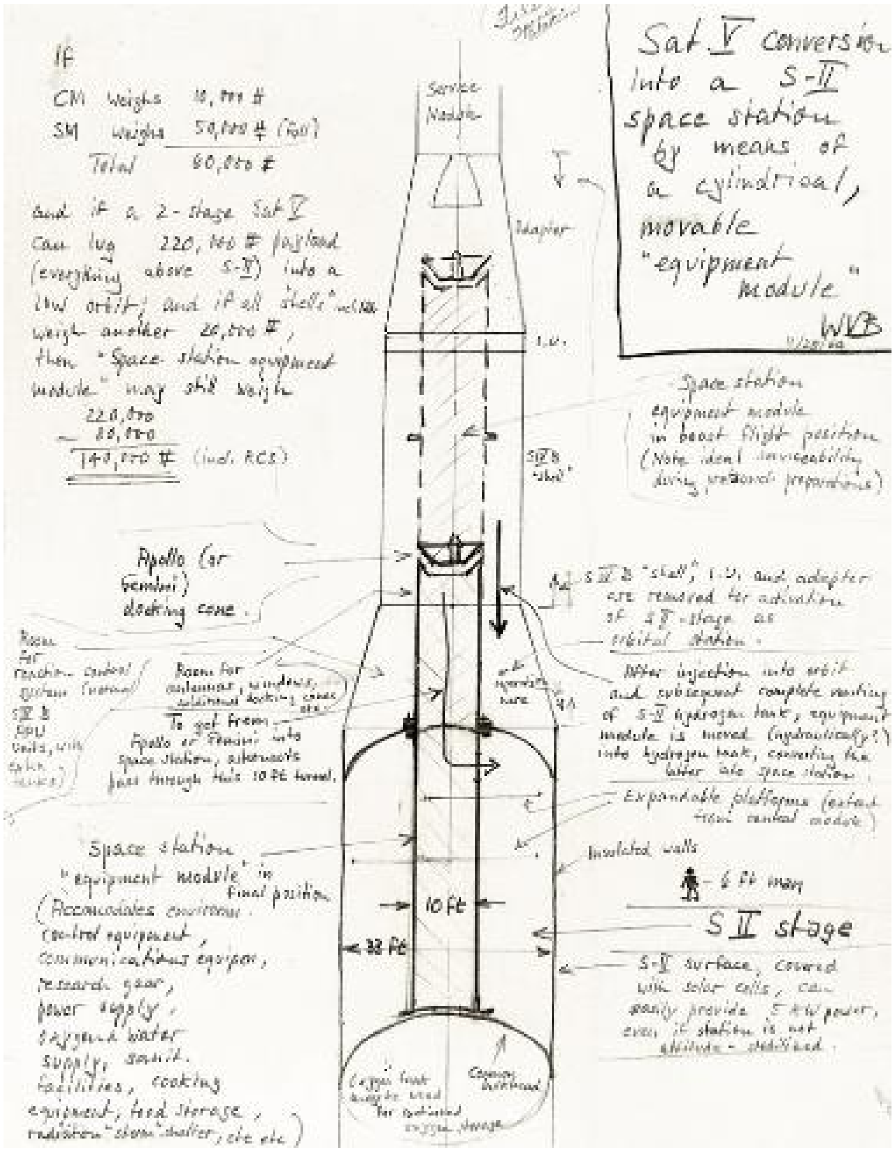

Figure 5.1.2.1-1: Original Werner von Braun Sketch for Saturn V Conversion into Space Station Platform[29]

It is fortunate that today, in the context of repurposing upper stages, NanoRacks has the benefit of hindsight to understand why such ventures as initially proposed in the 1960s with SkyLab, and the 1980s with the Space Shuttle's external tank, failed. Namely, this was due to a general lack of robotic capability. Similarly, today's LEO marketplace would not be adequately represented if prediction of future capability relied solely on current technological advances—implementation of such ideas proves to be a conceptually insurmountable hurdle, until it is actually crossed by some innovative and unexpected solution.

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[29] Wikipedia, *Wet Workshop,* 2018

For instance, had repurposing actually been deemed technically feasible for STS external tanks, it could have yielded an extremely low-cost and long-term solution to the challenge of constructing in-space volume[30][31]. Even provided the high front-end investment in robotics and repurposing, an entirely different present day could have been imaginable, with potentially hundreds of people living—and working—in space. Over the course of three decades, LEO would possibly have seen the construction of over 130 space station modules, with approximately 195,000 cubic meters of available volume[32] for commercial and scientific endeavor, at low cost, vastly augmenting the 915 cubic meters available for the past two decades on the ISS. In the absence of a competitive market that could foster such unexpected and paradigm-shifting innovation, it is perhaps unfortunate that this future never had the chance to be realized—even though this represents an exercise in speculation.

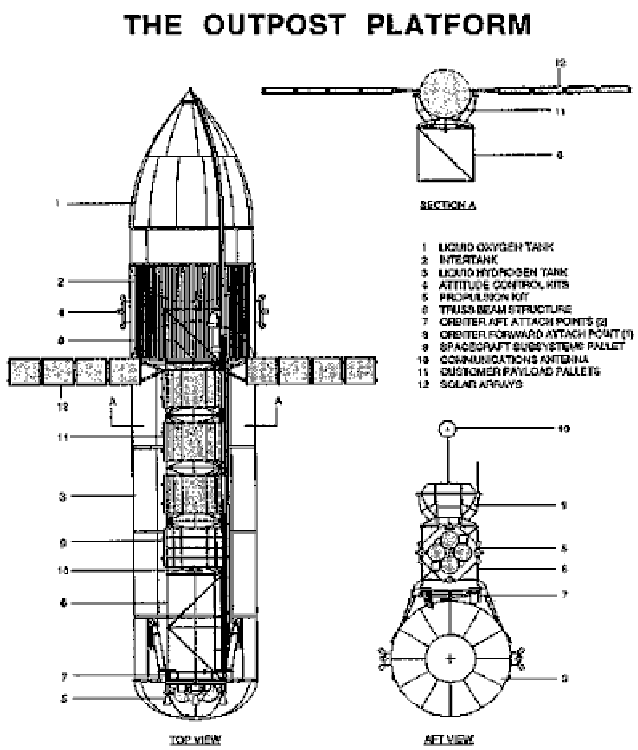

Figure 5.1.2.1-2: STS External Tank Outpost Platform Schematic[33]

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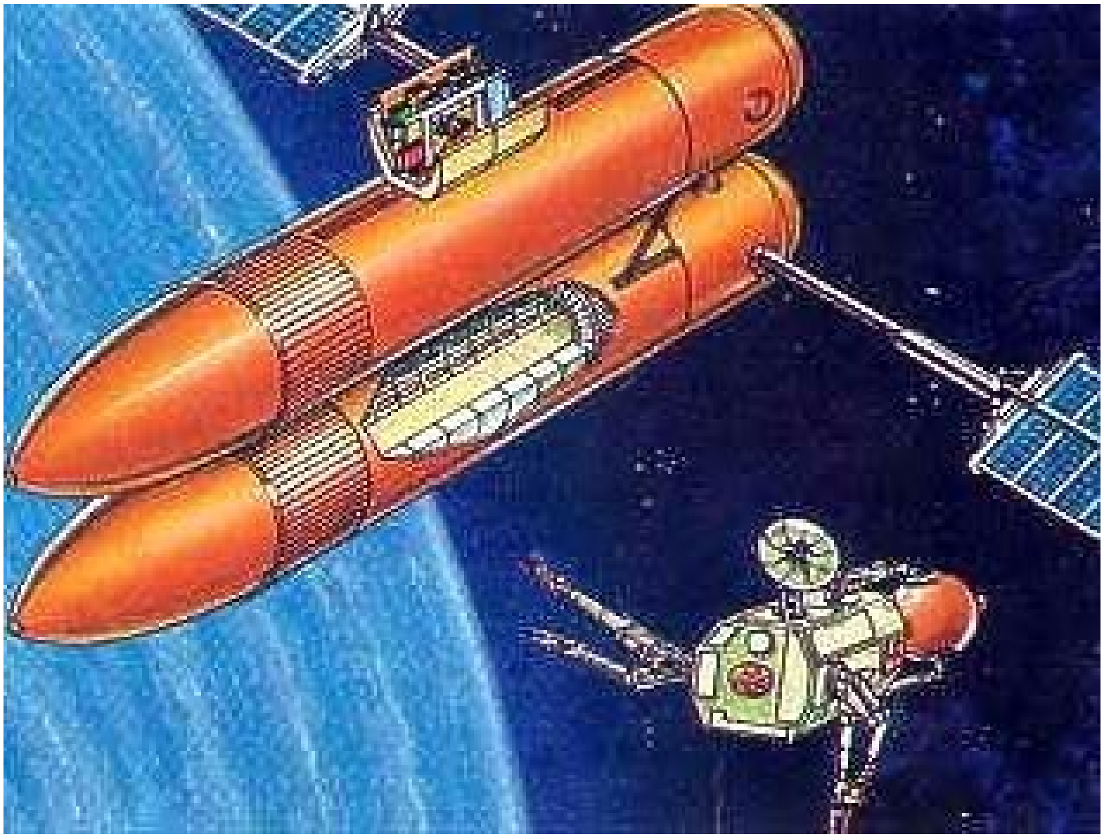
[30] Space Frontier Foundation, *External Tanks in Orbital and/or Suborbital Applications*

[31] Schematic for the components of a repurposed STS external tank, also known as the *Outpost* program, though unrelated to NanRacks' proposed *Outpost* repurposed Centaur upper stage: Gimarc, *Report on Space Shuttle External Tank Applications,* 1985

[32] Approximate figure determined by multiplying the number of STS external tanks disposed of on-orbit since program inception (134) by volume of Liquid Hydrogen Tank (~1,515). Even if only one tank had ever been converted into an upper stage, it would still almost double the amount of volume available on the ISS today. Information on the STS external tank can be found here: https://science.ksc.nasa.gov/shuttle/technology/sts-newsref/et.html

[33] Gimarc, 1985

Figure 5.1.2.1-3: STS External Tank Outpost Space Station Concept [34]



[34] This artist's concept of the STS tank, repurposed into a wet lab system with the capability to scale growth by linking multiple modules. Note the concept for use of an OMV with robotic manipulating arms to conduct repurposing and repositioning activities, as well as deployable solar panels, and a tool and supply depot near the top: Gimarc, 1985

5.1.2.2 Cash flow summary

Outpost's commercial model is designed to facilitate a LEO ecosystem with opportunities for a variety of cash flows in different directions across multiple potential scenarios, as determined by the commercial requirements of the given architecture. A primary result of this study is that NanoRacks realizes that multiple iterations and configurations of a commercial space station will be necessary to support differing activities and environments.

In general, the two highest overall project costs are expected to be the cost of launching materials and crew from Earth to an orbital station, and the initial development of technology and hardware. These costs, in combination with other up-front expenses needed to develop a viable space economy, have led many of NanoRacks' commercial partners to forecast negative cash flow for their commercial ventures in space for at least the first few years (although this could vary widely depending on customer demand for various products). From that point forward, the cumulative effect of business development, customer demand, and infrastructure investments is predicted to start to generate positive cash flow for the space economy. It is therefore critical to have up-front funding from key investors and from government agencies during the early development of the LEO economy to bridge the finance gap until the market becomes self-sustaining.[35]

A more detailed analysis of cash flow in the LEO economy is provided in the financial model in section 5.3 that NanoRacks has developed as part of this feasibility study. The NanoRacks financial model gets its data from three primary sources:

1. Commercial partners listed in this study
2. Previous company experience and commercial sales data
3. Findings by insurance and risk consultants engaged by NanoRacks

These are explored in the model narrative.

[35] For more information on cash flow predictions, please make reference to the commercial partner contributions in Section 4 of this study, as well as the financial model.

5.1.2.3 Approach for investors

General Challenges Related to Investor Approach

NanoRacks operates in a unique trade space, where infrastructure to conduct commercial activities either does not exist or is otherwise heavily mediated, whether by intergovernmental agreement, safety regulations, or access and cost concerns stemming from those factors. In short, this is a market in its infancy. With the exception of the MirCorp experience, human-rated platforms have been completely government dominated.

As such, it is easy to perceive why NanoRacks has faced difficulties in previous approaches to the venture capital community. This community is inherently mistrustful of space venture business cases that close with respect to any perceived dependence on government investment. NanoRacks has experienced cases where the possible near-term end of the ISS program negatively impacts the perception of potential investors.

These perceptions run parallel to a misperception within the government that investment liquidity is readily available for all space-based projects. While it is true that investment interest has never been greater, that interest is limited to a core group of space-based markets: launch vehicles, satellite constellations, and big data use of in-space systems. Commercial space stations have yet to attract investment interest to the degree of these other markets.

On another note, however, NanoRacks provides platforms for the enabling of space activities, rather than a specific tangible product like a launch vehicle or specific subsystem. Indeed, even the Outpost architecture provides a methodology for repurposing upper stages to fit identified demand, rather than a particular solution built in anticipation of specific use-cases. While specific and potentially profitable use-cases were found in this study, in particular manufacturing and tourism, investors may be poised to invest in the services or associated hardware itself rather than the enabling platform, unless such a platform were also to describe revenue sharing options with its tenets. Raising capital for the platform component, therefore, must be predicated on the formulation of a demonstrably sustainable model to generate returns.

The "space station" market suffers from its nascent stages. Despite requests from NanoRacks for several years now, no NASA administrator, for example, has made the simple statement that the ISS is indeed the final human-rated LEO space station to be owned and operated by the federal government. The lack of such a statement, and uncertainties over core issues—as exhibited by the unique calling for this study program—signal to the investment community that the marketplace for commercial Outposts is by no means a sure bet.

Another perception NanoRacks has encountered is the view that human-rated platforms, as government-dominated ventures, cannot compete against more mature markets like satellite deployment and Earth observation. With the Outpost program, NanoRacks is collaborating closely with NASA to show that this is not the case, and that there is a role for human-rated and crew-tended platforms that can support multiple services such as Earth observation and materials science, for instance. This model works provided only that the demand for such combined services can be shown definitively to exist. Nevertheless, continued informative conversations are necessary with the investment and private equity markets to educate them on the growth opportunities in these markets, and the possibilities created by continued progress in lowering costs and tailoring services precisely to market needs.

To demonstrate a stable investment opportunity, NanoRacks must continue to work with NASA to ensure the further development of Outpost. A major part of this is achieved by exercising caution not to develop hardware for the sake of engineering, but rather building it around a market need—and perceived market price tolerance—to ensure that demand can be sustained. NanoRacks believes that one platform does not make a market or an ecosystem. One platform attached to the ISS as a single-point (and single point-of-failure) solution to commercialization would by itself not be the most ideal environment for having investment levels like those in other, more mature, space markets.

The ISS, as one large platform with multiple nationalities (and their respective requirements) placed together, demonstrates the detrimental results of such compromise to commercial outcomes. Due to the need to negotiate between multiple actors, the orbit achievable by the ISS is suited to only a very small range of commercial requirements, particularly those of commercial satellite and sensor platforms. A more robust ecosystem might have been achieved by, for instance, building an American station in SSO, with a Russian station at 51.6 degrees, and a European station at 28 degrees, all sharing resources, all working through barter arrangements, and all covered under the IGA. This is more akin to the LEO future NanoRacks envisions.

Findings on Investor Types for Outpost Infrastructure

As part of this study, NanoRacks conducted a survey of industry investors and the conditions under which they are most likely to be useful for a program, conveyed in Table 5.1.2.3-1. This table, however, presumes *ideal conditions* for investment, where an attractive commercial option is available; one that either finds itself in a dependable policy and regulatory environment, or otherwise is fairly independent of changing commercial policies and requirements. This table is split by investor type, the type of investment they issue, the average sizes of deals which they commit to, their general ability to take on risk, the point at which NanoRacks would potentially approach them to discuss commercial platform, the type of risk they are generally willing to accept, and the stage of Outpost's development where they could potentially be approached.

As should be evident, there can be no single definitive approach, but rather one optimized for the specific requirements for platform development, and the platform's stage of development. By combining a strategic and phased approach to commercial investment with a future of commercial consistency by NASA aboard its in-space platforms, the industry and NASA can work together to unlock enormous potential.

Table 5.1.2.3-1: Investor Types and Approach[36]

Prospective Investor Type	Type	Average Deal Size ($M)	Risk Appetite	Outpost Investment Opportunity	Acceptable Investment Risk	Outpost Investment Stage
Venture Capital Funds	Equity	<5	High	Seed – Round A	Technology, Market, and Financial Risk	Early: Financing of Technology Reduction and Demo
Strategic Corporate Capital	Equity, In-Kind Resources	<10	High	Seed – Round B	Technology, Market, and Financial Risk	Early: Financing of Technology Reduction and Demo
Private Equity Funds	Equity	<50	Medium	>Round A	Market and Financial Risk	Middle: Financing of Commercial Prototype Outpost
Private Debt Funds (High Yield)	Debt	<100	Medium	>Round B	Financial Risk	Late: Financing Post Success of Prototype Outpost
Family Offices	Equity, Debt	1 to 20	Low to High	Seed – Round B	Technology, Market, and Financial Risk	Middle – Late Financing
Sovereign Wealth Funds	Equity, Debt	>100	Low to High	>Round B	Financial Risk	Middle: Financing of Commercial Prototype Outpost
Supranational Funds	Equity, Debt, Financial Guarantee	10-500	Low to High	Seed – Round A	Technology, Market, and Financial Risk	Early – Late Financing

NanoRacks also tracked previous sources of revenue by nationality. Figure 5.1.2.3-2 provides a notional glance at the relatively central role of US-based commercial activity. Within FY 2017, many of these deployments occurred via the ISS program, highlighting the central role it plays in forming the backbone of commercial space. It is likely that the current investment environment would note this perceived dependence, even if NASA were to behave largely as a commercial customer as is the case today. NASA would need to send assurances of policy and regulatory consistency—a primary concern of this community of investors. With such a large role for ISS-bound U.S. companies within the customer base, attracting investment could remain difficult; a separate platform, or otherwise commercial consistency or expectation-setting would be required.

[36] Figures based on NanoRacks interviews, analysis, and historical conversations conducted since 2011

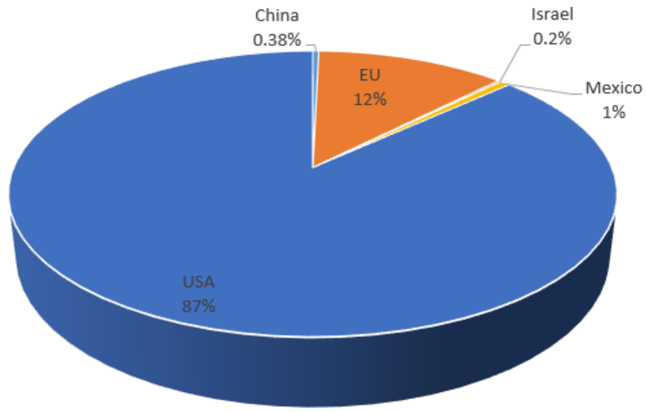


Figure 5.1.2.3-2: NanoRacks Revenue Streams by Country, FY 2017

The central role of government organizations in ISS utilization is emphasized by the fact that such revenues comprise the bulk of ISS utilization.

5.1.2.4 Major suppliers

The NanoRacks Outpost program depends on multiple hardware suppliers, business relationships, and an entire host of potential service providers. NanoRacks has found, as discussed throughout this study, that it is impractical to think of any one end service as the only model for generating revenue aboard a commercial space station. A commercial station cannot be a monolithic solution, but rather must have a deep foundation across multiple services and capabilities to make a primary revenue-generating model function.

To demonstrate this, consider a station that manufactures some unique product, necessitating not only the hardware to manufacture these goods, but also the supporting services to make possible a constant flow of necessary materials into, and end product out of, the station. Such services cannot therefore be taken in isolation in support of optimistic revenue assumptions; they must be contextualized within the architecture that makes them possible.

Jeff Bezos has spoken extensively[37] about how Amazon came about leveraging the existing infrastructures built by the government and the private sector, from UPS to the U.S. Postal Service. Without this infrastructure, Amazon would not have been able to deliver the revolution in the buying and selling of consumer goods. Bezos has taken his own experience and now speaks about the need for infrastructure in the development of a space-based marketplace—not about the need for a new program, but of infrastructure.[38] Bezos sees his company, Blue Origin, as one of the providers of that infrastructure, just as NanoRacks sees Outposts as another component of that infrastructure. Some parts of an infrastructure, especially for an emerging market, can be funded by the private sector; some aspects require government support.

Consider the required commercial infrastructure necessary to support product manufacture onboard an Outpost, aside from the basic shell of the Outpost system to include power, docking, heat exchange, orbital maintenance, and basic robotic capabilities. It would include, at the most basic level:

1. Actual hardware to conduct manufacturing activities
2. Downmass capabilities to bring produced materials down – requires a fairly capable return capsule to make it economically viable in the long term
3. Upmass capabilities to bring new raw materials to station
4. If the station is uncrewed, then telerobotic operation of hardware to transfer raw materials and end-product between capsules, and manipulate the capsules themselves
5. The necessary regulatory and legal environment, plus a supporting foundation of private capital

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[37] Choudhury, *Jeff Bezos explains why Blue Origin is 'the most important work I'm doing',* 2018
[38] Boyle, *Amazon's Jeff Bezos compares space to internet, and he'll build the infrastructure,* 2018

In every case, NanoRacks expects that the only means whereby such complex services would be made viable are creative commercial relationships in which finances do not solely flow in one direction, but instead between multiple partners. To understand financial flow across the lifetime of a commercial station, it is necessary to break it down into two separate costs, which flow between the operator of the station and all associated providers—one at the station's inception, and the other during the actual operation. For the sake of simplicity, assume that NanoRacks plays the role of station keeper, providing power and communications to all system users; robotic servicing is required for part of the end concept; and a commercial user wishes to utilize this architecture to manufacture a Product. A resulting model is provided below:

Initial Cash Flow Prior to Launch

To NanoRacks **(From Product manufacturer and robotic support services)**

- Additional costs associated with installing special equipment not already baselined into the design of the specific Outpost

From NanoRacks **(To Product manufacturer and robotic support services)**

- Costs or incentives meant to attract a broader range of possible services to the Outpost – potentially lower costs for integration

From User **(To NanoRacks)**

- Basic costs associated with integration of platform and required interfacing with existing station architecture, or costs paid to potentially lower the per-use costs/revenue sharing later in station life

From Service Provider **(To NanoRacks)**

- Up-front costs to be included in station installation, which should be reasonable in lowering the cost of procuring the station, but also allow a relatively rapid return on investment during commercial operation on-orbit

Cash Flow during Instance of Service On-Orbit

To NanoRacks **(From users and service providers)**

- Revenue sharing and/or "rental" payments on volume used for production, as well as costs of energy and upkeep of station deriving from hardware operation

From NanoRacks **(To service providers)**

- Payments to ensure continued operation on the station, or materials provided in kind and required to conduct services like orbital operation of space-tugs including Xenon or other fuels

To User **(From NanoRacks)**

- Business development efforts to solicit users, from which outside revenue flows to keep the Outpost operational

From User **(To NanoRacks and Service Providers)**

- To NanoRacks for basic station services like power, data, and hosting

- Directly to service providers, per use of hardware not assumed part of the station itself, like robotics meant to operate payloads

To Service Provider(s) **(From NanoRacks and Users)**

- Potential initial incentives from NanoRacks, if the service is built into daily station operations
- Costs per-use from users requiring given hardware

From Service Provider(s)

- Recurring costs paid to NanoRacks, if utilization of basic station hardware is required on a regular basis (so not on a per-use basis when servicing end users)

As demonstrated by this relatively simple example, a truly commercial service would see funding flowing in multiple directions, because the architecture required to maintain commercial operation would be vast, and multiple business cases would need to close to attain sustainability. To reach such a level of functionality, however, assumes that scale would be attainable. In order to scale up to such a level, either initial investment or continued government support will be required, and multiple suppliers will need to be engaged, whether they supply the platforms themselves or the services with which they are filled.

5.1.2.5 Balance of government vs. commercial revenue

Government demand for services is critical to sustaining operation in the early stages of commercial operation, but also during commercial operation of critical infrastructure. NanoRacks proposes an "airport model" to best describe what will be required in the balance of government versus commercial revenues in the future LEO economy.

In such a model, several key factors are present. First, the government recognizes that the development of critical infrastructure is of interest to the national (or local, as may be the case) economy. Therefore, government funding is utilized to pay for the airports and runways through a variety of financial mechanisms. In aviation public-private partnerships, for instance, the payments made for necessary infrastructure come both from the airline companies and from the users, the passengers, via taxes on their travel, airport fees, and general taxes levied by the government on commercial revenue and personal incomes. Yet even in this most mature of industries, the direct contributions from the private sector (via levies on ticket prices for instance) are kept small enough that they do not impact the desirability of travel. Were the U.S. government to require full investment by the private sector, ticket prices would no doubt be in the tens of thousands of dollars for each ticket, which would dampen travel demand, drastically lower the business of airplane manufacture, and stifle interstate commerce.

So too with commercial cargo to and from the ISS. Adjustments over the next decade in how the government funds the basic infrastructure must be judicious and must assure that the ecosystem is encouraged via investments in new space services.

To continue the aviation/airport model, while the government provides initial investments, it does not operate the airports or the businesses inside the airports except in limited cases; that is left to private-sector organizations. One may consider space stations to be the airports of the future—operated by the private sector, having customers from all segments of the society, yet supported by government funding for the basic infrastructure. The exact nature of which organizations will be managed in the operator/tenant relationship remain unclear as yet, but NASA's October 26, 2018 white paper on *Forecasting Future NASA Demand in Low Earth Orbit*[39] provides valuable insights as to which industries this may include.

It also is worth nothing that in aviation, as in any government-dominated market, changes in regulation, policy, and in fees or procedures are made only after consultation and advance notice. Private businesses need ample time to develop adequate responses to changing policy, especially when such changes would affect their business cases. When such changes are proposed in relation to privately operated infrastructure, adequate discussion to allow the commercial sector to acclimate to new policy is especially important.

It is NanoRacks' opinion that NASA should not be in the business of creating policy or regulations. That is best left to the executive branch, including the Department of Commerce with its long history of relations with the private sector and the Department of Transportation with its regulatory

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[39] NASA, 2018

history in aviation and space, but also naturally to Congress. NASA's expertise is not in the formation of commercial marketplaces. Development of such expertise would require a build-up of knowledge and experience that exists today in other agencies.

The airport model is a good start to understanding the vital intersection between government regulation, policy, and private investment and commerce that is so critical for development of the LEO ecosystem. A good place to begin is the 1995 World Bank[40] study on the ways in which airport infrastructure functions in coordination with government investments. Though these remarks were made regarding airports, NanoRacks suggests applying these key factors into a model for LEO commercialization.[41]

Presuming NASA funds development and manufacture of hardware, NanoRacks also anticipates that NASA will impose stringent requirements, including procedural and safety restrictions, on the commercial marketplace when operating on the ISS platform. If these restrictions were expanded to free flying platforms, NanoRacks would consider them an imposition on the growth of the LEO economy.[42] That said, government intervention will continue to be critical with the considerations outlined above, especially in the realm of basic infrastructural investments, and the establishment of a business-friendly regulatory framework.

In this scenario, NASA would come in early to fill a gap in pricing that the commercial sector could not meet in its current state. Specifically, the government would provide continued support for platform development and transportation to and from these platforms. Investors in new space companies like NanoRacks are sometimes willing to take on anticipating commercial needs, but in general, private capital responds to existing needs, seeking assurances on the usefulness of developed hardware and a return on initial investment. Successive Outpost functions will be developed based on actual demonstrated market needs, even though some adaptations of the system should reasonably be expected to show little or no commercial promise. The core of the overall ecosystem is that the market will optimize for the applications that are actually useful. There is no "one size fits all" solution, and just as with any commercial sector, some applications should be allowed to fail and be phased out to make way for newly identified potential.

Major investment would be necessary only for the initial infrastructure; management would then be handed over to the commercial sector so the infrastructure can be utilized to generate public revenues via taxation and other more intangible knock-on effects of free market activity. Returning to the illustrative airport model, this management style can be seen at Dulles International Airport[43], where in 1987 under a leasing arrangement management was transferred from the federal government to the local authority, the primary reason being the need for infrastructure

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[40] World Bank, *Airport Infrastructure and the Role of the Private Sector,* 1995, pp. 25

[41] Consider also the billions of dollars in government support provided by indirect subsidy and tax relief offered to the oil & gas industry—a strategic sector by all accounts from the perspective of both the national economy and job-creation: Tesoro, 2018

[42] A 2014 NASA study supports the notion that initial investments were necessary in critical infrastructure, like commercial air transportation, in order to be successfully handed over for operation to the private sector: Launius, *Historical Analogs for the Stimulation of Space Commerce,* 2014

[43] World Bank, 1995, pp. 45-52

improvements. The benefits to the Washington, DC metropolitan area were difficult to measure, but the intangible benefit of having easier access for international business and political exchange can reasonably be expected to have played some contributing role in the city's spectacular growth since the late 1990s.

Even in such cases where extensive demand is identified, and market outlooks are able to forecast more than a few years out, government investment would still play a substantial role. That role is anticipated to shift over time, with NASA initially having a vital part to play in infrastructure development, and over time transitioning to being for the most part a customer of the commercial providers operating in the space market. In the current regime, most commercial providers engage directly with NASA for operations based on and around the ISS. But eventually, as other orbital platforms become available, these commercial ventures could transition some or all of their operations to these other platforms, reducing their reliance on the ISS as the primary (or for now, the only) platform for commercial operations.

Most of the commercial partners NanoRacks engaged for this study verified through their financial forecasting that they can achieve self-sustaining commercial operations in space within a span of several years.[44] At that point, NASA would continue in an important role as ongoing, but by no means primary customer. This self-sustaining operability can be reached only with significant assistance from NASA in the early stages of infrastructure development, so that commercial enterprises can focus their resources on developing services and technologies to serve the market. If private-sector companies have to spend the bulk of their initial investment capital on infrastructure development, they will not have the financial resources necessary to develop the services and technologies to utilize that infrastructure, nor seek out customers to utilize it.

NanoRacks therefore finds the discourse suggesting that further investment in LEO should be fully in the hands of the private sector neither insightful nor realistic. This arrangement would quickly negate the private sector's ability to actually function, and would not follow the pattern of public sector investment in infrastructure in many other facets of American life and business that has made the U.S. a world leader in market development.

[44] For more information on financial forecasting from the commercial partners, please make reference to the commercial partner contributions in Section 4 of this study.

5.1.2.6 NASA contributions

CRS-2 and CCDEV

Like the entirety of the LEO Ecosystem, NanoRacks' return on investments and ability to attract new capital are dependent on the continuation of the CRS-2 program—or at the very least, continued government support of range and diversity of transportation providers. NanoRacks envisions an expansion of capability in the transportation arena, accessing a variety of inclinations and orbits, where cross-fertilization will occur between platform owners and transportation providers.

NanoRacks seeks to engage such transportation providers to include the provision of return vehicles. This provision should not be limited to single providers as selected by NASA, but rather grow to one that supports market resiliency by including as many potential providers as possible. Within this context, the continuation of the CCDEV program is absolutely critical, as it gives the private sector a critical price signal that investments in human-rated programs will yield returns. Including commercial customers in CCDEV, like commercial astronauts, will also be critical to its progress, for the downward pressure on pricing it would exert as described in previous sections.[45]

Complete Handover of Funding Responsibility

As NASA looks to lay the foundations for the exploration of the Solar System, NanoRacks believes that continued support for LEO infrastructure is critical. NanoRacks, and indeed all current commercial providers, depend on this infrastructure—within which the ISS plays a critical role—to support commercial activities. Any movement toward full commercial management therefore must be carefully phased, as it is not feasible in the next decade. Just as it is not feasible for airline companies to pay the full cost of airport infrastructure, so must the cost of maintaining space infrastructure to support the LEO economy not fall on a very limited set of companies working in part with NASA.

As with the far more mature infrastructure of U.S. public transportation, commercialization is not fully feasible, allowing NASA and the U.S. government the unrealistic luxury of moving forward to deep space while surrendering total fiscal responsibility for continued LEO build-up. While revenue will come in from LEO, with many companies joining efforts to lower the overall cost of operations and provide services at less cost than the federal government, this arrangement cannot replace the stabilizing and necessary influence of government funding. As in major cities all across America, public transportation represents a reasonable and desirable use of tax dollars, because such expenditures stimulate commerce, facilitate free exchange and flow of people and ideas, and create tens of thousands of jobs[46]. That said, private companies like MegaBus still operate between

[45] For more information on cost analysis of space infrastructure, please make reference to the financial model accompanying this study, and also the Space Adventures commercial partner contribution in Section 4.3.3 of this study.

[46] Job creation possibilities of public transportation systems are substantiated in the APTA Study: American Public Transportation Association, *Public Transportation: Moving America Forward,* 2010

cities and optimize for commercially valuable routes. For all services that even partially serve a public or strategic good, the government necessarily must serve a partial role in some basic capacity which commercial companies are not equipped to fill.

NanoRacks is concerned that many in the public sector are increasingly convinced that a rapid handover to the private sector in LEO is possible in the short term. To name the most important factor – such a handover simply is not possible at the current costs of transportation to and from the Earth to LEO. NanoRacks argues that while the private sector can provide the "busses" and "trains" of LEO, and can engage commercial customers while working to lower operating expenses, this must be done in a strategic manner over time where the government provides infrastructure support similar to that of more mature industries.

An example from earlier in American history is the Rural Free Delivery Act of 1896, which had the federal government underwriting the cost of mail and parcel service to rural communities, providing free transportation via the trains.[47] So, much like CRS-2, the government was paying the transportation for commercial companies like NanoRacks. One of the noteworthy beneficiaries of the Rural Free Delivery Act was the Sears Roebuck catalog, which brought the opportunity for consumer commerce to the new Western frontier. In short, the role of NASA in opening up the space frontier is neither novel nor unprecedented in American history. Whether support via train service, or new air travel for "air mail" to airports today, public-private partnerships are a critical part of how America opens new markets when industry is incapable. For reference, free transportation for cargo on the trains lasted about fifty years before being phased out.

Costs & Benefits to Outpost on Providing Support to NASA

The singular most important role NASA can play in LEO is that of stimulating commercial demand by assuring that space transportation is at price points that allow for private sector investment and services to thrive. Critically, Outpost is not being developed to support NASA programs. Safe failure across multiple uncrewed platforms should be an option; otherwise, a program intended to vastly lower the cost of space access like Outpost might become weighed down by an unrealistic set of requirements compounded on it to address multiple needs. While high-requirement missions certainly can be designed to NASA human spaceflight specifications, they cannot represent the singular aspect of the architecture; doing so would make the commercial platform unreasonably expensive for commercial access, for instance solely requiring robotic work.

So the primary benefit in Outpost providing support to NASA programs is the opportunity to have a major customer within the U.S. government, one reliable and therefore attractive to sources of capital as a marker of stability. The potential cost, however, is the possibility for requirements associated with NASA safety and other processes to overwhelm what is commercially reasonable if they are levied against all future space systems. Safe failure on non-NASA systems should therefore be allowed on commercial systems. This would allow a lowering of requirements and

[47] Historian – United States Postal Service, *Rural Free Delivery Act,* 2013

the ability to iterate on innovations at a rapid pace currently not achievable with any existing space platform; the ability to test new technologies, methodologies, and commercial markets, would be immediately and vastly increased.

NanoRacks envisions a future where such platforms will serve and enable multiple commercial sectors' desires to go to space. NanoRacks seeks to provide an ecosystem that requires cargo, raw materials, and people to move to space, while building in the infrastructural efficiencies to bring finished products down from LEO. This would be possible within the scope of a PPP with NASA, where infrastructural solutions are not prescribed or mandated, but rather where end results guide the system's growth.[48] NanoRacks seeks customers and provides the demonstrated commercial demand necessary for NASA to continue politically supporting these programs, while also allowing a refocusing of energy and resources where extensive government involvement is most required—in deep space.

[48] The NASA study on historical analogs for commercialization gives further context here, wherein a government could reasonably be expected to provide support for nascent commercial activity for later handover: Launius, 2014.

5.1.2.7 Liability and insurance

To fulfil requirements under this component of the Study, NanoRacks worked with partners Oliver Wyman and Marsh & McLennan to complete a comprehensive market survey of available insurance options as well as a risk analysis of current market conditions. The results of that study component are available in Section 5.4, "Risk Analysis Results."

5.1.2.8 Export control and intellectual property

Export Control – Focus on ITAR and Resources – IGA Benefits

NanoRacks works with all appropriate agencies to remain compliant with all current requirements, both U.S. and international. However, NanoRacks does not assume within its models that future expansions of current export controls will be imposed. NanoRacks does assume that the ITAR regime will be continued, much to the detriment of the American commercial sector. NanoRacks believes this regime is motivated by dated political considerations stemming from a time when retaining American leadership in satellite deployment involved limiting the extent to which technological advance was disseminated, rather than genuine contemporary concerns about technology loss. Indeed, and as supported by the Potomac Institute analysis of ITAR[49], this regime inevitably will require NanoRacks, and all American companies, to specialize at great cost to deal appropriately with the regulation, thereby restricting American industry's available talent pool and potential market outreach.

NanoRacks does not assume that this regulatory regime will change, though it continues to have dampening effects on U.S. competitiveness. Indeed, at the same time that ITAR thwarts genuine exchange on non-missile-related technologies, it also stymies small commercial companies' growth by forcing them to focus burdensome legal resources on compliance for such insignificant hardware elements as CubeSats, in an era when NanoRacks is actively working with several high schools to do just that. While NanoRacks does not believe ITAR is likely to change, the expansion of these regulations further into the space domain would be disastrous for future innovation and collaborative efforts.

NanoRacks therefore will adapt to meet these requirements by creatively structuring international engagements and working within the scope of international partnerships that are not burdened by current regulations. For example, to ensure both ITAR compliance and retain the opportunity to engage in international business, NanoRacks, like many other new space companies, must undertake expensive and burdensome processes associated with setting up entities abroad.

NanoRacks also believes that, barring an increase of resources to enable the Department of State to monitor and administer the regulatory environment efficiently, ITAR should be overseen by the Commerce Department, as with the Export Administration Regulations (EAR). This is true especially within the context of increasing demands for commercial platform providers to consider collaboration with international partners in the future.

Indeed, the ISS export control model does provide an instructive example of how exceptions should be handled, as delays deriving from processing of controlled items can generate critical risk

[49] Potomac Institute, *An Analysis of the Impacts of the International Traffic in Arms Regulations (ITAR) on U.S. National Security and Economic Interests*, 2016

factors aboard space platforms. Category 15 of the U.S. Munitions List[50] specifically excludes the ISS and its components, which otherwise would have been subject to the EAR. Part 740 of the EAR also provides a license exemption to the ISS, and "authorizes exports and reexports required on short notice of certain commodities subject to the EAR that are classified under ECCN 9A004 to launch sites for supply missions to the ISS."[51]

Based on NanoRacks' experience working on board the ISS, and current discussions with commercial partners pertaining to this study, NanoRacks does applaud the extent to which the IGA has set the standard for collaborative efforts in space over the past two decades. The IGA is especially helpful in the two domains of intellectual property (Article 21) and liability (Article 16) in setting expectations for commercial activity in space.

Intellectual Property

NanoRacks finds and asserts that expectation-setting is absolutely critical for small companies requiring stable and predictable markets, especially as they seek venture funding that is notoriously averse to regulation-dominated enterprises that vary drastically with changing political climates. Investors need the security and stability of a clear statement by NASA, any future NGOs set up in partnership with NASA, and the Administration, clarifying that—at least within the context of all platforms owned by the United States—all IP generated on commercial platforms would be under the sole ownership of the concerned private entity rather than the owner of the platform itself.

Additionally, the commercial sector *must* have assurances that, even though NASA's rights to IP first produced under the agreement aboard the ISS are waived per the Space Act Agreement (SAA) (article 9.B), the remainder of the U.S. and other governments' rights to such IP are additionally waived. NASA must provide a clarification of the term that "…Data will be disclosed and used (under suitable protective conditions) only for U.S. Government purposes."[52] This is especially critical for customers of NanoRacks, who are not covered under the definition of "Related Entity"[53] as they are not "…assigned, tasked, or contracted to perform activities under this Agreement," and instead task NanoRacks—the commercial service provider—to deliver a set of specific services.

Clarity on the fact that a commercial operator's customers' IP is fully protected from disclosure by NASA, even to additional U.S. government agencies, is critical. If a NanoRacks customer makes a breakthrough in cancer medicine aboard the ISS, that customer (and their associated investors) must have assurances that such findings, developed at commercial expense, would not be disseminated publicly or to the NIH for instance. NanoRacks customers provide data to NanoRacks only insofar as it is necessary to ensure safety compliance with NASA standards.

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50 e-CFR, *Part 121 – The United States Munitions List,* 2018

51 Cornell, *15 CFR 740.11 - Governments, international organizations, international inspections under the Chemical Weapons Convention, and the International Space Station (GOV)*, 2018

52 Notable example: NanoRacks Space Act Agreement, *SA-OZ-14-16763*, P9

53 Ibid, P8

Forcing the further sharing of the full scope of their research, commercially enabled by hardware NanoRacks has invested in, would have a chilling effect on the already limited ability of the ISS to serve as a truly commercial platform.

Barriers to Commercial Activity

NanoRacks is concerned that the current licensing and export control regime thwarts private sector innovation. These regimes provide expansive openings for commercial competition from other actors, namely the Chinese, who have been barred by U.S. regulations from participation in the commercial space industry with American companies. The proliferation of privately operated—and ITAR-free—companies like OneSpace and Landspace means that foreign non-U.S. customers unwilling or unable to meet the requirements of the ITAR regime would be more likely to carry their launches over to Chinese (or other non-U.S. launch) companies—thereby depriving U.S. industry of revenue and even the ability to compete and partner. As NASA and the U.S. government look to develop commercial LEO, the industry cannot support such barriers being erected that bar the sort of cross-fertilization in capital and technology that exist in other markets including software, database technology, big data, and manufacturing. NanoRacks does not wish to give away technology to America's competitors, and applauds the Administration's efforts to modernize the IP regime between the U.S. and China. Having noted that, NanoRacks does want to ensure that the U.S. market can remain competitive, and participate in, in the context of China's lower-cost space-based services.

5.1.2.9 Risks, challenges, and barriers

NanoRacks' core business model is driven by the simple commercial need to have revenues exceed expenses, even if not necessarily at first. NanoRacks expects that such models do not start out immediately profitable because of upfront costs inherent to the establishment of a commercial infrastructure. NanoRacks therefore expects to place great reliance on reusing upper stages to reconstitute and replenish in-space assets via three avenues along an evolutionary pathway based in the rapid iteration that a lower-cost approach like Outpost lends itself to. This core approach allows much more room for maneuver in the mitigation of programmatic risk based in full dependence upon one hardware solution.

International Risk Elements

Regarding international partner-related risk, NanoRacks observes that the end of the ISS program, whenever it occurs, will force the space community to emerge from one of the most extraordinary and unique periods of programmatic stability in the history of space exploration. Though there are many lessons to be absorbed, it is worth noting that to work successfully with so many international partners within the same set of parameters, for such an extended period of time, is not something that NASA should assume to be a reality going forward in LEO and deep space. Whether it will be the norm going forward or an exception is not yet known.

NanoRacks believes an argument can be made that the commercial pathway between companies of differing nations is more robust and more likely to survive political tensions. This, especially as international players and partners may begin to compete with the ISS, could become more important. With customers in over 30 countries, NanoRacks has come to understand the robustness of the commercial marketplace over the dependence on shifting political alliances.

NanoRacks recognizes the ISS as a time-sensitive hardware platform with an unknown endpoint. NanoRacks recommends, however, that NASA should keep the ISS *program* moving forward indefinitely while replenishing hardware commercially and regularly. Given the age of the ISS system, and the likelihood of increasing incurred costs for maintenance of aging hardware in the future, such replenishing is likely among the best ways to continue the ISS' evolution, with supporting legal, regulatory, and services regimes, into the future during potential international partner transitions.

All this should be done while remaining mindful of the roles that international partners play, including the capabilities of partners to bring certain critical supplies, like oxygen and orbital re-boosting capabilities. Such capabilities would have to be backed up quickly and decisively to prevent operational gaps.

A partner pulling out of the Space Station Program, and potentially removing key hardware from the ISS, could well result in a proven competitor in the same orbit with already commercially viable technology. This is why it is so critical for NASA to advocate for multiple orbits and inclinations by commercial platforms.

In this context, Japan is rapidly changing policies to adapt to commercial markets. This is demonstrated by JAXA's selection of Space BD, a NanoRacks partner in this study, to lead commercialization of the Kibo Airlock. NanoRacks views such competition as healthy and desirable. That said, NASA would do well to take note of this developing trend.

As an illustrative example, out of 30 existing modules currently installed on the ISS, 13 are non-US built. Of those, six are operated by the United States, so it is safe to say that fully 20% of the ISS is non-U.S. built, but U.S. operated. The table below shows this breakdown clearly.

Table 5.1.2.9-1: ISS Module Manufacturing and Ownership by Country

ISS Component:	Manufacturer:	Owned by:	KEY	Total
Bigelow Expandable Activity Module	Bigelow	US	FOREIGN BUILT	7
Canadarm2(SSRMS)	MDA - MacDonald Dettwiler Robotics	Canada	FOREIGN BUILT - US OWNED	6
Columbus(European Laboratory)	Thales Alenia Space	European	US OWNED - US BUILT	17
Cupola	Thales Alenia Space	NASA		
Destiny (US Laboratory)	Boeing	NASA		
Dextre (SPDM)	MDA - MacDonald Dettwiler Robotics	Canada		
ExPRESS Logistics Carriers	Goddard Spaceflight Center	NASA		
Harmony(Node 2)	Thales Alenai Space	NASA		
Japanese Experiment Module (JEM + JEMRMS)	JAXA	JAXA		
Leonardo(PMM) and EXPRESS Logistics Carrier 4	ASI/Thales Alenia Space?	NASA		
NanoRacks Airlock Module	Thales Alenia Space (Boeing building co	US		
Nauka (MLM) TBD	Roscosmos State Corporation?	Russia		
P1 Truss	Boeing	US		
P3/P4 Truss & Solar Arrays	Boeing and Possibly Lockheed Martin? T	US		
P5 Truss	Boeing	US		
P6 Truss & Solar Arrays	Boeing	US		
Pirs (Docking Compartment & Airlock)	RKK Energia	Russia		
Poisk (MRM-2)	RSC Energia	Russia		
Quest (Joint Airlock)	Boeing	US		
Rassvet(MRM-1)	RSC Energia	Russia		
S0 Truss	Boeing	US		
S1 Truss	Boeing	US		
S3/S4 Truss & Solar Arrays	Boeing	US		
S5 Truss and ESP-3	Boeing	US		
S6 Truss & Solar Arrays	Boeing	US		
Tranquility(Node 3)	Thales Alenai Space	NASA		
Unity (Node 1),[7] PMA-1 & PMA-2	Boeing	US		
Z1 Truss & PMA-3	Boeing	US		
Zarya (FGB)	Khrunichev State Research and Productio	US owned		
Zvezda(Service Module)	RKK Energia	Russia		

Risk from Other Nationalities

NanoRacks believes that the future Chinese space station will in part be marketed commercially, which NanoRacks welcomes, because within that competitive environment exists the opportunity to partner and to stimulate the overall marketplace. NanoRacks again advises the expansion and evolution of the IGA to the point where it can feasibly include China. This expansion would help continue to ensure that all spacefaring nations abide by the same rules of the road. Excluding China from open, market-driven competition would carry significant political symbolism and may encourage reciprocal exclusionary measures. Far better to include China, much like it is included in the WTO, to ensure that perceived non-competitive practices are subject to dialogue and joing collaboration leading toward amenable correction.

Indeed, NanoRacks makes no recommendation to "manage" potential governments as competitors. They should instead be treated as being no different from markets on the ground. What NanoRacks vehemently protests is when governments market their own goods and services at below-market prices. This not only hurts NanoRacks, but works very much to the detriment of the evolution of the overall commercial sector. Preventing this requires the U.S. government to exercise leadership and utilize its full arsenal as directed by the Space Council, with the engagement of the Department of Commerce, to ensure that the rules of the commercial road are respected, anti-dumping provisions are honored, and space can function as a legitimate commercial ecosystem. NanoRacks worries that non-U.S. agencies will not take the time, as NASA has done, to carefully grow various PPPs, weighing the strengths and weaknesses of each, rather than outright selecting national champions.

Free-Flyer Risk

If free-flying platforms become part of the LEO commercial ecosystem, they should have the opportunity to be covered under the IGA. Doing so could help mitigate perceptions of mission risk in the insurance industry, lowering overall rates and stimulating increased demand with resulting lowered mission costs. Having one standard across government and industry players for the whole of LEO could do much to ameliorate future risks, like IP sharing and liability determination, deriving from space activity.

Node 2 and Related Risk

NanoRacks believes in the overall ecosystem approach, and in political realities. For the United States to risk its future pathway to space by crowning any one company with a singular commercial platform aboard the ISS is shortsighted. It is shortsighted because this approach does nothing to answer the question of sustainability or enable a marketplace. As an ecosystem in nature requires different species serving different functions to sustain the overall whole, so does the LEO marketplace require different modules, focused on serving different market niches.

In this regard, NanoRacks also believes that if different modules are to be attached to the ISS, there also must be oversight to ensure that they do not necessarily compete in the same market, unless there is just that much demand for those specific services aboard ISS. While initially this sounds contrary to the point that the government should encourage competition, it should do so within the context of free-flying platforms. Allowing, for instance, only commercial tourist modules to be attached to the ISS misses an opportunity presented by manufacturing or other modular configurations, and also of the ISS to maximize its function as a commercial testbed for multiple technologies. Each additional platform should address a key component of the existing marketplace.

Robustness will be developed only if multiple markets are served. NanoRacks has, on its part, identified space tourism, staging operations for forward missions (or deep space exploration), astronaut training, and manufacturing as the four markets most likely for immediate commercial revenue generation. By attaching only one module to Node 2, a LEO marketplace is much less likely to develop—especially from the perspective of only allowing one company the ability to learn how to manage operations. These lessons are applied easily to the CRS program, where robustness via multiple launch providers, such as SpaceX and Northrup Grumman, is an absolute requirement to ensure continuity of the ISS program.

To ensure that reliability and expertise are spread out as strategically as possible, commercial operations must be open to all commercial actors via Node 2. NanoRacks envisions a transition period—whether 2024, 2028, or beyond—where there are a growing number of commercial platforms in different orbits. A growing number of platforms would thereby allow a robust market to develop as the ISS evolves into either a new, reformulated infrastructure, or is otherwise decommissioned based on the health of the rest of the infrastructure.

NASA Policy Risk

Perhaps the biggest risk is that NASA will seek, without Congressional and administration concurrence, to make changes to the basic and core guidelines for the operation of the U.S. National Lab. Unilateral alterations to such fundamental concepts as commercial use of space station resources, ability to have ISS partners as commercial customers, and other key provisions could prove harmful to the current commercial players and to attracting future investors.

Challenges from ISS Safety and Other Processes

While NanoRacks is sensitive to the safety and protection of the ISS crew, the speed at which new technology is allowed to be used in or around the ISS is an issue for the commercial marketplace and for continued exploration leadership. This hesitation causes significant costs in time and money for extra meetings and extensive testing, sometimes proving obvious results. NanoRacks has experienced several instances where this safety process hinders overall progress.

In one instance, for example, small vehicles (CubeSats, etc.) are treated as large vehicles doing rendezvous, docking and proximity operations.[54] In another case, NASA limitations on field strength for radio frequency operations are overly conservative with respect to hazard potentials, which leads to unnecessarily complex designs that are more expensive and require more time to review and approve. The battery certification process for use inside the ISS (and even for use external to ISS) is extensive, requiring both destructive and non-destructive testing, regardless of battery size or type, even when the use does not pose a hazard to the ISS.[55] This results in increased costs of the system and time needed for review and approval. The ISS Program's current Jettison

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[54] On the difficulty of compliance with extensive requirements applied uniformly across payloads, regardless of type, see: *NASA SSP 51700, Baseline: Payload Safety Policy and Requirements for the International Space Station,* 2010
[55] On the safety review process, see: *NASA SSP 30599, Rev. F: Safety Review Process – International Space Station Program,* 2015

Policy,[56] which is imposed on satellites long after they have been deployed and are far from the ISS, is almost a complete deterrent to satellite usage and expansion of missions. In some cases satellites are restricted from operating until the system has had significant orbital decay. The consequent reduction in on-orbit life, and the costs of restricted operations and negotiations with NASA, has proven to be too heavy a burden for some users.

There are logical, industry-standard solutions to these questions, but as yet there is no clear commercial or accessible pathway to resolving them.

According to NanoRacks' view on the total market value of deployments in FY2017-2018, about 20% of the market prefers the space station as a deployment platform[57]. Since its orbit is not the most useful for satellite activities, much of this demand is attributable to technology demonstration missions. Whatever the case may be, this still marks an important success for the program and represents a genuine American growth story. Clearly though, the industry seeks more flexibility.

Propulsion operations above and below ISS could extend the lifespan of commercial satellite systems and lower program costs. The industry believes that NASA is overly conservative in restricting use of those propulsion systems, despite the fact that most of these systems proposed for deployment from the ISS are not designed in a manner that poses credible risk to the Station or visiting vehicles. NanoRacks also argues that private-sector companies should be allowed to perform their own safety certification via NASA franchising safety permission when the private-sector companies have the experience and sufficient knowledge to perform the safety certification.

Risk Mitigation via Multiple Orbits

Robustness will take root, and risk further mitigated, only when multiple platforms serve multiple orbits and customer bases. Should one platform not function properly, or not generate as much demand as previously expected, neither NASA nor the private sector would be forced to pump additional resources into sustaining it beyond its usefulness, as resources could be refocused into an arena where they may provide returns. The value here is also that commercial providers will be able to tailor services and products in a manner where they are forced to provide returns to investors.

For manufacturing as for tourism, a polar orbit provides a different value than an equatorial orbit. As companies develop sensors for one set of platforms in one orbit, for instance, they may find use on another orbit altogether—or even in deep space. Cross-fertilization of ideas happens when problems are being considered across multiple platforms, but in a focused manner within the scope of each platform. One company or market segment being addressed does not get humanity to LEO or deep space. Risk mitigation based fundamentally on a multiplicity of product offerings that address as many market segments as possible, however, does. Multiple offerings grow the supply

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[56] On jettison policy: *NASA SSP 57003, Rev. L: External Payload Interface Requirements Document – International Space Station Program,* 2015
[57] NanoRacks customer database, 2018

of vendors, with multiple vendors having different life cycles across different programs. Only thus will an ecosystem develop.

Table 5.1.2.9-2: Risks and Mitigation Strategies for Space Development

Risk	Potential Mitigation
Space agency competition (foreign)	Must be treated with the full tools of U.S. government, promoting free and fair trade, commerce-led rules of road, and rules against dumping fully articulated to all partners.
Political risk of partners pulling out	Rapid procurements of commercial hardware; repurposing of available hardware represents risk mitigation if a period of multiyear instability ensues with ISS.
One company to one node	Award to more than one company attached to the node, or enable and award support for free-flying space stations.
Pure technical risk	Multiple avenues – NanoRacks proposes utilization of existing and proven platform hardware, or "wet labs," rather than creation of entirely new platforms.
Unclear regulatory regime risk	Evolve IGA to work for a more open set of targets and international partners, and address additional issues; provide early clarity on which organization exactly will conduct regulatory activities and which proposed changes will actually materialize.
Government or NASA chooses winners and losers, and who gets subsidies for critical infrastructural elements like transportation	National Space Council and Congress must ensure continued evolution of the government as a commercial customer, not a driver of capabilities.
Continued burden of increasingly strict NASA Safety Regulations	Maturation of PPP relationships with commercial providers, increasing expertise in management of safety requirements, and close inspection of safety requirements that may be reasonably lowered without posing significant risk to astronaut safety aboard ISS.
Overregulation from FAA and other agencies	Consolidate regulations into one harmonized regime; ensure proper staffing and capacity of regulatory agencies to ensure rapid turnaround times.

5.1.2.10 ISS international partner considerations

One of the enduring legacies of the ISS will be the international partnerships strengthened through years of in-space operations and cooperation. These partnerships have shown themselves to be critical from both a programmatic and political viewpoint, and their importance cannot be minimized. As NASA seeks to transition to a more commercial LEO presence, NanoRacks sees the value of maintaining these partnerships as core elements of the ability of markets to function effectively in space. Engaging in these partnerships will continue to bring great benefits for American industry, namely by putting downward price pressure on services—particularly transportation—as the foreign agencies serve as commercial customers and providers of new markets.

It is to support these continued relationships that NanoRacks urges the continuation and evolution of the IGA as a proven multilateral working document, with changes made to reflect current political and economic considerations. This includes the expansion of the IGA to commercial entities. In concert with the IGA, a lowering of barriers to trade and engagement with international partners in the space domain must also occur—but that is unlikely to change without a major update to the ITAR regime, and a serious reconsideration of protectionist policies. When an RFP is issued by NASA, for instance, a Japanese company may not answer, or when an RFI is issued by JAXA, it cannot be answered by NanoRacks.

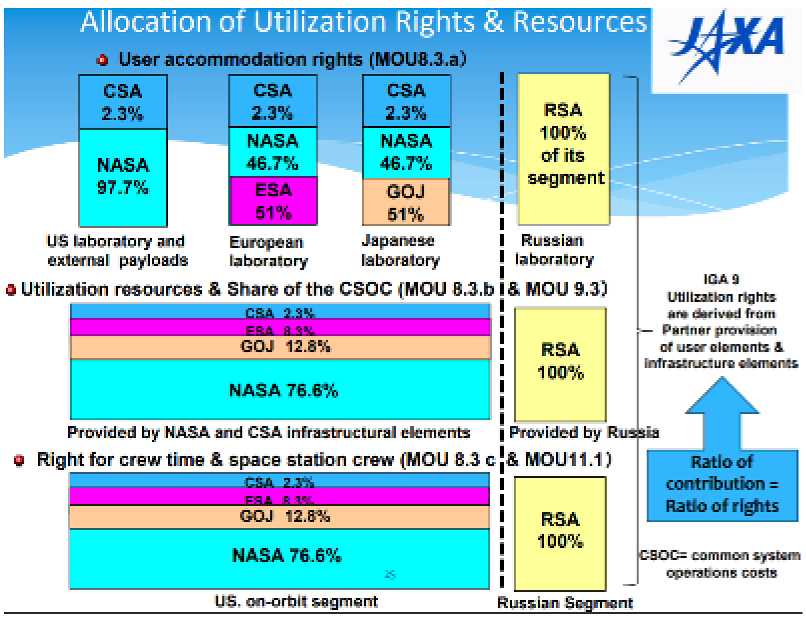
To circumvent this, we are beginning to see an increase in companies forming offices internationally; as Airbus has opened offices in Houston, so has NanoRacks opened offices in Europe. International collaboration allows companies to be closer to their talent pool when serving their international customers. NanoRacks must be in Europe to serve European clients; as such, NanoRacks may tap ESA resources far more effectively. This is indicative of a need for commercial industries to be able to tap whichever national space agency resources are available, as is true in any commercial market. One lesson that has been learned over the years of NanoRacks' operation is that deals cannot be closed remotely. Additionally, having an understanding of international partners' capabilities, and keeping channels of communication with them open, represents an important source of business knowledge about such partners' objectives and strengths, allowing commercial actors to make better suggestions about hardware, goods, and services tailored to meet their specific requirements.

International Partnership Challenges

The risk that commercial companies of any nationality run into while working abroad is the inherent criticism that any company would receive doing business in another country: namely, taking business away from domestic industry. There is a certain nationalism built into international business norms; for instance, the Italian Space Agency (ASI) is concerned about how much to work with NanoRacks in Italy, while NASA is concerned about how much to work with foreign companies.

Part of this challenge on the ISS could be ameliorated by revisiting the barter arrangements put in place to govern the contributions and allotments of each space agency in return for use of the U.S. shuttle, the complexities of which are detailed in Figure 1 below.[58] Though the argument has been made that this arrangement is necessary for avoidance of cash payments for shuttle transportation services and price uncertainties[59], this argument and the complex series of allotment interrelationships it necessitates does not hold when considered commercially—unless, of course, such allotment were sold commercially and reflected investment in hardware already made in the ISS. These arrangements were not established in consideration of various national governments as customers, and by realigning intergovernmental collaboration as service-based, resources and needs can flow more capably to where they are required.

Figure 5.1.2.10-1: Allocations and Utilization Rights per Barter Agreement



Within this context, ISS partners already are beginning to commercialize competently. JAXA, for instance, is emerging as a formidable commercial competitor on the ISS, rapidly commercializing its assets like the airlock and external facility. NanoRacks and other commercial actors find themselves in a position where JAXA is both a valued partner and formidable competitor, realizing that the agency is moving far faster than NASA in allowing commercial payloads with little scientific merit. Rather than attempting to stymie their commercial progress, like filming advertisements for cultural events aboard the ISS, NASA rather must embrace such advances to allow itself (and American companies like NanoRacks) to maintain competitiveness.

[58] Farand, Frank, Porokhin, St-Arnaud, & Uchitomi, *The Legal Framework for the International Space Station,* 2013
[59] Grifoni & Veldhuyzen, *No Exchange of Funds – The ESA Barter Agreements for the International Space Station,* 1999

New Agencies and Partners
NanoRacks first and foremost calls on the IGA to be expanded to invite additional governments with their own space agencies independent on the ISS, including China. NanoRacks does not propose inviting China on board the ISS, out of conformity with U.S. policy, but rather inviting them in to the shared responsibilities, liabilities, and norms that the Agreement establishes, especially given the country's ongoing plans to build their own space station.[60] As with the World Trade Organization, common rulemaking and expectation setting are critical to establishing a fair market, since China certainly will actively seek the commercial sector's participation in future iterations of its space platforms, and is already intending further collaboration on opportunities with the United Nations[61]. Keeping such international collaboration near the IGA and within range of American observation gives a distinct advantage—especially if no technology or IP would be exchanged. Indeed, the WTO provides an excellent example, as the commercial sector would benefit greatly from such measures as those surrounding anti-dumping, to ensure that the commercial environment remains diverse.

Regarding new partners for the ISS family, NanoRacks looks forward to bringing them on board as customers to advance the existing market. Such work already is being conducted with the UAE Space Agency, and NanoRacks believes that the commercial pathway should be open for as many space agencies as possible to utilize commercial activities in space. As for commercial companies wishing to join the ISS family, NanoRacks argues that they should be included in the IGA if they seek to own and operate their own platforms. Such inclusiveness would allow for direct relationship formation, direct bartering, and direct partnerships between space agencies and the private sector internationally.

Commercial International Governance Model
NanoRacks envisions an "airport" model to guide future collaboration on space-based platforms. In this model, the private sector owns the means of transportation (airplanes/rockets), the real estate (airports/space platforms), and the support infrastructure (plumbing, electric, OTVs, solar arrays, etc.), while the public sector takes care of activities requiring the use of state resources and authority, like security (DHS/ODAR requirements) and regulations (FAA/FCC licensing).

In this model, the government invests in the infrastructure, but the infrastructure is operated fundamentally by the commercial sector, with profits accruing commercially and reinvested in infrastructure maintenance by the government utilizing tax funds from the newly enabled commercial sector. Again, the IGA must be the driving force behind the evolution of such a sector when facilitating international commerce. In any case, different regulations would apply to different operators in space; the policy environment (like the commercial environment) cannot be monolithic. Just as the maritime sphere accommodates both defensive fleets and trading vessels, both the physical and international policy infrastructure of LEO must accommodate multiple users.

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[60] UNOOSA, *Office for Outer Space Affairs and China renew commitment to cooperation in space activities,* 2017
[61] Jones, *China Could be Facing Space Station Delay, Tiangong-2 to be Deorbited,* 2018

The administration must integrate such an understanding and raise commercial spaceflight issues in upcoming trade negotiations. NanoRacks urges a lowering of tariffs for space-related activities, and the designation of space as a protection-free zone where free commerce between private-sector actors is secured.

Table 5.1.2.10: ISA Partner Risks and Mitigation Strategies

International Space Agency Partner Risk	Potential Mitigation
IGA is restricted to U.S.-only government partnerships.	Congressional action must allow IGA to be extended to both commercial actors and additional potential international agencies.
Trade restrictions extend to collaborative efforts in space.	Reduce barriers to international engagement while remaining vigilant for noncompetitive practices.
International partners compete with U.S. commercial efforts on a state-level, and engage in non-competitive practices like price support and dumping.	Extend terrestrial trade practices to space, and prosecute noncompetitive practices, like artificial lowering of prices for services, in available terrestrial courts like WTO.
Barter arrangements are retained as-is and not revisited to account for today's commercial requirements.	Update barter arrangement to reflect commercial usage of ISS assets; allow companies to bid for barter allotments and guaranteed upmass, while favoring those who have invested in ISS infrastructure.
China and other national partners are kept out of IGA and international collaboration – opening up pathway for noncompetitive practices and poaching business.	Extend IGA to any international partners willing to sign up to oversight of competitive practices.

5.1.2.11 Current and future competitors

Healthy Commercial Competition

As NanoRacks outlined previously in this report, there are clear market niches in the nascent LEO marketplace. NanoRacks has competitors in the pressurized research labs known as NanoLabs. NanoRacks encouraged this competition early on in the development of this technology by patenting neither the designs of the NanoLabs, nor the concept of subdividing pressurized volume as standard modules attached to powered platforms. NanoRacks did this to support the small ecosystem of differing vendors. NanoRacks also has competitors in the deployment of satellites from the ISS, and competitors that use modules like the Bishop Airlock to be manifested in 2019. Indeed, there are several proposed competitors to the NanoRacks Outpost private module.

None of these competitors, however, acts as a fully commercial space station company with an already existing diverse customer base, except for NanoRacks' competitors that are national space agencies. While NanoRacks cannot speak to how other commercial players interact with the ISS program, and does not wish to comment within the scope of this study on whether or how NanoRacks is different in terms of services, the Company can say confidently that all company hardware for use on the ISS and elsewhere was funded mostly by an existing commercial customer base—not solely by government or via venture capital investment—which is unusual in the industry.

The Company believes in competition. Our concern is when the competition is: a) from a government agency or organization; b) comes from a policy of allowing too much hardware on board the U.S. National Lab without thought to the customer base; and c) makes changes to core policies without input from the industry.

Unusual Utilization Obstacles

NanoRacks, like other owners and operators of privately funded commercially operated space station facilities, faces a gatekeeper to utilization of privately-owned hardware that was never anticipated by Congress, in which commercial utilization of fully commercial hardware like that of NanoRacks can be stymied by an organization for purposes other than lack of resources. The organization CASIS currently has, and often exercises, the ability to deny flight to commercial payloads on the basis of its own priority system.

It is time to re-examine the role of the gatekeeper. In this regard, NanoRacks applauds the administration for adding a subcommittee to the NASA Advisory Committee (NAC) dedicated to commercial policies regarding space utilization, and the Company is a member of the subcommittee. In its first meeting, the subcommittee proposed carving out two important allotments for Station utilization from CASIS: one for purely commercial projects via an auction process, and the other an allotment guaranteeing owners and operators of privately owned station hardware access to their own hardware.

A provision must be introduced that once a company is granted space aboard the ISS, and once privately funded hardware is operational and has customers, that company and its customers have certain guaranteed access to this hardware, based on the amount of private funding. Without this provision, future investment in ISS for private hardware and resulting services will be challenged, and the case for commercial operations aboard the ISS, and indeed LEO commercialization, will be made that much more difficult. With this provision, NASA will weigh carefully the granting of new hardware requests (supply) without a corresponding pipeline of customers (demand), which is the case today.

Healthy versus Unhealthy Competition

Fundamentally, the difference between healthy and unhealthy competition lies in the ability to generate a sustainable ecosystem of supply and demand as mediated by service and hardware provision, and the end products resulting from those processes, whether physical (like ZBLAN), experiential (like tourism), or commercial (like advertising or branding). Where a demand is not met in a marketplace, a company steps in to meet that demand and profit from the result. In an unhealthy scenario, NASA or CASIS encourages competition for the sake of competition on the supply side, and funneling business to one competitor in an attempt to stand them up as a functioning company, without examining market demand for these new entrants. It is picking winners and losers, which is dangerous in an emerging market.

Another concern exists for companies such as NanoRacks potentially looking to set up services in the same orbit and inclination as the ISS. If these services are set up on a commercial basis, then the ISS must not be in a position to compete against such actors, unless the prices being charged are market determined. It is this one provision that is of the most concern. The end date of the ISS is not the issue. It is the promise by NASA not to compete or allow competition on the ISS when the private sector can stand up the same service, at the same orbit, on a private platform. Without this, NanoRacks has a difficult time believing that private investment would finance future platforms if NASA simply continues allowing companies to utilize the ISS at reduced rates.

America historically has supported pioneers into new marketplaces. Rules are changed slowly and carefully. Care is taken to avoid government competition. Economic incentives are awarded, whether to fledgling launch companies prior to their first launch, or entrepreneurial companies carrying cargo to the Moon, or suborbital ventures that have never flown, with minimal public discussion. All this has been done without an NGO gatekeeper. NASA works directly with the launch companies, the lunar-based efforts, providing funding in return for services as it deems of merit.

The ISS has several unique attributes, both for NASA and for the industry:

1) The government has a player in the LEO platform arena (imagine if the space shuttle program still existed, what would be the right rules for supporting the Rocket Labs, Vectors, SpaceXs, and Dream Chasers of today?);

2) No market or government actor wants a station gap, in one part for the market disruptions that would cause, and in another for the gap in national access to LEO with associated leadership and national security implications;
3) There is a large industry and government constituency that wishes to keep the space station hardware in orbit as long as possible;
4) NanoRacks recognizes that it needs to stand up private-sector efforts for orbiting platforms in differing orbits to support the ecosystem in LEO for the long-term health of the American LEO marketplace.

Balancing these desires is a delicate undertaking, and NanoRacks recommends that strategic U.S. government support continues, and that within this support, that ISS commercial pioneers are provided more access to their own hardware, so that market leaders can feel more secure in investing further.

5.1.2.12 Impact on U.S. economy

Government Role in Securing Benefits

It is not for NanoRacks to ask how to create a more diverse and robust U.S. economy. This industry as it exists today in nascent form, is the product of correct steps taken by Congress and NASA to reach the extraordinary tipping point where dozens of companies in the United States are raising funds, hiring employees, and undertaking in-space services on behalf of an equal number of new and legacy companies and organizations.

The continued growth of this emergent marketplace requires: 1) continued support for transportation services; 2) regulatory and funding support for a number of diverse private space platforms; 3) payload and safety regulations less restrictive than the current regulatory regime; 4) encouragement for commercial, market-driven payloads to be flown on existing platforms to jumpstart interest in building out a marketplace; and 5) continued R&D technology financing from the government. Only with such continued support can the U.S. ever reap the benefits of the markets possible in LEO over the next decades.

The impact of this government support cannot be understated. United Launch Alliance, in their investigation of economics on past space projects, has determined that NASA financial support has a multiplier effect on leveraging investment funding by a factor of 1.2 to 2.8, and there is no reason to believe that NASA support for the Outpost project would have any less of an impact. Also, the aerospace commercial sector, including its supporting industries, contributes to more than 10 percent of the U.S. manufacturing employment base. [62] A compelling argument can be made that NASA's continued support of infrastructure development for the space industry is in the overall economic interest of the U.S.

NASA and the U.S. government as a whole should be mindful of the fact that investing in commercial space enterprises in 2018 is not analogous to investing in Internet startups in 2004 or even 1994. In the latter case, an infrastructure of services (DNS, etc.) and resources (phone lines, electricity) already existed upon which those web services could be built. Any investment in space companies will have to be concurrent with continued government support for the expansion of such resources and basic infrastructure.

Such investments will benefit not only U.S. industry as a whole, but also NASA directly. With infrastructure development assistance from NASA, commercial providers will be able to spend more of their investment capital developing hardware and service innovations that reduce per-flight costs. As these costs come down for the private sector over time, they also will come down

[62] For more information on ULA's analysis of the impact of NASA investments on previous space projects, and statistics on the aerospace industry's contribution to the U.S. economy, please make reference to the ULA commercial partner contribution in Section 4.1.2 of this study.

for NASA. An up-front investment by NASA to help develop space infrastructure will result in NASA—and all other customers—paying less in the future to take crew and materials to space.

NASA financial partnerships with commercial providers in the space industry have enabled not only the growth of those providers, but also the development of a network of a second tier of specialized service providers. NanoRacks is proud of its role in bringing Planet Labs to market. Planet estimates that the availability of the NanoRacks ISS satellite deployment service and handling of launch coordination logistics assisted them in building and launching satellites at a rate unachievable in today's marketplace[63]. Today, Planet's valuation is in excess of a billion dollars, with almost 500 employees conducting work for both the public and private sectors. Spire, which also has enjoyed extensive growth and a workforce now in the hundreds, also got its first deployments from NanoRacks' ISS platforms, among several other companies that were NanoRacks customers now publicly traded on European stock exchanges.

All told, NanoRacks has supported the technology demonstrations and commercial launches of what is now valued to be over a billion dollars of the new space industry. This achievement, the jobs it has supported, and the science it has enabled, would have been impossible without the publicly funded infrastructure to enable the applications that kicked off these new markets. If the ISS continues serving as a runway for such companies by retaining its support for overcoming launch costs while they are extremely high, and lowering restrictions to promote station utilization via privately owned and operated hardware, the prospect for a commercial future in LEO is bright.

As another example of this tiered commercial development, NanoRacks has commercial customers who are exploring opportunities to manufacture ZBLAN optical fiber in space. This ultra-efficient fiber has the potential to make telecommunication on Earth faster, more efficient, and more affordable, which will benefit not only the space industry but virtually every other American business sector.[64] Another aerospace company, Stratolaunch, currently is developing a two-stage medium expendable launch vehicle that could provide a means for Made In Space and other manufacturing companies to get raw materials up to orbit, as well as to bring finished product back to Earth.[65] But both of these ventures require the availability of commercial manufacturing space in orbit—which could be provided by a NanoRacks Outpost.

None of these companies by itself could finance all of the complex infrastructure needed for this network of business ventures. But if NASA takes the lead in that infrastructure development, then companies such as NanoRacks will be empowered to provide hardware and services to form the basis of a LEO community—which in turn will enable other companies such as Made In Space and Stratolaunch to engage in development of goods and services that will affect other business

[63] NanoRacks, 2015
[64] For more information on Made In Space's ZBLAN manufacturing venture, please make reference to the Made In Space commercial partner contribution in Section 4.3.2 of this study.
[65] For more information on Stratolaunch's medium expendable launch vehicle (MLV), please make reference to the Stratolaunch commercial partner contribution in Section 4.1.1 of this study.

sectors. By contributing to infrastructure development, NASA not only is helping space service providers; NASA also is helping those providers to sponsor and enable other private-sector companies. This ripple effect demonstrates the influence and importance of NASA contributing to the infrastructure development that is so necessary for the LEO ecosystem to grow and thrive.

Indeed, such an ecosystem also will serve strategic purposes. A maturing commercial market in LEO means that multiple agile companies would stand ready to deliver services and hardware to customers in times of need. Among the greatest dangers to national security in challenging times is overreliance on any single provider. Such reliance leads not only to higher prices, but a potential lack of evolved capabilities, with only a very few capable companies handing entire architectures.

Another strategic consideration is speed of response. One of NanoRacks' commercial partners, Lunar Resources, is commercializing in-space vacuum deposition technology deployed by its material fabrication facility (MFF) to produce functional coatings and thin materials in the vacuum of space. A fully developed LEO ecosystem will enable companies like Lunar Resources to fabricate products in space for in-space manufacturing and space asset servicing applications, with the ability to fabricate functional materials on demand, and without having to rely on the costly and time-consuming process of flying materials up from Earth.[66]

An American space program where the LEO economy functions as a PPP, with governments acting as one among many customers, will—as is true for all American markets—yield the most innovation. Where early, pioneering investments are protected from significant policy changes, a second generation of investors will be encouraged, even if the first generation suffers inevitable market failures. Where, for instance, a transportation infrastructure continues to be supported by the government, innovative projects that otherwise could not have afforded the costs of launch can make their business cases early.

[66] For more information on Lunar Resource, Inc.'s development of an on-orbit material fabrication facility (MFF), please make reference to Lunar Resources' commercial partner contribution in Section 4.3.1 of this study.

5.2 Role of Government

Government as Enabler
NanoRacks has grown concerned that, for NASA and the U.S. government as a whole, the value of commercial applications is viewed as being in the money that they can return to NASA or other agencies. This is fundamentally flawed in the opinion of NanoRacks, because the commercial sector does not operate in order to free up government budgets to do additional work. Sadly, the amount of funds that could be returned to the space agency are not material for NASA programs. It remains too small a marketplace of users. Philosophically, American innovation is driven by private sector growth, and by the public sector's support of that growth by ensuring continued funding for security, basic research, and infrastructure. Returns accrue to the government via the taxation of the revenues generated by this commercial activity.

There is, in short, no "balance" in the PPP that both stimulates commercial ventures and private funding while also helping NASA maximize its budget. A better question would be, *what is the right form a PPP should take in order to stimulate commercial ventures' ability to grow a commercial infrastructure in LEO with NASA as one of its customers?*

In such a scenario, NASA benefits from lower commercial service prices (provided a realignment in complex requirements as previously mentioned), but also from an ability to leave commercial operations to the private sector and refocus on building scientific and physical infrastructure in deep space, where the private sector is not nearly so well equipped to take on those challenges or requirements (and indeed, where no clear business case is yet present, given the associated technical difficulties). To this end, 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.

Concurrently, however, the commercial and government sectors would need to come to terms with the fact that, at least for the foreseeable future, government investment is required to ensure the overall stability and security of the marketplace—much as the government does by paying for the security of American airports, and their upkeep, while allowing airline operators to develop a robust business selling tickets, which in turn stimulates the need for additional aircraft that provides thousands of jobs for the domestic airline manufacturer and those overseas as well.[67] Within this context, the ISS provides a critical lynchpin in the overall commercial infrastructure of connected, and free-flying space stations in various LEO orbits.

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[67] NASA's study considers the Airline Industry, Transcontinental Railroad, the Telephone Industry, Public Works, and Cultural Conservation Zones. In this study, NASA investigated the feasibility of PPPs and other collaborative arrangements in Satellite Servicing, Interplanetary SmallSats, Robotic Mining, Cargo Transport beyond LOE, Crew Transport beyond LEO, Biomedical Research in Microgravity, Liquid Rocket Engines, Wireless Power, Space Communications, and Earth Observation Data Visualization. Lanius, 2014.

ISS Transition Process

While the ISS will continue to play a critical enabling role in the commercialization of LEO by serving as a staging point and vital testbed of new commercial technologies, one of the primary concerns NanoRacks has regarding the platform is its age and the outdatedness of much of the technology being used on board. This will continue to grow in importance, especially as the ISS ages into the intended commercial transition dates. With annual operational costs exceeding $1 billion, and likely to grow as the station ages, the commercial sector can provide extremely valuable ancillary platforms as free-flyers, meeting 2020s needs with 2020s technologies—platforms built specifically to the requirements of the customers they service. This will allow ISS the opportunity to continue functioning as an invaluable commercial testbed. If fiber-optic spinning for long periods of time cannot happen in environments where exercise cycles disturb the machinery, for instance, then those activities should transfer to a commercial free-flyer, while laboratory and university research can continue aboard commercial station racks. Liberating high-throughput commercial activities from burdensome ISS safety and policy regulations also would vastly benefit the commercial transition process and de-conflict station operation with private sector activity.

As NASA and the private sector embark on this commercial transition process for LEO, it is important to keep in mind the 50-year history of cooperation between strategic, national security interests of the United States, and the satellite and communications industry, as well as the 10-15 year history and growing relationship between the government and the Earth observation community for both large and SmallSats. As with the ELV industry, which contains many dual-use applications, communications companies provide both civilian and military needs. A great deal of precedent therefore exists on how to handle potential transitions between commercial and strategic applications in space, as well as the assurance that national government jurisdiction is retained over such missions. This is applicable, however, only provided that increased requirements levied by government jurisdiction over missions and domains would be met with less commercially competitive prices, much like the ELV industry charges more for government and military launches than civilian. In short, there are numerous factors involved in the transition from the ISS of today to the more commercial LEO marketplace of tomorrow. However, it appears that the overall issues are not unique. Whether with the trains linking the east and west coasts of the United States, maturing the aviation transportation business, or finding the right role of government in its turnover of the internet to the private sector, the philosophical foundation is the same: government support is needed for pioneering companies that invest, innovate, and bring customers to the marketplace, or otherwise provide services needed by the government.

5.2.1 Ideas for ISS transition

Table 5.2.1-1: Transition Scenarios and Outpost Roles

Logistical Transition Scenario	Market/Outpost Role
Commercial crew, sovereign, and commercial astronaut support module needed for ISS for basic housing requirements while on-orbit	Outpost habitable concept provides viable habitable staging area with minimal modification, potentially at low cost if it can draw power and resources from ISS; can also act as storage.
CRS vehicles visit multiple destinations in ISS orbit	If feasible, LEO ecosystem benefits greatly from this possibility—reduces requirement to procure extensive additional launches. Outpost and free-flyer program effectively enabled.
ISS international partners pull out	Free-flying Outposts serve as staging areas for international partners, facilitating continued communications and engagement as mediated by commercial sector.
Commercial crew program prices are unrealistic for single customers	Outpost proposes a fully robotic platform to enable continued engagement by multiple customers with space science, research, and industrial activity—no full dependence on commercial crew, unless realistic to market demand. Possible breakthroughs allowing the cost of transportation to be reduced dramatically. The market role is that Outposts are scalable and can take advantage of the increased demand and increase desire for multiple dedicated platforms in differing locations and subsidies from NASA could be appropriately scaled back.

Role of Government in Commercial Upmass

Congress has directed NASA to support space transportation costs today because it is too expensive to allow a commercial marketplace to develop, and too important to return to the single-point dependency of previous eras.

There is nothing unusual nor different in NanoRacks' history about this support. Clearly, it is the role of government to support infrastructure development, allowing the private sector to focus on specific services of public benefit. Whether in aviation, where the government funds airports and security, whether in oil and gas where land leasing is marginal, or (to cite one more example) in the domain of highways and roads, which have never been the domain or financial responsibility of auto manufacturers. There is no reason for the emerging market of space exploration and utilization to be treated any differently than these now-mature markets. The support by Congress in the development of a robust cargo transportation system, plus the more recent human-rated capacity, is in line with this historical norm.

For the foreseeable future, the cost of upmass will be prohibitive to true private sector investment in both launch and operation of private platforms. We look forward to two possible developments: true breakthroughs in the cost of sending materials and humans to and from space, and/or generation of enough in-space revenue to begin contemplating revenue "give-back" from space customers, much like tolls on roads, the gasoline tax, tax on airplane tickets, and so on.

Absent these two fundamental developments, the concept of scaling back or even eliminating government support for transportation costs will herald the collapse of American commercial activity in low Earth orbit.

As NASA and the U.S. government envision commercial handover of some ISS functions, the focus of the private sector should be on ensuring that public funding works to encourage greater use, facilitating at reasonable costs the hotels, warehouses, fuel depots, and Earth observation outposts of tomorrow's infrastructure.

Regarding vehicle transition, NanoRacks emphatically believes that all CRS-2 contracts must be honored, but also envisions a potential expansion in the range of available CRS-2 vehicles toward those that potentially offer more innovative methodologies for providing upmass to orbiting platforms. If future platforms to be partially supported by NASA or the U.S. government are not well serviced by current players, whether polar or elsewhere, then the range of available vehicles for resupply surely would need to be expanded by NASA.

Another point needs to be raised. Today there is available private-sector capital for launch vehicle start-ups. Dozens of companies are in a race to profitability, utilizing differing manufacturing methods and seeking different areas of the satellite market. The next revolution will take place when there is also a dramatic increase in the type of demand for in-space services, whether via in-space manufacturing or other services. Sustainability of the growth in launch services therefore, NanoRacks believes, requires a corresponding growth in the size and width of the market that launch vehicles can address. And this will take place only with a dramatic drop in launch costs.

Solutions for Commercial Human Transportation

The presence of humans in LEO must be viewed in the context of today's requirements, and the market demand to secure astronauts' presence in space—commercially and otherwise. In today's world, the role of humans is rapidly transitioning from the sole provider of experience and capability into one where many of those roles are being fulfilled by increasingly sophisticated automated tools, whether robotic or virtual. As with machine-human interfaces on automotive assembly lines, sophisticated robotics will increasingly obviate the need to send humans to space for all but tourism and scientific missions with research on the human body being a specific goal;

or otherwise to conduct advanced missions for which robots do not yet have the capacity. And for the most majestic reason of them all: the expansion of humans beyond Earth. Rather than asking what solutions are available for commercial human transportation to LEO, then, the following questions should be considered:

1. What does the space industry require human intervention for?
2. What does NASA require human intervention for?
3. What do humans seek to learn from space exploration?
4. Do humans wish to move beyond Earth on a permanent basis?

From the discussions conducted as part of this study, these three questions result in differing markets, from tourism to advanced manufacturing and national objectives. Only through a robust discussion with non-space industrial planners, politicians, would-be tourists, and industrial customers can one begin to answer such a question and optimize a solution. NanoRacks does not believe that the market currently is in an advanced enough state for such solutions to be practically discernible on a commercial basis.

Outpost as Scalable Facilitator to Transition Process

NanoRacks envisions Outpost as a transition facilitator for the ISS, in that it will be a fully flexible platform that can be tailored to service the specific needs of customers enabled by the ISS platform. Since the ISS cannot conceivably focus on one specific commercial activity, devolving such activity (like, say, protein crystal growth) to commercial free-flyers can enable new markets both by de-conflicting activities aboard a given platform and by focusing resources (in this case robotic and volume resources) on one specific production effort. As such, concepts like free-flying Outposts are launch vehicle providers' "best friend," as multiple commercial platforms in differing locations will be the next big leap of the launch vehicle marketplace. It is a virtuous circle, one not possible with one location, one orbiting station. The more launch vehicles, the more innovations, and the more chances for a technological breakthrough allowing lower costs and driving demand for better cadence. This means more customers can rely on in-space manufacturing and research.

For these reasons, NanoRacks believes that in the shorter term the current ISS logistical and transportation architecture should be made available to Outpost and other potential commercial platforms that are under the IGA. ISS is America's investment, just as the national highways support interstate commerce and tourism for automobile companies, grocery chains, hotels, and all other industries that depend on American citizens and companies having access to transportation networks. Along with the example of airports oft-cited in this work, these examples derive from mature, multi-billion dollar markets with decades of legacy and hundreds of billions of dollars of investment from both the public and private sectors.

While Americans typically do not think of these sectors as representing public-private partnerships, in reality that is exactly what they are. In some cases, the public pays through taxes and tolls and via the purchase of gas; in other cases Congress authorizes and funds the Department of Transportation (at a federal and state level) to pave the roads, while other agencies are responsible for the safety of those roads—not least of which are local police forces. These industries, while among the most mature in our society, also represent two of the most heavily subsidized in our country due to the critical and enabling services they provide. Consider for instance the Essential Air Services program, which subsidizes access to air transportation to 163 rural communities nationwide[68] [69]. These questions are critical to remember, especially when faced with pushback from a limited number of individuals in the space community against the continued support given by Congress to this emerging marketplace. Such pushback goes against how we, as a nation, support both emerging and mature markets, and profit collectively as a result.

Returning to the space industry, the Outpost is a destination. As such, the incredible "rush to market" of dozens of vehicles is a positive benefit for NanoRacks and all other "destination" projects. The key for NASA and the U.S. government is two-fold: a) how to assure continued support until prices drop dramatically or revenue dramatically increases, and b) how to assure additional destinations that almost force space transportation providers to increase their cadence and mission profiles and cause local governments to support additional spaceports ideally suited for the new in-space destinations and orbital inclinations. At some point in the future, government support can reflect that of more mature marketplaces. Innovation in launch vehicles will be key to reaching this moment.

[68] U.S. Department of Transportation, *Essential Air Service,* 2017
[69] BoardingArea, *10 Ways Taxpayers Subsidize U.S. Airlines,* 2017

5.2.2 Evolving ISS operations for commercialization

Optimizing Contracting Mechanisms

Before entering into serious discussions regarding the transition of ISS operations toward commercialization, NanoRacks and the commercial sector will require extensive additional information and supporting data about the intent and process behind this transition. Critical pieces of data will include:

1. A statement or announcement clearly defining an intent to transition to commercial operation
2. An announcement or stated pathway leading to commercially owned and operated platforms
3. A public statement from NASA that it will not use the ISS to compete against commercial platforms offering the same service
4. An announcement clearly listing NASA requirements in LEO
5. Note: If an announcement is made for an ISS attachment, an announcement that multiple nodes should be made available by competition

If only one node is made available, NanoRacks believes that it should be complemented by, at the very least, a free flyer station in an appropriate orbit.

NanoRacks has deep concerns that the transition to commercial operation will not be optimized to accurately reflect the nascent state of the industry. NanoRacks will work to ensure that there is an open dialogue, in the industry and with Congressional and administration officials, about the merits of continuing government support for space station resources for commercial opportunities. This dialogue also should explore whether it is time to revisit the existing station landscape put into place more than a decade ago, long before the pool of station customers expanded as it has. The industry seeks to be assured that this marketplace will be treated as no different than other core industries critical to U.S. competitiveness, like energy, terrestrial and air transportation, and technology, which receive needed support from multiple appropriate agencies to remain competitive on the world stage and viable to the American public. NanoRacks and its partners have observed that some in the government believe, incorrectly, that somehow commercialization will result in significant short-term revenue to the extent that it can fund NASA and other programs. This view is patently—if not dangerously—wrong. For NASA to push customers onto pay-as-you-go plans for launches and station services will cause this extremely fragile market to collapse. The optimal pathway is for NASA to continue to support, stimulate, and encourage the development of a full ecosystem. If NASA cannot support both LEO and Deep Space efforts on its current budget, then the solution is to turn to Congress, not the private sector, which is nowhere near making a sustainable business case in LEO with current technological capabilities.[70] [71]

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[70] NASA, *NASA Seeks Partnership with US Industry to Develop First Gateway Element,* 2018
[71] Messier, *NASA Releases RFP for Lunar Gateway Power & Propulsion Element, 2018*

NASA may lose its well-earned reputation as the leader on ISS for commercial partnerships with private companies. JAXA, for instance, has a multi-year blueprint for turning the ISS over to the commercial sector, as exemplified by the recent RFP rewarded to Space BD for the commercialization of the Kibo Airlock Module—for which NanoRacks is a partner.[72] JAXA plans to introduce a larger CubeSat deployer on the ISS to compete directly against the NanoRacks Bishop Airlock. JAXA and Japanese industry recognize the value of the NanoRacks-NASA efforts to increase station utilization, and seek to compete against such efforts. China's Space Station also will involve European and other partners, presenting formidable competition to the ISS.[73]

These new events put the entire NASA ISS commercialization debate into perspective. There is competition as other actors also see the value of space stations as commercial platforms. Leadership will be maintained only by staying the path that has been forged so far by the effective collaboration between NASA and ISS commercial actors. .

It is important to consider the points being made throughout this report, that there is no way to "leverage the commercial sector" effectively without also the resources of the public sector, especially at this nascent stage of the market's evolution. The public sector, as previously mentioned, also plays the important role of leveling the playing field internationally—potentially ensuring that all state operators of orbiting space stations, such as China, will someday be part of international agreements such as the IGA (albeit in a more sophisticated evolution).

It is worth noting here that believing that the ISS can be privatized, with all costs borne by a private operator, or consortia of private operators, is unrealistic. One must consider aging components and extremely high operating expenses. In addition, the hardware will be decades old, and more practically, NanoRacks learned from the experience of the aging Mir space station that space stations require more and more time spent on repair, rather than research, as they age. Add in the limitations of the station configuration, as mentioned throughout this report, and this is not a space station that can be sustained by a commercial operator. If NASA funds are required, better at some point to also devote further funds to new, state-of-the-art, commercial free flyers supporting the ISS and the ISS program.

We support greater commercialization of the ISS, with private operators taking on station activities, being responsible for their own payload safety and integration, and NASA behaving more and more as a customer in LEO. It is far better to imagine the ISS for exactly what it is: a model of international collaboration, and the backbone of the new LEO economy that will eventually evolve the capabilities to take over many of its functions across multiple orbits.

Benefits and Challenges to Commercial Astronauts on ISS

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[72] Goh, *JAXA Selects 2 Commercial Partners for ISS Satellite Deployment,* 2018
[73] Jones, *Why China is Opening its Space Station to International Partners, 2018*

The question of commercial crew flights reflects one of the key challenges of ISS commercialization: how to justify the high costs associated with station operations to pursue more Earth-based business models. For NanoRacks, it is unclear if a dedicated astronaut, private sector or public, would speed up station research. This was tried in the Space Shuttle program with Charles Walker and others, but the platform (space shuttle) did not easily facilitate any "return" based on a dedicated "astronaut."

The benefit of private-sector astronauts on the ISS is unclear. One still faces the challenges of conducting a given activity a) in a platform where the hardware is often aging; b) when a foreign presence can limit some activities; and c) when legal uncertainty regarding IP rights limits corporate investment and other specific issues.

Regarding branding, NanoRacks believes that sending a celebrity into space would help with branding, probably only once or twice, but this is unlikely to serve as a sustainable business model. Jeff Manber, CEO of NanoRacks, worked with Mark Burnett of "Survivor" and NBC to undertake a game show with the winner going to the Russian space station Mir. The appeal to Mr. Burnett and to NBC was to be first with a game show in space. But this was not perceived as a sustainable business model. It is unclear if a non-celebrity would attract the needed tens of millions of dollars in endorsements.

Also consider the high costs compared to terrestrial campaigns. To send a celebrity into space would cost on the order of tens of millions of dollars in transportation fees, not to mention the cost of the celebrity. What sort of campaign can justify, say, \$30-\$50 million in the startup fees alone? We can see this as a one-off, but again, not as a sustainable model if not subsidized by federal funds.

It also is worth noting the impact on the ISS on the coming opening of the sub-orbital market. Within a few short years, there will be a steady stream of celebrities, sports figures, artists, politicians, students, and so on riding up with New Shepard and Virgin. To those in the industry, there is a difference between a short suborbital flight and weeks on board an orbiting space station. But NanoRacks is less convinced the public will see that distinction. The excitement, the branding, and the novelty of the rush to experience space all will be with the new programs, not the aging, governmental ISS.

There are other important issues. If Russia pulls out of ISS, the platform could be known for its political disagreements. To compound this uncertainty, no clear guidance as yet exists on who might control branding rights—current restrictions are relatively stringent. As NASA well knows with its own logo, a brand is degraded when no one is in control of the message. Who will control the brand message of the ISS? If NanoRacks controls branding on the Bishop Airlock, and Bigelow on BEAM and JAXA on its module and NASA on its module, the result is a cacophony of messages that reduce the value of the brand.

To summarize, it is very difficult to say that a government controlled and operated facility, with multiple governments and commercial operators, with an unproven track record in any one commercial field other than satellite deployments, can be worthy year in and year out with multi-million-dollar investments. NanoRacks welcomes increased ISS commercialization, as well as NASA astronauts being involved in worthy commercial science, tech demo, and educational projects, and the existence of commercial astronauts. But to put these all together and show a business model that will sustain the ISS without sizeable federal funds is difficult to envision.

5.2.3 Recommendations for Future Government Actions

General Comments

NanoRacks believes that the most important outcome of the LEO Commercialization Study is for NASA and the U.S. government to consider deeply the comments and suggestions made by the industry and absorb these comments carefully. This, rather than rushing forward under the assumption that commercialization is a panacea that can ameliorate budget concerns and free up limited resources for expenditure elsewhere.

Additionally, NASA must come to the realization that no one launch vehicle or commercial platform can create a commercial marketplace in LEO. For that, a community of providers and buyers is required and true demand for space products and services must be created. In this regard, NanoRacks urges NASA and the Administration to consider either expanding the available ISS port, allowing more than one commercial company to operate in differing markets, or as a backup, supporting one company to dock and another to build a free-flying platform. Ideally, this latter case also would extend out to multiple orbits.

For this ecosystem to take root, NASA must strike a balance between continuing support of critical infrastructure and access, but also not favoring any particular commercial approach or company over another. To continue stimulating this economy over the next five years, NASA must ensure it protects the pioneers currently on the station, assuring guaranteed access for customers to use the private hardware now manifested, and not having to go through intermediaries for permission to use that hardware (except for cases in which safety or capacity concerns are raised). In ten years, or otherwise by the time a truly robust LEO economy takes root, the most useful action NASA can take to encourage the continued commercial operation of LEO is to retire the ISS, and utilize the savings therein to support its further work in deep space, but also in part to continually improve infrastructure and access to LEO.

Indeed, the best way to send a positive signal to the commercial and venture sectors that the LEO commercial environment is stable and ready for investment is to assure these actors that the ISS is the last government-operated space station in LEO. NASA may well require research facilities and an outpost for other reasons, but it must assure the private sector that no further platforms would be built in to LEO in a non-commercially driven manner. The Administration also must announce support for funding the development of private Outposts and keeping the current ecosystem of launch vehicles in place. Removing support for those vehicles and forcing future commercial space stations (or modern commercial operators aboard government space platforms) to pay the full price of rides, upmass, and other infrastructural goods would cause an immediate and dramatic collapse in all gains made within the scope of the good situation currently in place. The PPP will mature in due course, but it is not ready to shed government support yet.

If NASA wishes to kick off the push for commercialization by using the ISS as a platform, it must assure the owners of private hardware on the ISS, like NanoRacks' Bishop Airlock, that they have some amount of guaranteed access to their own hardware. It must also allow fully commercial projects aboard the ISS. Additionally, it must not compete with the commercial sector with subsidized or favored commercial projects, however tempting that may be. NASA also should explore an expansion of the IGA to include owners and operators of major ISS modules and hardware. Finally, NASA must revisit the barter system to allow space agencies to behave as commercial customers for American companies; the barter system must reflect growing support for commercial services.

NASA finally must realize that the growth of the future space economy will be driven by customers, and private companies rushing to meet those customers' requirements. NASA must not strive to support multiple hardware or commercial solutions when not enough customers exist to demand those solutions.

The ISS is a foundation—but it must not be the end. It is only a starting point for the future LEO economy.

Specific Policy Directions

NanoRacks is proud to have served as a market pioneer in greater commercial services on board the ISS, and is appreciative of the openness of NASA to embark on a new path with greater public-private partnerships. That said, there are concerns regarding how private companies can continue to scale up aboard the ISS and in LEO generally.

First, on the supply side there is no definitive policy on limiting hardware on station. This redundancy has led to a surplus in certain types of equipment or services that has a detrimental effect on the market because of excessive financial outlay for redundant equipment without sufficient market demand to justify the redundancy.

On the demand side, there is no definitive policy on assuring upmass is allocated to those who have invested private funds to build own and operation facilities on board the ISS. For example, NanoRacks is investing millions of dollars in company investment in the Bishop Airlock, with no consistent policy regarding access to the Airlock. Without certain guaranteed access to that privately owned hardware, investors are hesitant about investing in ISS and private-sector platforms as well, in particular when government-funded NGOs like CASIS have the assumed authority by NASA to limit access to those platforms by prioritizing some customer payloads for flight over others.

NanoRacks believes there should be new categories of access to ISS resources, including but not limited to upmass, astronaut time, and power. NanoRacks suggests the following three categories:

1. The majority of ISS resources should be allocated in a manner consistent with the current policy, with priorities given to those projects that enable scientific and/or educational programs of merit.

2. A new category should be formed, comprised of a smaller percentage of ISS resources. This category uses an auction process for those projects that are purely commercial with no scientific and/or educational components. This must be smaller, both because the auction process may be harmful to emerging markets (per studies focused on the "winners curse")[74], and because the advantage would accrue to deep-pocketed organizations regardless of the commercial merit of the project.

3. A third category should exist for those who own and operate their own hardware on the ISS, with this percentage allocated based on a combination of capital invested plus commercial utilization. This would be for an interim period (3-5 years), and would allow NanoRacks and other pioneers of LEO commercialization to assure availability and use of their own hardware. This will encourage private ventures to invest in business development and scale to greater levels of utilization as a stable environment would be ensured and expectations set. Continued investment in ISS hardware requires assurance to the investor of access to their hardware. Significant investment and significant utilization should come with a guarantee of utilization when customers are present.

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[74] Thaler, *The Winner's Curse: Paradoxes and Anomalies of Economic Life,* 2012

5.3 Financial Analysis Results

The below section outlines the methodology for the financial model, which is provided in Excel format to NASA separately. The bibliography for the interviews used to describe this financial model is provided at the end of the section, separate from the primary bibliography of this study, in order to highlight individual sources.

5.3.1 Explanation of Methodology and top-line assumptions

To assess the economic feasibility of a private space station the Outpost team leveraged the collective knowledge of its partners and conducted extensive research to identify both revenue-generating opportunities as well as associated costs. While government-led partnerships will provide fundamental support to a nascent LEO economy private financing sources and customers will ultimately determine its sustainability. As such, the Outpost team constructed a flexible financial architecture in the form of a comprehensive excel model, and supporting assumptions, that determine the potential profitability and financial returns to a prospective investor in a private space station under Outpost's proposed ecosystem approach. While Outpost has developed its own assumptions to support the business case the team has purposefully built the model with significant input variability for NASA use in its plotting a roadmap to commercializing LEO. Accompanying this narrative description is a summary appendix intended to be used as a quick reference guide and to orient users to the general approach and structure of the financial model. This appendix includes descriptions to each major tab listed in the model.

5.3.2 Approach to Model

NanoRacks' approach to modeling the financial performance of a potential private space station includes the following elements:

- Identifying and assessing relevant revenue-generating opportunities, and direct costs, for a private space station;
- Incorporating these business opportunities into one station to analyze the economics of a space station at the individual unit (i.e. individual station) model;
- Aggregating the combined performance of multiple projected Outpost stations and layering in corporate-level expenses to better understand the financial dynamics of a proposed station;
- Calculating financial returns or losses that ultimately form the basis of private sector interest. Financial returns are evaluated using two metrics common to sources of private sector financing: Internal Rate of Return (IRR) and Cash-on-Cash (CoC) multiples.

Outpost's financial analysis considers the project economics of a private space station over the 10-year period from 2021 to 2030. This analysis takes a "bottoms-up" approach by analyzing 20 individual business cases that are organized into five general revenue categories and subsequently assimilating those business cases into one individual Outpost station (see "Unit Model - Per Station Summary" tab in excel model). The "Unit Model – Per Station Summary" tab summarizes all assumed revenue-generating activities, and associated direct costs, and layers in additional expenses at the individual station level that cannot be traced to only one specific revenue item (e.g. mission control expense, Outpost astronaut crew, communications expense, various insurance expenses). Revenue and direct cost assumptions for each of the five general revenue categories are listed on their own respective tabs in the excel model, as follows:

- Human Habitat
- Additive Manufacturing
- Research & Development
- Satellite Services
- Other Markets

Additional detail on these categories is provided in Section 5.3.3 below.

A key assumption made is that all revenue generating activities incorporated in the model take place on one station. However, the model allows for significant variability in turning on and off specific activities to analyze the financial impact on a private space station's operating performance. Given that multiple Outpost stations may be launched over a ten-year period a "rollout schedule" was incorporated to account for multiple stations being launched in different years. The combined performance of these multiple stations is then aggregated at the corporate level with additional corporate-level expenses considered (e.g. management compensation, corporate marketing expense, rent expense for headquarters). This combined operating performance of the aggregated stations is captured on the tab titled "Rollup".[75] Note that specific years (e.g. 2021, 2022, etc.) are labeled in this tab whereas years are titled generically in others (e.g. "Year 1"). This is intentional as the user has the ability to select the year in which stations are launched. Thus, generically titled years represent years associated with an individual station whereas specific years denote the aggregate stations, inclusive of all stations launched from 2021 through 2030. As such, the "Rollup" tab is the only tab with specific years listed to match our evaluation window. Note that the evaluation window is over a 10-year period and thus any stations selected for launch in subsequent years capture only the financial performance of that station within the fixed evaluation window. For instance, while a station selected for launch in "Year 2026" on the "Control Panel" tab will operate for at least 10 years in reality, this model only incorporates the financial performance of that station from 2026 through 2030.

[75] Please note that this and other tabs in the Financial Model are marked as Proprietary, and are furnished to NASA and the U.S. government with limited rights.

The Outpost team further considered that a private space station may take different formats. For instance, an Outpost station could operate as a free-flying module fully automated through robotic processes and unable to support human crew. This has clear impacts on certain business cases such as a private space station's provision of space tourism services. Accordingly the user has the ability to select these station configurations on the tab titled "Control Panel". The effects on the business case will automatically cascade through the model upon selection of a station configuration. The excel model enables the selection of one of two specific station configurations from a drop down menu. In either configuration a user is still capable of altering many inputs to tailor the scenario. The two station configurations include:

- Crewed Free-Flyer: a human-rated, crew-tended Outpost station operating without the assistance of another facility, such as the International Space Station (ISS)
- Uncrewed Free-Flyer: an independently orbiting station operating under full automation and teleoperation

The Outpost team recognizes that other configurations are quite possible, particularly temporary configurations involving docking to ISS. However, for purposes of this forward analysis those configurations have not been fully analyzed. Furthermore, Outpost has heavily weighted its analysis to a station configuration amenable to human habitation on orbit. While advancements in robotic hardware and software may render this configuration possible, especially by first Outpost launch in 2021, an uncrewed station fails to address a number of targeted markets that would not only generate additional business for a station but also contribute to stimulating a broader commercial demand, as well as supporting longer-term NASA goals. For instance, the provision of a LEO platform to facilitate space tourism, sovereign astronaut training, and biological research is integral to moving forward commercially into LEO and building on the legacy of the International Space Station. While the narrative study above focuses largely on the potential role of robotically tended platforms, this model places key focus on the costs and dynamics of a crewed module.

In preparation for its study, Outpost first identified 29 different revenue opportunities and developed business cases for each one. 20 of these revenue opportunities were ultimately selected for final inclusion into the financial model. These 20 revenue items are further organized into five general categories listed on the table on the following page.

Unless noted otherwise, all revenue and expense items are adjusted for inflation at a 2.0% annual rate.

Table 5.3.2-1: Revenue Sources

Revenue Category	Average Revenue	% of Total	Description
Human Habitat			
Private astronauts	$92,114	*10.6%*	Hosting private passengers for recreation; established business model with demand backlog
Sovereign astronauts	$116,941	*13.5%*	Providing research and training platforms in LEO for professional astronauts
Additive Manufacturing			
3D Printing	$2,074	*0.2%*	Utilizing 3D printing technology to manufacture components for assembly of on-orbit products
Thin-film production	$31,663	*3.6%*	Production of thin-film coatings external to station for utilization in telescope apertures, etc.
ZBLAN	$226,659	*26.1%*	Economically produce higher purity fiber optic cable (i.e. ZBLAN) for terrestrial use
Research and Development			
United States Government agencies (ex NASA)	$83,402	*9.6%*	Includes technology demonstrations, experiments and remote sensing for USG entities (excludes NASA)
International space agencies	$10,124	*1.2%*	Includes technology demonstrations, experiments and remote sensing for international space agencies
NASA	$112,906	*13.0%*	Includes technology demonstrations, experiments and remote sensing across NASA departments
Private sector	$46,454	*5.4%*	Enables private sector research in the pharmaceutical, consumer packaged goods, and computing sectors
Satellite Services			
Satellite upgrades	$1,642	*0.2%*	Providing protective coatings or upgrades such as optical sensors to in-space assets
Satellite de-orbit	$43,249	*5.0%*	Outpost enables asset protection for large satellite operators (e.g. OneWeb) by fueling de-orbit service vehicles
Satellite assembly	$28,688	*3.3%*	Satellite assembly on orbit reduces launch costs and enables new satellite architectures
Small satellite deployment	$13,914	*1.6%*	Deploy small satellites on orbit to ensure operable condition and increase flexibility to launch
Earth observation	$17,541	*2.0%*	Imagery provision to insurance carriers based on externally-mounted camera on station
Other Markets			
Films	$16,823	*1.9%*	Provide footage for feature films and documentaries and/or host film crew on station for a fee
Product placement	$1,706	*0.2%*	Marketing and advertising revenue associated with crew and station affiliation
Sponsorships	$2,190	*0.3%*	Monetize prestige of LEO presence through sponsorship opportunities
Naming rights	$10,950	*1.3%*	Target innovative and highly visible brands for exclusive naming rights to a space station
Sponsored & sporting events	$7,406	*0.9%*	Host sporting and other events on station
Educational initiatives	$1,555	*0.2%*	Paid communications with Outpost-based astronauts primarily for educational purposes
Total	$868,000	*100.0%*	

5.3.3 Model Revenue Elements

To assist in individual evaluation of each revenue category these five revenue categories are listed on separate tabs. All listed revenue categories, and associated expenses, are then automatically incorporated into one Outpost station on the "**Unit Model - Per Station Summary**" tab.

Under the *Human Habitation* tab: revenue sources derive from a crew-tended free flyer that could host both sovereign and private astronauts on station and charge a fee for use.

- Private Astronauts: Outpost management's experience in previous successful space tourism charters and its existing partnership with Space Adventures provides meaningful substantiation of projected demand. As part of this LEOCOM study, Space Adventures contributed its analysis of projected private passenger demand variable to the total cost of a spaceflight experience. This analysis has been incorporated into the excel model to automatically adjust to the projected passenger demand based on the total price charged including an Outpost fee plus launch costs, the primary cost driver of a spaceflight experience. Our base case assumptions assume a $10 million fee to Outpost for each private passenger's 12 day stay (excluding launch costs). As a partner with Outpost, Space Adventures is expected to receive a revenue share for its management of private astronauts visiting an Outpost station. Our base case model assumes a 10% revenue share with Space Adventures, yielding $9 million in net revenue to Outpost per private astronaut. Our base case scenario further assumes the estimated launch cost for a private astronaut to be $15 million[76], bringing the total cost of a spaceflight experience to approximately $25 million. At this price level our base case scenario considers 4 private astronauts visiting the station in its first year of operation, and scaling up to 11 annual tourists in 2030. The cost of consumables for a visiting astronaut would be borne by Outpost as an expense and is estimated at $1.4 million for each 12 day stay. Finally, private astronauts must complete requisite training which has been estimated at $50,000 per week for 15 weeks, the length of comparable planned trainings for private astronauts.
- Sovereign Astronauts: There are currently approximately 105 active flight-ready astronauts across programs for NASA, ESA, JAXA, CSA, Russia, and China. An Outpost station could host a number of these sovereign astronauts on station to generate revenue. Our base case assumptions account for 3 sovereign astronauts utilizing an Outpost station in its first year of operation, and scaling up to 12 sovereign astronauts annually in 2030. For context, an average of 28 sovereign astronauts were launched per year between 1978 and 2015. While significant opportunity for international partnership exists Nanoracks has assumed at least 70% of sovereign astronauts launched in any year are NASA astronauts. Outpost

[76] $15 million assumed launch cost per passenger contemplates a marginal pricing approach to launch whereby spare seats on NASA crew launches are offered at discounted prices to both promote private sector participation and to assist in reducing overall crew launch costs for NASA. Additional detail on launch cost assumptions is provided below.

anticipates charging $20 million per sovereign astronaut for a 60-day visit. As national flight programs likely maintain their own training regimen Outpost expects sovereign astronauts to undergo their own training and thus no cost has been allocated to Outpost aside from the cost of consumables for the duration of stay. Launch costs per sovereign astronaut, under the aforementioned marginal pricing approach, are estimated at approximately $39 million. It is also assumed Outpost-employed astronauts will be on hand to manage station activities. As these costs span multiple business cases expense detail for these astronauts are accounted for on the "Unit Model - Per Station Summary" tab in the excel model. Two Outpost crew are assumed to be present on station, working six month stints before rotating.

Under the *Additive Manufacturing* tab: given the unique properties of lower earth orbit (e.g. vacuum and microgravity), a private space station could generate meaningful revenue from leasing space for manufacturing. As commercial partner contracts for use of a proposed Outpost station are not yet formalized, this study assumes Outpost collects a percentage of commercial partner revenue in lieu of a flat lease fee for use of a station to deliver its services. Outpost worked in concert with commercial partners to iterate and calibrate an appropriate revenue share that appropriately compensates a private space station for its services while still enabling each partner's business case to close.

- 3D Printing: Printing products from basic materials is of special value in lower earth orbit. Outpost's commercial partner Made-in-Space already utilizes its 3D printer on the International Space Station and maintains a significant backlog of at least six months of demand. Outpost's base case assumptions assume one job is completed per day on an Outpost station and charged one of two prices based on complexity ($40,000 per complex job and $7,500 per simple job). The split between complex jobs and simple jobs is assumed to be 110:255, for a total average revenue per station per year of $2.1 million.
- Thin-Film Production: Application of Lunar Resources' vacuum deposition technology enables multiple revenue-generating activities for a private space station, including repair of radiator coatings, solar cells, and optical surface reflector coatings. A private space station with existing robotic architecture, materials storage, and support capabilities enables Lunar Resources to affix its Materials Fabrication Facility (MFF) to an existing in-space asset at significantly reduced costs than developing an independent platform. Used in tandem with Bulldog servicing vehicles developed by Altius a MFF could meaningfully extend the life of satellites already on orbit. One such application is applying specialty coatings to large telescopic apertures on orbit at significantly reduced costs compared to terrestrial methods. Lunar Resources estimates sufficient demand for such a service at a price of $35 million per meter of coating. Outpost and Lunar Resources evaluated two recent telescope projects that could have captured meaningful cost savings by utilizing this approach: the LUVOIR and HabEx telescopes. The combined surface area of these

telescopes approximate 27 cubic meters, yielding an illustrative revenue opportunity of $945 million for the provision of these services. Outpost assumed coating for 27 cubic meters could be coated over the 10 year period projected, yielding an annualized gross revenue opportunity of $94.5 million. A private space station is expected to participate in this revenue opportunity through a revenue-sharing agreement. For purposes of financial modeling, the Outpost team assumed a revenue share equivalent to 30% of gross revenue received for these services. While additional satellite services exist to manufacture specific equipment upgrades to satellite constellations (e.g. protective coatings, phase array antenna, replacement optical sensors) telescopic coatings are deemed the nearest and most likely revenue opportunity so comprise the entirety of revenue for the "thin-film production" revenue line item. Additional revenue consideration is given to protective satellite coatings under the revenue category titled "Satellites Services".

- ZBLAN: An Outpost station's unique environment in microgravity offers significant revenue opportunity to leverage Made-in-Space's production technology to manufacture ZBLAN. The production of ZBLAN is highly automated and generally commands market prices between $175 per meter and $1,100 per meter. Outpost has assumed an approximate midpoint of $500 per meter sold. ZBLAN can be used in shorter length fiber applications such as surgical instruments but also has the potential to replace existing fiber optic networks to increase data transmission and reduce the need for costly repeaters in subsea cables. While the market for ZBLAN would be significantly larger than our base case assumption of $690 million per year, Outpost believes all of current market demand could be met on one Outpost station. As such, our base case assumptions subject the production of ZBLAN fiber to a demand constraint by which the amount of ZBLAN produced does not exceed this market threshold in the excel model. As such, a user may note that as they input additional stations on the "Control Panel" tab ZBLAN production revenue declines on a per-station basis. This is inbuilt into the study's assumption that all revenue generating activities are performed on one station. In reality, ZBLAN production would likely reach capacity on one station before being incorporated into another. Outpost intends to conduct separate studies into relevant capacity and configurations that optimize each station's profitable utilization.

Under the *Research and Development* Tab: as the ISS evolves, a private space station could fill the void by charging fees for research and development conducted on its platform. This could take the form of technology demonstrations or advanced experimentation. While a specific number of experiments or technology demonstrations is difficult to predict, research and development budgets provide a clearer indication of potential markets for a private space station's research capabilities. Consequently, Outpost researched a number of specific customers with demonstrated or stated interest in LEO research and assumed a nominal percentage of R&D expenditures captured. In some instances, these are based on ongoing marketing discussions. Direct expense associated with this R&D spend is approximated based on an average cost of experiments and technology demonstrations on station. For this study, four categories of R&D customers have been identified and assessed:

- United States Government Agencies (ex NASA)
- International Space Agencies (ex NASA)
- NASA
- Private sector customer demand is anticipated to come from a broad array of industries with existing ISS research participants including Goodyear (materials science), pharmaceutical companies (drug development, delivery, storage, and manufacturing), Anheuser-Busch (plant research), and Procter & Gamble (manufacturing).[77]

Concurrently, a number of factors are expected to drive R&D Demand:

- Decrease in launch costs
- Increased launch cadence
- Downmass capabilities come online
- Market awareness of R&D opportunities broadens (CASIS trends in ISS research already show increased demand)
- A private space station could operate under a lower cost model than the ISS by offering streamlined processes for design, setup, and implementation of R&D projects, similar to the approach NASA is currently exploring through its Revolution ISS for Science and Exploration (RISe) initiative.[78]
- A number of research platforms are currently being developed for use on the ISS to augment its research capabilities. Such capabilities could be incorporated into a private space station to further support growth of R&D customer demand. A sampling of these commercially-developed research platforms are included below.

Table 5.3.3-1: Platforms Currently In Development for Use on ISS[79]

Research Platform	Format on Station	Developer
Materials on ISS Experiment-Flight Facility (MISSE-FF)	External	Alpha Space
Multi-User System for Earth Sensing (MUSES)	External	Teledyne Brown Engineering

[77] NASA, *FY 2019 Budget Estimates,* 2018
[78] NASA, *FY 2019 Budget Estimates,* 2018
[79] Ibid, pp. 169

BioChip SpaceLab	Internal	Hnu Photonics
BioBox	Internal	STaARS
Tango Lab	Internal	Space Tango

Under the *Satellite Servicing* Tab:

- Satellite De-orbit services (fuel depot for Altius): Altius intends to utilize its Bulldog servicer vehicle to provide de-orbit services to large satellite developers such as OneWeb and SpaceX. Based on planned constellations amongst major satellite operators, Altius estimates more than 8,000 satellites will be manifested for launch in the next decade. Assuming typical post-mission satellite failure rates continue at 15%, approximately 1,200 satellites are expected to require de-orbit. A private space station provides significant value in a de-orbit scenario enabling a Bulldog servicer to re-fuel. "Outpost stations could store tanks of commonly-used propellants in an easy-access external bay" (Altius report). For this study, Outpost and Altius have assumed a 20% revenue share model for provision of these services. The model further considers that Altius may not capture 100% of this market. Accordingly, Outpost's base case assumptions considers that Altius achieves only a 4% penetration of this $4.5B potential market (8,000 satellites x 15% failure rate x $3.75M price per de-orbit). In calibrating its assumed penetration rate, Outpost considered other potential risk factors that impact this business case such as advances in satellite bus technology to reduce failure rates as well as increased satellite deployments from a private space station.
- Satellite Upgrades: In addition to generating revenue through mirror coatings for large aperture telescopes, Lunar Resources anticipates extending the life of satellites on orbit by utilizing its Materials Fabrication facility to apply protective coatings to satellite buses, a common source of satellite degradation. Lunar Resources estimates gross revenue per satellite coated of $5 million. Outpost is expected to collect approximately 30% of gross satellite coating revenue as Outpost revenue for hosting Lunar Resources' MFF. Lunar Resources maintains significant excess capacity above projected demand but expects 3 satellites to be coated in a station's first year of operation, increasing gradually to 12 satellites per year by Year 10.
- Satellite Assembly: Current satellite architecture is limited by launch vehicles used to deploy them. As such, meaningful opportunity exists to generate revenue on a private space station through the assembly of satellites on orbit with bolstered capabilities (e.g. more antennas attached) and without the attendant cost in designing satellites that must survive launch. Leveraging detailed analysis in the STPI report furnished to NASA in 2017, Outpost assumed a comparatively lower estimate of 1 satellite produced per year at a total price of $26.2M per satellite.

- Small Satellite Deployment: Approximately a third of cubesats launched since 2000 were deployed from the ISS, primarily through Nanoracks services. On-orbit deployment offers significant flexibility in getting customers' satellites to orbit as deployments are less vulnerable to launch variability and secondary payload integration. Nanoracks expects continued growth in its provision of such services. For purposes of this study, Nanoracks assumed an average deployment cost of $125,000 per satellite deployed and assumed an Outpost station captures 20% of nano/microsatellites launched. Annual assumed satellites deployed range from 58 to 182 and are based on the SpaceWorks 2017 Nano/Microsatellite Market Forecast.
- Earth Observation: Affixing remote sensing equipment external to an Outpost station offers additional revenue-generating opportunities. As significant value is ascribed to remote sensing capabilities that offer redundancy in a large constellation, Outpost has assumed only marginal revenue is derived from this business case. Outpost also considered only marginal revenue from this activity as increased provision of satellite services presents risk of cannibalizing business from existing satellite providers. Potential applications for remote sensing from an Outpost station range from consulting on capacity management projects (e.g. counting cars in parking lots) to hedge funds (e.g. provision of unique data points to better predict companies' earnings) to insurance (e.g. aerial imagery used to assess property damage). For purposes of this study, Nanoracks included only the insurance application to project potential revenue from remote sensing. Based on interviews industry expert interviews and analysis, insurance carriers incur an average of $200 cost to send an third party contractor to inspect a newly underwritten home and verify its condition. Advances in computer vision algorithm software now enable technology firms to provide this same inspection without the presence of a human by leveraging aerial imagery. Outpost evaluated the number of properties insured in the United States by the top 25 insurance carriers and assumed Outpost is capable of providing imagery on 2% of these properties. Industry experts suggested current pricing for aerial imagery in such capacities is typically around $5 per image, yielding an average revenue opportunity of $17.5 million per year. See the tab titled "LEOCOM Insurance Imagery Market" in the excel model for detailed calculations.

The final tab on *Other Markets,* is treated individually within the model and not explored in this narrative.

5.3.4 Additional Model Properties

The NanoRacks Financial Model includes significant flexibility in allowing a user to input their own assumptions and see the resulting impact to the business case and economic viability of a private space station. All assumptions are capable of alteration by the user are highlighted in bolded blue font.

The Model evaluated 5 general revenue categories on separate tabs with specific revenue items under each and direct expenses (COGS) for each one; these are represented as individual "income statements." Assumptions and relevant calculations for each revenue and expense line item are delineated in columns to the right of the income statement for user review. These 5 categories roll up into one individual station "income statement" that layers in additional operational expenses associated with one Outpost station (see "Unit Economics-Per Station Summary" tab)

The performance economics of an individual Outpost station are reflected on the "Unit Model-Per Station Summary" tab, and this captures the summary revenue and direct expenses associated with the 5 different revenue categories. This tab also factors in additional expenses associated with an individual station that cannot be allocated solely to any one revenue category (e.g. cost of maintaining Outpost-employed crew members on station, communications cost associated with one station). Using standard working capital assumptions, depreciation (straight-line depreciation method), and additional annual expenditures associated with maintenance of the station, we calculated expected annual free cash flows for each individual station over its 10-year life. We then used these annual cash flows and the initial investment dollars assumed for an individual station to calculate the IRR and Cash-on-Cash return in each year of the station's 10 year life to evaluate the profitability of an individual Outpost station.

NanoRacks envisions multiple stations potentially being launched over the projected timeline of 2021 to 2030. Consequently, after capturing the unit economics at the individual station level Outpost considered the financial impact of launching multiple stations over a ten year period. Our base case assumptions assume only one station is rolled out in 2021, for a total of one station in orbit over the stated ten year period. Given that this study considers financial returns over a specific ten year period, stations launched in years later than 2021 will almost certainly continue to conduct business after 2030 but profits generated after 2030 have not been factored into the financial returns analysis. As such, an Outpost space station could generate significant value not factored into this analysis. This cadence and number of stations rolled out by year can be adjusted to the user's preference on the "control panel" tab. The summary calculations and effects of rolling out stations in different years can be viewed on the tab titled "Rollout."

Launch costs are also assumed to lower by Year 2021, but then the model conservatively assumes that launch costs remain constant, though they would likely continue to decrease over this 10 year period. The model expects multiple launch providers coming online both in crew and uncrewed sectors. With this profusion of market entrants as well as advanced technologies enabling reusability and larger payloads, a significantly lower launch cost is likely. According to NASA publications, 2019 launch cost per crew member is expected to drop more than 28% from 2018 launch costs. While this reduction is likely to be stepped, not linear, opportunity exists for continued launch cost reductions.

Therefore the model takes a bifurcated approach to astronaut launch pricing under the base case assumptions, including "Unadjusted launch cost per astronaut" and "Adjusted launch cost per astronaut." The model also assumes more astronaut hours are available on station (8 hrs per day) to conduct experiments compared to current time available on ISS, due to both automation capabilities and updated technology on station requiring less astronaut maintenance

Automation capabilities are factored in as an additional costs that have been calibrated in concert with Olis Robotics, and based on detailed calculations of expected time reductions for specific tasks.

5.3.5 Forward Diligence

In forward work, NanoRacks may consider refining flight planning and cadence to better assess potential launch cost efficiencies. Calibrating exact hardware technology costs for automation robotics and R&D lab equipment (e.g. how many racks, what types of experimentation hardware is required, what is throughput based on lab equipment and automation hardware on station) may also be beneficial. Further factoring the volume capabilities of Outpost would also be highly beneficial.

Further refining NRE and recurring per-station investment would also be necessary in future work, as well as charting specific financing plan for Outpost stations. Substantiate demand further through in-person business development discussions with target markets could help target model functionality. Critical to building a more complete picture of astronaut work would be refining estimates of astronaut time spent on station for both Outpost and sovereign astronauts. For instance, drilling down on Outpost crew responsibilities will help determine how many crew are required. The model could reasonably ask if Outpost crew are solely focused on station maintenance or are they assisting in experiments conducted by sovereign astronauts. Additionally, it could consider what tasks sovereign astronauts would be performing on station.

An exploration of the effects of modularization versus launching separate free-flyers (e.g. potential to save meaningfully if we can use one ECLSS for two stations) would also benefit the model, as would a refining of cash flow characteristics that impact working capital (and thus capital requirements). The model currently assumes standard working capital based on AR/AP but actual client contracts likely to include milestone payments that make this more "lumpy."

5.3.6 Base Conclusion

Outpost's financial analysis yielded a number of conclusions, many of which provide direction on forward paths to consider in potential NASA approaches to commercializing LEO as well as actionable recommendations for current implementation.

Based on Outpost's analysis, given the heavy capital expenditures associated with developing and launching a private space station there is no one revenue opportunity that generates the requisite financial returns. However, a balanced portfolio of station activities does not only cover a station's costs but achieves meaningful financial returns to at least attract preliminary private sector investment. However, a number of opportunities exist to safeguard current private sector interest and drive projected returns to a range more commonly expected from investors and lenders. Expected returns for private equity and venture capital investors generally range from 20% to 30% IRR.

First, a **marginal pricing approach** to launch significantly improves a private space station's ability to achieve targeted financial return metrics, and thus encourage investment from private sector financing sources. The highlighted grey sections in the tables in Section 5.3.7 reflects the cargo price and crew launch price at which the business case achieves requisite financial returns for private sector interest. Employing a marginal pricing approach not only spurs demand but also offers the potential to partially offset NASA crew launch costs.

Partial prepayment for NASA services is a highly valuable method of assisting a private space station in achieving requisite financial targets (i.e. 20% to 30% IRR). Outpost's base case assumptions assume NASA offers prepayment terms on two years of projected R&D revenue, amounting to $208 million. This feature enables Outpost to project a 38.2% IRR, compared to a 27.1% IRR without such NASA prepayment terms. Prepayment also addresses another key investor consideration that has hampered past private sector companies seeking financing; NASA commitments to multi-year contracts. While NASA is projected to comprise only 28.0% of station revenue over its 10 year life, its presence as an anchor customer is critical to market validation of a private space station, by both customers and financing sources. Typical due diligence on behalf of financing sources for satellites, a relevant analog to a private space station, includes evaluation of customer contracts. Multi-year contracts are prerequisites to securing private sector financing in these scenarios.

5.3.7 Illustrative Tables Supporting Conclusions in Section 6.2

The below tables help provide context for conclusions of this study provided in Section 6.2 below.

Table 5.3-1: Probability Distribution for Non-Recurring Investment costs and Recurring Investment costs

(Reflects probability that NRE and Recurring Investment per Station Module are both below values given)

Probability that NRE and Unit Costs are both below values given

Non-Recurring Investment (NRE)	Recurring Investment per Station Module (i.e. one-time costs per station module)										Key
		$200.0	**$225.0**	**$250.0**	**$275.0**	**$300.0**	**$325.0**	**$350.0**	**$375.0**	**$400.0**	0.00%
	$300.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0 % to 10%
	$325.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	11% to 20
	$350.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	21% to30%
	$375.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	31% to 40
	$400.0	0.0%	0.1%	0.6%	1.9%	3.9%	6.3%	8.0%	8.3%	8.3%	41% to 50
	$425.0	0.0%	0.5%	2.8%	8.5%	18.22%	28.70%	46.36%	47.64%	47.72%	51% to 60
	$450.0	0.0%	0.8%	5.3%	16.80%	34.78%	55.10%	78.52%	80.88%	81.08%	61% to70%
	$475.0	0.0%	0.9%	6.7%	21.34%	43.86%	69.80%	96.68%	99.78%	99.98%	71% to80%
	$500.0	0.0%	0.9%	6.7%	21.34%	43.86%	69.82%	96.70%	99.80%	100.00%	81% to 10

Table 5.3-2: 10-Year IRR Sensitivity Analysis: Scenario 1

(Scenario 1 assumes no inclusion of a NASA prepayment feature and 100% of NRE is allocated to a single crew-tended station built to NASA specifications)

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)										Probability Key
		$200.0	**$225.0**	**$250.0**	**$275.0**	**$300.0**	**$325.0**	**$350.0**	**$375.0**	**$400.0**	0.00%
	$300.0	42.6%	40.5%	38.6%	36.9%	35.3%	33.8%	32.4%	31.2%	30.0%	0 % to 10%
	$325.0	40.4%	38.5%	36.8%	35.2%	33.7%	32.3%	31.1%	29.9%	28.8%	11% to 20%
	$350.0	38.4%	36.7%	35.1%	33.6%	32.3%	31.0%	29.8%	28.7%	27.6%	21% to30%
	$375.0	36.6%	35.0%	33.5%	32.2%	30.9%	29.7%	28.6%	27.6%	26.6%	31% to 40%
	$400.0	34.9%	33.5%	32.1%	30.8%	29.6%	28.5%	27.5%	26.5%	25.6%	41% to 50%
	$425.0	33.4%	32.0%	30.7%	29.6%	28.46%	27.41%	26.43%	25.50%	24.62%	51% to 60%
	$450.0	31.9%	30.7%	29.5%	28.38%	27.34%	26.36%	25.43%	24.55%	23.71%	61% to70%
	$475.0	30.6%	29.4%	28.3%	27.27%	26.29%	25.36%	24.48%	23.65%	22.85%	71% to80%
	$500.0	29.3%	28.2%	27.2%	26.21%	25.29%	24.41%	23.58%	22.79%	22.03%	81% to 100%

Table 5.3-3: 10-Year IRR Sensitivity Analysis: Scenario 2

(Scenario 2 assumes inclusion of a NASA prepayment feature and 100% of NRE is allocated to a single crew-tended station built to NASA specifications)

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)										Probability Key
		$200.0	**$225.0**	**$250.0**	**$275.0**	**$300.0**	**$325.0**	**$350.0**	**$375.0**	**$400.0**	0.00%
	$300.0	75.4%	68.8%	63.3%	58.7%	54.8%	51.4%	48.4%	45.7%	43.3%	0 % to 10%
	$325.0	68.6%	63.1%	58.5%	54.6%	51.2%	48.2%	45.6%	43.2%	41.1%	11% to 20%
	$350.0	62.9%	58.4%	54.5%	51.1%	48.1%	45.5%	43.1%	41.0%	39.0%	21% to30%
	$375.0	58.2%	54.3%	51.0%	48.0%	45.4%	43.0%	40.9%	38.9%	37.2%	31% to 40%
	$400.0	54.2%	50.8%	47.9%	45.2%	42.9%	40.8%	38.8%	37.1%	35.4%	41% to 50%
	$425.0	50.7%	47.7%	45.1%	42.8%	40.65%	38.72%	36.96%	35.34%	33.84%	51% to 60%
	$450.0	47.6%	45.0%	42.7%	40.55%	38.62%	36.87%	35.25%	33.75%	32.37%	61% to70%
	$475.0	44.9%	42.6%	40.4%	38.53%	36.77%	35.16%	33.67%	32.28%	31.00%	71% to80%
	$500.0	42.4%	40.3%	38.4%	36.67%	35.07%	33.58%	32.20%	30.91%	29.71%	81% to 100%

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**

Table 5.3-4: 10-Year IRR Sensitivity Analysis: Scenario 3

(Scenario 3 assumes no NASA prepayment feature and 40% of NRE is allocated to a single crew-tended station built to NASA specifications)

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	Probability Key
										0.00%
$120.0	69.3%	63.8%	59.2%	55.3%	51.9%	48.9%	46.2%	43.8%	41.7%	0 % to 10%
$130.0	66.9%	61.8%	57.5%	53.8%	50.6%	47.7%	45.2%	42.9%	40.8%	11% to 20%
$140.0	64.7%	60.0%	55.9%	52.4%	49.4%	46.6%	44.2%	42.0%	40.0%	21% to30%
$150.0	62.7%	58.2%	54.4%	51.1%	48.2%	45.6%	43.2%	41.1%	39.2%	31% to 40%
$160.0	60.7%	56.6%	53.0%	49.8%	47.1%	44.6%	42.3%	40.3%	38.4%	41% to 50%
$170.0	58.9%	55.0%	51.6%	48.6%	45.98%	43.60%	41.45%	39.50%	37.71%	51% to 60%
$180.0	57.2%	53.6%	50.3%	47.49%	44.95%	42.67%	40.61%	38.72%	37.00%	61% to70%
$190.0	55.6%	52.2%	49.1%	46.39%	43.97%	41.78%	39.79%	37.98%	36.31%	71% to80%
$200.0	54.1%	50.8%	47.9%	45.35%	43.02%	40.92%	39.01%	37.26%	35.64%	81% to 100%

Table 5.3-5: Adjusted Launch Cost per Passenger – IRR sensitivity analysis based on adjusted launch cost approach (marginal pricing)

Adjusted Launch Cost per Passenger ($ in millions)

Cargo ($ / kg)	**$46.3**	**$42.5**	**$38.8**	**$38.8**	**$35.0**	**$31.3**	*<-- Sovereign astronaut pricing*
	$5.0	**$10.0**	**$15.0**	**$20.0**	**$25.0**	**$30.0**	*<-- Private astronaut pricing*
$10,000	*107.0%*	*80.5%*	*65.7%*	*50.5%*	*40.9%*	*30.7%*	
$15,000	*93.6%*	*70.9%*	*57.8%*	*44.2%*	*35.5%*	*25.9%*	
$20,000	*82.0%*	*62.3%*	*50.7%*	*38.4%*	*30.3%*	*21.3%*	
$25,000	*71.8%*	*54.6%*	*44.2%*	*32.9%*	*25.5%*	*16.8%*	
$30,000	*62.9%*	*47.6%*	*38.2%*	*27.8%*	*20.8%*	*12.5%*	
$35,000	*54.9%*	*41.2%*	*32.6%*	*22.9%*	*16.4%*	*8.2%*	
$40,000	*47.6%*	*35.3%*	*27.4%*	*18.3%*	*12.0%*	*3.8%*	
$45,000	*41.0%*	*29.7%*	*22.4%*	*13.7%*	*7.6%*	*-0.7%*	
$50,000	*34.9%*	*24.5%*	*17.6%*	*9.2%*	*3.2%*	*-5.4%*	

**Assumes one station rolled out in Year 1*

5.3.8 Model Summary under Base Case Assumptions

Control Panel

Summary & Key Functionality:

- Directory of the financial model tabs with active links to each one
- Select a station configuration:
  - *Crewed Free-Flyer*; or
  - *Uncrewed Free-Flyer*
- Turn on/off various business cases under each station configuration
- Select the number and timing (by year) of stations launched

Financial Output

Summary & Key Functionality:

- No user inputs are specified here
- Provides summary financial results of user inputs (saved model is set to Base Case assumptions)
- Financial results include:
  - Evolution of Internal Rate of Return (IRR) for all stations rolled out
  - Evolution of Cash-on-Cash (CoC) returns for all stations rolled out
  - Evolution of Internal Rate of Return (IRR) for an individual station
  - Evolution of Cash-on-Cash (CoC) returns for an individual station
  - Station revenue breakdown by revenue category
  - Revenue breakdown by customer (NASA vs All Other Customers)
  - IRR sensitivity analysis based on cargo and crew launch cost

Non-Recurring Investment

Summary & Key Functionality:

- Non-recurring investment costs include initial design, development, testing, and evaluation of the Outpost concept
- These investment costs are not tied to any specific station and thus are spread across performance of all stations
- Shows illustrative non-recurring investment cost for both station configurations:
  - *Crewed Free-Flyer*; and
  - *Uncrewed Free-Flyer*
- Non-recurring investment costs shown are approximations calibrated by required investor returns and not reflective of actual Outpost investment estimates
- Total non-recurring costs included automatically populate in the yellow cell based on which station configuration is selected on the *Control Panel* tab

Investment per Station Module

Summary & Key Functionality:

- Recurring costs per station are one-time investment costs associated with each station's development and launch
- Recurring costs are not annual costs
- Shows illustrative recurring investment cost for both station configurations:
  - *Crewed Free-Flyer*; and
  - *Uncrewed Free-Flyer*
- Recurring investment costs shown are approximations calibrated by required investor returns and not reflective of actual Outpost investment estimates
- Total recurring costs included automatically populate in the yellow cell based on which station configuration is selected on the *Control Panel* tab

Human Habitat Assumptions

Summary & Key Functionality:

- 1 of 5 revenue categories, includes 2 subcategories:
  - Hosting sovereign astronauts
  - Hosting private astronauts
- Shows the revenue and cost assumptions associated with these station uses over a 10-year period
- Revenue and direct expenses associated with these revenue lines roll up into the *Unit Model-Per Station Summary* tab
- Calculations automatically adjust based on which station is selected on the Control Panel tab:
  - *Crewed Free-Flyer*; or
  - *Uncrewed Free-Flyer*
- Assumption inputs are available for user alteration in column R

Additive Manufacturing Assumptions

Summary & Key Functionality:

- 1 of 5 revenue categories, includes 3 subcategories:
  - 3D Printing
  - Thin-film production
  - ZBLAN
- Shows the revenue and cost assumptions associated with these station uses over a 10-year period
- Revenue and direct expenses associated with these revenue lines roll up into the *Unit Model-Per Station Summary* tab
- Calculations automatically adjust based on which station is selected on the Control Panel tab:
  - *Crewed Free-Flyer*; or
  - *Uncrewed Free-Flyer*
- Assumption inputs are available for user alteration in column R

R&D Assumptions

Summary & Key Functionality:

- 1 of 5 revenue categories, includes 4 subcategories:
  - US Govt Agencies (ex NASA)
  - NASA
  - International Space Agencies
  - Private sector
- Shows the revenue and cost assumptions associated with these station uses over a 10-year period
- Revenue and direct expenses associated with these revenue lines roll up into the *Unit Model-Per Station Summary* tab
- Calculations automatically adjust based on which station is selected on the Control Panel tab:
  - *Crewed Free-Flyer*; or
  - *Uncrewed Free-Flyer*
- Assumption inputs are available for user alteration in column R

Satellite Services Assumptions

Summary & Key Functionality:

- 1 of 5 revenue categories, includes 5 subcategories:
  - Satellite upgrades
  - Satellite assembly
  - Small satellite deployment
  - Satellite de-orbit services
  - Earth observation
- Shows the revenue and cost assumptions associated with these station uses over a 10-year period
- Revenue and direct expenses associated with these revenue lines roll up into the *Unit Model-Per Station Summary* tab
- Calculations automatically adjust based on which station is selected on the Control Panel tab:
  - *Crewed Free-Flyer*; or
  - *Uncrewed Free-Flyer*
- Assumption inputs are available for user alteration in column R

Other Markets

Summary & Key Functionality:

- 1 of 5 revenue categories, includes 6 subcategories:
    - Films
    - Product placement
    - Sponsorships
    - Naming rights
    - Sponsored/sporting events
    - Educational initiatives
- Shows the revenue and cost assumptions associated with these station uses over a 10-year period
- Revenue and direct expenses associated with these revenue lines roll up into the *Unit Model-Per Station Summary* tab
- Calculations automatically adjust based on which station is selected on the Control Panel tab:
    - *Crewed Free-Flyer*; or
    - *Uncrewed Free-Flyer*
- Assumption inputs are available for user alteration in column R

Rollout

Summary & Key Functionality:

- No potential user inputs on this tab
- Captures the waterfall analysis from launching multiples stations over Outpost's 10-year period
- These calculations feed into the *Rollup* tab

Launch Costs

Summary & Key Functionality:

- Includes calculations of launch costs that drive other expenses in the model
- Includes two-pronged approach to crew launch pricing:
    - Unadjusted (even split)
    - Adjusted (discounted)
- Other calculations include:
    - Cargo launch ($ / kg)
    - Cost of consumables (pp/day)
    - Astronaut cost per hour
- Inputs highlighted green can be altered to user preference

Unit Model – Per Station Summary

Summary & Key Functionality:

- Aggregates all selected revenue categories into one Outpost station;
- Incorporates the revenue and direct expenses from business categories and layers in additional operational expenses associated with the individual station
- Evaluates the unit economics of an individual station to understand the basic profit formula
- Station-level operational expenses include:
    - Mission control support
    - Data/communications expense
    - Outpost crew on station
    - Insurance
- Calculates projected cash flow for an individual station as a basis for analysis of financial returns for an individual station
- Financial returns analysis includes evolution of a station's Internal Rate of Return (IRR) and multiple of Cash-on-Cash (CoC) over a 10-year period
- Includes assumptions input for number of Outpost crew on station and launch pricing approach (i.e. see *Launch Costs* tab for pricing approach)

Rollup

Summary & Key Functionality:

- Summary performance of Outpost combined stations
- Layers in additional corporate-level expenses common to all stations launched, including:
    - Senior management compensation
    - Corporate office expense
    - Sales, marketing and administrative overhead
    - Taxes
- Calculates corporate-level cash flow for a private space station
- Uses corporate cash flow to identify the potential peak cash need of a private space station to consider various financing options.

5.3.9 Internal Model Bibliography

Interviews:

- Bakkers, Steen; (ING) – August 28, 2018
- Coneybeer, Rob; (Shasta Ventures) - November 2, 2018
- CPG Firm Representative – July 29, 2018
- Frazer, Tony; President of Radiant Solutions, Public Comments at NYC Economist Space Summit – November 2, 2018
- Hewlett Packard Representative on LEO utilization of test hardware - November 6, 2018
- ING Satellite Financing Representative (ING Wholesale Banking research) - July 16, 2018
- Kozlewski, Robert; computer vision algorithm technology entrepreneur – November 2, 2018
- Lyman, David; insurance technology entrepreneur – October 5, 2018
- Manber, Jeff; CEO of NannoRacks – Multiple Dates, 2018
- Moon, Chris; (ING) – August 15, 2018
- Newman, Rob; CEO of Nearmap (large public aerial imagery vendor) – November 10, 2018
- Tobias, David; insurance technology entrepreneur – October 20, 2018
- Team Interviews including
  - Deep Space Industries
  - KSAT
  - Lunar Resources
  - Made In Space
  - Marsh & McLennan and Oliver Wyman
  - Olis Robotics
  - Space Adventures
  - Stratolaunch
  - Terminal Velocity
  - ULA

5.4 Risk Analysis Results

PARTNER FINDINGS NOT AVAILABLE FOR RELEASE

5.5 Policy Simulation and Associated Findings

5.5.1 Introduction

As part of the LEO Commercialization 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 document the process that NASA took in order to answer that question. Relevant areas of concern included which organizations, both internal and external to NASA, were consulted with to arrive at a response; what further information NASA sought and what was excluded from the initial request; and any concerns NASA had with the request itself. The results of this exercise were then used to provide general observations and recommendations on the policy process itself, as well as notional responses to the hypothetical scenario.

NanoRacks would like to express gratitude toward the team at NASA for their willingness to engage in this exercise and extensive support throughout the process. This support included ensuring that scenarios were crafted with the appropriate degree of depth, and that an equally well-considered response was received in return.

5.5.2 Challenges & Limitations

Given the limited timeline available for the LEOCOM study and the extensive and careful consultation required to answer the multi-layered policy questions posed in this exercise, NanoRacks believes that more time would have been helpful in providing a deeper analysis of the policy questions at hand. Indeed, another round of simulated "responses" to the NASA response, and then awaiting a further round of NASA response, would have been particularly instructive.

5.5.3 Further Study

NanoRacks recognizes that conclusions drawn from this exercise would have benefited from another round of simulation with NASA, so future work would continue these hypothetical back-and-forth correspondences with ample time for NASA to properly vet the responses. This would also afford NanoRacks and partners ample time to consider realistic potential future implications of NASA's response and compose an appropriate hypothetical email in return. In particular, NanoRacks would appreciate an opportunity to revisit, in consultation with NASA, Scenarios 2 and 3. Scenario 2 could be reworked to set out terms and conditions for the Space Act Agreement that the company in question hypothetically signed with NASA, as those terms would change the overall scope of the question and affect the manner in which it was answered. Scenario 3 could potentially be reworked to see how selecting a different nationality for the sovereign astronaut would affect the overall response.

Additionally, NanoRacks and the study overall could benefit from further understanding of what elements of the exercise NASA found valuable.

5.5.4 Scenarios

For this study, NanoRacks provided three scenarios, conveyed as questions to NASA via email, from three commercial operators. They included:

- A question on the nature of the IGA, and whether (and under what circumstances) it covers commercial platforms
- A question on NASA's response to competition by two platforms in the same orbit, one of which is attached to the ISS
- A question on how NASA makes the determination on which nationalities are able to fly via commercial crew vehicles, and other associated considerations like IGA coverage

The initial hypothetical emails are reproduced below in full.

5.5.4.1 IGA, Investment, CRS-2

From: Robert Warbucks <warbucksr@SSO.com>
Sent: Monday, October 23, 2018 10:58 AM
To: [YOU]
Cc:
Subject: Question on Free Flying Station and IGA

Dear NASA,

I am the CEO of the space station startup company *Star Station 1*. We have procured the funding to deploy in the ISS orbit, reachable by CRS-2 vehicles, a small uncrewed operational platform that also has the ability to be crew tended. As you know, this is a repurposed upper stage that is not designed to attach to the ISS, but can accommodate CRS-2 vehicles.

Our market is in-space industrial manufacturing.

My key challenge is as follows: the financing for the platform is based on our facility being under the Intergovernmental Agency Agreement (IGA) due to the favorable legal and financial certainties involved, as well as our backers believing it removes obstacles for customer IP and relations with space agencies worldwide.

My question is whether this platform, which will, after all, be visited by CRS-2 vehicles, can be included in the IGA program, both today and as I understand it is being updated for this new, commercial environment. This CRS-2 vehicle would have extra capacity, and after unberthing from the ISS, would utilize this rideshare capacity to service our free-flying *Start Station 1*. No NASA crew will be present onboard, nor will any additional national space agencies be present.

May I ask NASA to let me know as soon as possible whether this is doable?

To be clear, I am not seeking NASA or U.S. government funding (except perhaps as a customer!)

Many thanks,

Robert Warbucks

5.5.4.2 Use of NASA Resources

From: Adam Smith <asmith@SSMEnterprises.com>
Sent: Monday, October 29, 2018 9:30 AM
To: [YOU]
Cc:
Subject: Question on availability of ISS Resources from SSME

Dear NASA,

I am writing with some good news. My company, ***Sunny Side of the Moon Enterprises***, has landed a major industrial customer for manufacturing high quality fiber optics. And this exactly fits the bill for our existing Space Act Agreement (SAA) with the NASA Program Office, so we are well underway!

My question today is as follows: Our investors, as we draw up the final version of the business plan, are questioning whether our module, when attached to the ISS, can still draw power and other space station resources from the ISS, even though MegoRacks – our competitor – has their own planned independent manufacturing facility located in the ISS orbit. From our perspective this is a sign of the growing PPP between NASA and the private sector, and our efforts should be encouraged, even though we are direct competitors to MegoRacks.

To be clear, SSME is not baselining power generation into its design, since we would be attached to the ISS and hope to draw full power requirement from that system.

I welcome your response.

Regards,

Adam Smith

5.5.4.3 Allowable Nationalities

From: Conrad Knottlib <conrad@spacelyfe.com>
Sent: Thursday, November 8, 2018 11:13 AM
To: [YOU]
Cc:
Subject: Allowable Nationalities to SpaceLyfe Space Hotel?

Dear NASA,

I have wonderful news. My company, which signed the Space Act Agreement with you two months ago on transporting commercial visitors both to the ISS and to the SpaceLyfe Hotel, now has our first serious customers.

My question is a simple one: How would NASA make the determination to a UAE Customer riding up and down via the Commercial Crew vehicles also transporting NASA and ISSP astronauts to the ISS? As you can imagine, this impacts on our overall market size and hence our investors' valuation of our company's worth. Our customers would go to the ISS, as tourists, stay as required to transit to a departing vehicle, undock, and then head to the hotel; otherwise we are open to a direct route to the hotel, if the mission profile allows. In such a case, the vehicle would go straight to the SpaceLyfe Hotel, drop off the tourists, head to the ISS to pick up returning astronauts, and return to Earth.

We are also curious if this individual's program would be covered under the terms and conditions of the IGA, given that the vehicle is a component of the ISS?

Let me add that we are willing to work with NASA and SpaceX and Boeing to assure that our customers are not professionally trained, only in terms of their own, and the crew's safety.

Look forward to your response.

Regards,

Conrad Knottlib

5.5.5 Questions for Consideration

The section below documents both the instructions that participants at NASA received, as well as the questions that were provided to help guide the response. NASA elected to provide this response in narrative form, and documented the responses to the below questions for consideration therein.

BEGIN SIMULATON QUESTIONNAIRE

STATEMENT

Thank you for taking the time to answer the questions on the above hypothetical scenario email. This is a simulated scenario intended to help NanoRacks better define decision-making processes at NASA, and produce recommendations on the ISS transition process as requested information in the CLINs. NanoRacks hopes that, based on the answers provided, NASA may attain a useful resource for better formulating policy and procedure for interacting with the commercial sector. We are not asking for answers to the scenarios themselves—we are rather asking for answers *to how NASA would go about answering the questions themselves*. In short, this is a new tool for NASA to use at its own discretion.

INSTRUCTIONS

Please work to draft a response to the above email. If applicable please include the office or agency symbols to which you would route such a request in CC (for instance – NASA/HEOMD; NASA/Legal; DoS; FAA) Should further clarifications be required, NanoRacks will facilitate one more round of Questions & Answers. The below Scenario Supplement lists out a series of questions intended to assist NASA in documenting its decision making process, but does not represent a comprehensive list of all possible justifications, concerned actors, or outcomes. Therefore, please treat it as a guide only, with room available for additional responses or documentation.

SUPPLEMENTAL SCENARIO QUESTIONS

Please consider the following statements:

1) Please describe to which degree NASA has received a request like this in the past:
    a. NASA has NEVER encountered such a question or request like this in the past
    b. NASA has encountered a question or request that is somewhat similar to this in the past
    c. NASA has encountered almost exactly this question or request in the past
    d. NASA is likely to encounter a question or request like this in the future
    e. Other – Please explain

With relation to the above hypothetical email, please answer the following questions

2) Based on the drafted email response, if this email was passed forward to offices **WITHIN** NASA, please check the boxes corresponding to the offices **WITHIN** NASA included and write in a justification, at your discretion, as to why each was included:
    a. NASA Commercialization Manager – [FILL IN]
    b. NASA Utilization Office (OZ) – [FILL IN]
    c. NASA Human Exploration and Operations Mission Directorate (HEOMD) – [FILL IN]
    d. NASA Space Council Representative – [FILL IN]
    e. NASA General Counsel – [FILL IN]
    f. NASA International Office – [FILL IN]
    g. NASA Advisory Council (NAC) – [FILL IN]
    h. Other [specify] [FILL IN]

3) Based on the drafted email response, if this email was passed forward to offices **OUTSIDE OF** NASA, please check the boxes corresponding to the offices **OUTSIDE OF** NASA included and write in a justification, at your discretion, as to why each was included:
    a. ISS International Partners [FILL IN]
    b. Other Commercial Users who may have awareness surrounding this issue [FILL IN]
    c. Department of Commerce [FILL IN]
    d. Department of State [FILL IN]
    e. Department of Defense [FILL IN]
    f. Federal Aviation Administration [FILL IN]]
    g. Federal Communications Commission [specify office]
    h. Office of Management and Budget [FILL IN]
    i. Congress and associated Staff [FILL IN]
    j. Space Council [FILL IN]
    k. Industry advisory groups, like Commercial Spaceflight Federation, Aerospace Industry Association, or others [FILL IN]
    l. Other [specify] [FILL IN]

4) If NASA requires further information from the requestor with respect to this specific Scenario, please describe the relative importance of the below possible further additional data points in order of relevance for NASA to make a decision. If these data points to not represent your key decision making considerations, please write in additional items at NASA's discretion.
    a. Are they an ISS partner?
    b. Are the partners a strong ally of the United States?
    c. Are they from a country that can be construed as an adversary
    d. Are they on a restricted list?
    e. If it is a company in one of the boxes above, choosing a customer from another customer (A Russian company is holding an international competition
    f. The customer is technically capable – they have flown in space before
    g. What nation is hosting on the ISS
    h. Other [FILL IN]

5) What are NASA's main concerns, if any, with this specific request (select all that apply)?
    a. There was not enough information provided regarding the full scope of the request [optional elaboration]
    b. The request should not have been directed at my specific office [optional elaboration]
    c. The request clearly has legal, policy, or other ramifications which are not likely to be resolved over an email exchange, or without extensive additional coordination [optional elaboration]

d. The request does not require an immediate decision and should wait until further information is available or a policy is decided on at a different level or from a different office/agency, or otherwise at the national level [optional elaboration]
e. The request should have come through a different means (i.e. phone)
f. Other [specify]

6) On a scale of 1 to 5, What is the degree to which NASA believes the customers' question can be resolved – regardless of what that outcome would be (either a "yes" or a "no" response in request for permission, for instance)? If a question is unlikely to receive a conclusive response, that would be a 1; if the question is likely to reach a conclusion, that would be a 5. [fill in 1-5][explain

7) On a scale of 1 to 5, 5 being the MOST clearly, to what extent can the above question be responded to as based on currently existing policy?

8) Any additional comments? [fill in]

END SIMULATION QUESTIONNAIRE

5.5.6 Responses from NASA

To the Scenarios reproduced above in Section 5.6.6, NASA provided the following responses. The first section of each, clearly marked "NASA EMAIL RESPONSE" represents the email reply to the given executive, with the second section, clearly marked "NASA RESPONSE TO PROCESS QUESTIONS" representing the narrative responses to the questions outlined in Section 5.5.5.

The below highlighted disclaimer reinforces the notion that these are hypothetical responses to a hypothetical scenario, and in no way represent a current official statement of policy by NASA or the U.S. government at large. These responses have not been edited in any way except for the formatting required to fit them into this report.

5.5.6.1 IGA, Investment, CRS-2

THE BELOW IS AN ANSWER PROVIDED BY NASA FOR SIMULATION PURPOSES ONLY. THE ANSWER MAY DIFFER IN REAL SCENARIOS. LAWS AND PROCESSES CHANGE OVER TIME, AND DETAILS AND ACTION/REACTION FOR ANY SCENARIO WILL CAUSE OUTCOME VARIATION.

NASA EMAIL RESPONSE:

To: Robert Warbucks <warbucksr@SSO.com>
Sent: Monday, November 19, 2018
From: NASA

Subject: Question on Free Flying Station and IGA

Robert –

Thank you for your inquiry regarding use of the International Space Station (ISS) Intergovernmental Agreement (IGA) for commercial visiting vehicle missions to your *Star Station 1,* an in-space manufacturing platform in LEO.

The ISS IGA is an agreement between the U.S. Government and other ISS International Partner Governments concerning the ISS and is applicable to the signatories as well as other entities as spelled out in the agreement or contract during the performance of activities related to ISS. The IGA does not currently apply to commercial platforms as described in your correspondence. The IGA applies to visiting vehicles that are rendezvousing with and attaching to the ISS to the extent that it is provided for in their contract with the U.S. government. Details of the IGA and Memorandum Of Understanding with partner agencies can be found here:

IGA - Agreement Between the United States of America and Other Governments Concerning Cooperation on the Civil International Space Station –
https://www.state.gov/documents/organization/107683.pdf

MOUs between NASA and ISS International Partners –
https://www.nasa.gov/mission_pages/station/structure/elements/partners_agreement.html

NASA RESPONSE TO PROCESS QUESTIONS:

Agency Coordination:
For the purposes of this sim, this letter will address some possible agency coordination that could occur in such a scenario.

The ISS Program Office would review and approve the request to ensure appropriate contract conditions are followed with the commercial visiting vehicle provider regarding support to both the governmental (ISS) mission and the *Star Station 1* mission. The NASA Human Exploration and Operations Mission Directorate (HEOMD) would be informed for awareness. Additionally, coordination would be required with our ISS international partners as part of standard integration and flight readiness processes.

Additional coordination may take place with other stakeholders or offices in the U.S. Government, just to ensure awareness or due to required work needed to be performed outside of NASA. Some examples include:

- Space Commerce office in the Department of Commerce
- Federal Aviation Administration
- Federal Communications Commission
- Office of Management and Budget

- Congress
- NASA Advisory Council Policy and Regulatory Committee

5.5.6.2 Use of NASA Resources

THE BELOW IS AN ANSWER PROVIDED BY NASA FOR SIMULATION PURPOSES ONLY. THE ANSWER MAY DIFFER IN REAL SCENARIOS. LAWS AND PROCESSES CHANGE OVER TIME, AND DETAILS AND ACTION/REACTION FOR ANY SCENARIO WILL CAUSE OUTCOME VARIATION.

NASA EMAIL RESPONSE:

From: NASA
Sent: Monday, October 29, 2018 9:30 AM
To: Adam Smith <asmith@SSMEnterprises.com>
Cc:
Subject: Question on availability of ISS Resources from SSME

Dear Mr. Smith,

Thank you for your enquiry about conditions for continuing supply of ISS resources to your attached manufacturing module in a commercial market. As you know, NASA has been fostering the commercialization of low-Earth orbit (LEO) through Space Act Agreement partnerships, and is pleased to see a commercial market beginning to flourish.

Your module has been granted use of ISS resources through an open competition resulting in SSME selection for use of an ISS port. As detailed in our signed Reimbursable Space Act Agreement, SSME will be required to reimburse NASA for specific resources listed therein, in accordance with requirements included in NASA policy and statutory authorities. As the market develops, NASA expects to use all available authority, including Non-Reimbursable or No Funds Exchanged Space Act Agreements and/or contracts, to help enable a developing LEO market, maintain U.S. leadership and allow for fair competition among all interested U.S. parties. To this end, NASA must ensure it is not offering unfairly subsidized resources through its partnerships with SAA holders. NASA will continually assess the health and status of the commercial market during this development phase and will work with industry and our stakeholders regarding the timing and criteria to appropriately transition away from the current government-funded services regime. At the end of this letter, we have listed some of the statutory and policy guidance associated with this scenario.

NASA RESPONSE TO PROCESS QUESTIONS:

Agency Coordination

For the purposes of this sim, this letter will address some possible agency coordination that could occur in such a scenario.

The ISS Program would continue the technical work agreed to in your Space Act Agreement, including the internal work and coordination required across multiple ISS Program offices and branches such as the Research Integration Office (OZ), Vehicle Office (OB), and Mission Operations and Integrations Office (OC). ISS Program management would require continuing detailed assessment of the technical feasibility for providing the requested resources to support your module and operations. NASA's legal team, both at Johnson Space Center and NASA Headquarters would likely perform in-depth legal reviews for commercial operations and further agreements.

NASA Human Exploration and Operations Mission Directorate (HEOMD) was involved regarding this mission prior to signing the SAA, and transition of LEO away from a government regime to commercial enterprises is an on-going process that involves much of the agency at NASA HQ, including the Administrator. The Department of Commerce, Office of Management and Budget, and the National Space Council are involved as well. Congress has been involved, as is noted in the statutory guidance after this letter.

NASA will continue to honor the ISS Intergovernmental Agreement (IGA) and Memorandum of Understandings with the ISS International Partners (IPs). Resources made available to your commercial element will be provided while NASA honors these agreements with our Partners. NASA will also need to consult with the IPs as necessary.

For your reference, we have described below some of the statutory and policy guidance surrounding your question. Please let us know if you have any other questions.

Reference Information follows:

Statutory Guidance

The *NASA Transition Authorization Act of 2017* Title III, Section 301 (a)(4)(A) states, "utilization of the ISS will sustain United States leadership and progress in human space exploration by – facilitating the commercialization and economic development of low-Earth orbit," and Title III Section 303 (b)(1) states, "an orderly transition for United States human space flight activities in low-Earth orbit from the current regime, that relies heavily on NASA sponsorship, to a regime where NASA is one of many customers of a low-Earth orbit commercial human space flight enterprise.…"

Policy, Agency Goal, Agency Strategy Guidance

The National Space Policy of 2010 states that NASA should "Refrain from conducting United States Government space activities that preclude, discourage, or compete with U.S. commercial space activities, unless required by national security or public safety".

Also, *NASA Policy Directive 1050.1, Partnership Guide* states "NASA reimbursable partnerships with non-Federal partners should not be formed when an equivalent service, good, property, or resource is reasonably available in the U.S. private sector, even if at a higher cost to the partner. Determining whether a service or resource is "reasonably available" includes consideration of the uniqueness of NASA technical capability, timeliness of the service/resource, whether a partner would be required to obtain such services from one of its competitors, and other factors, but typically would not take price into consideration. Fundamentally the question to ask is, if NASA performs the service, would NASA be taking work away from a domestic commercial supplier?"

NPD 9080.1: "It is NASA policy not to compete with commercial entities in providing services or goods, property or resources to entities outside the Federal Government."
NASA Advisory Implementing Instruction 1050-1D, Space Act Agreements Guide: "… and to refrain from conducting United States space activities that preclude, discourage, or compete with U.S. commercial space activities, unless required by national security or public safety."

The *International Space Station Transition Report* was published pursuant to Section 303(c)(2) of the NASA Transition Authorization Act of 2017 (P.L. 115-10). The report includes several key ISS transition principles that "enable NASA and the Nation's long-term interest in LEO and human spaceflight exploration including supporting National security objectives, such as a competitive industrial base and U.S. leadership." Among them are these related principles: "Increase platform options in LEO to enable more ISS transition pathways, security through redundant capabilities, and industrial capability that can support NASA's deep space exploration needs;" and "Spur vibrant commercial activity in LEO;."

5.5.6.3 Allowable Nationalities

THE BELOW IS AN ANSWER PROVIDED BY NASA FOR SIMULATION PURPOSES ONLY. THE ANSWER MAY DIFFER IN REAL SCENARIOS. LAWS AND PROCESSES CHANGE OVER TIME, AND DETAILS AND ACTION/REACTION FOR ANY SCENARIO WILL CAUSE OUTCOME VARIATION.

NASA EMAIL RESPONSE:

To: Conrad Knottlib <conrad@spacelyfe.com>
Sent: Monday, November 19, 2018
From: NASA
Subject: Allowable Nationalities to SpaceLyfe Space Hotel?

Conrad –

Thank you for your inquiry about UAE tourists traveling to ISS and your Space Hotel. We have described some of the forward work and answers below.

Export Control Process:

Commercial visiting vehicle and ISS data are subject to export control regulations, and NASA as well as the commercial entities involved must comply with all U.S. export control laws and regulations, including the International Traffic in Arms Regulations (ITAR), 22 CFR Parts 120 through 130, and the Export Administration Regulations (EAR), 15 CFR Parts 730 through 799. The entity making each individual export is responsible for ensuring compliance.

The United Arab Emirates is currently a category IV designated country. Category IV indicates a Missile Technology Concern (*15 CFR Supplement 1 to Part 740, Country Group D, Column D:4*, of the Export Administration Regulations, administered by the Bureau of Industry and Security, Department of Commerce).
As you know, the Space Act Agreement we have signed with you includes standard language like the following:

ARTICLE 28 ACTIVITIES WITH NASA DESIGNATED COUNTRIES AND NON-ISS PARTNERS

A. The Partner shall notify NASA prior to engaging with a NASA designated Country (or entity or person therein) listed on NASA's Designated Countries List. If the Partner continues to pursue activities with the NASA Designated Country, the Partner shall continue consultations with NASA. Consultations will ensure NASA identifies to the Partner any concerns it might have with the contemplated engagement at the earliest possible moment and also ensure full compliance with all relevant policies, regulations and laws. The Partner is required to follow the most current list of NASA's Designated Countries, which can be found at the NASA Export Control website at https://oiir.hq.nasa.gov/nasaecp/.

B. NASA retains the right to approve the implementation of any Partner agreement with users or customers from a non-ISS Partner nation in furtherance of this Agreement. It is recommended that the Partner provide advance notification to NASA of its plans to conclude any such an agreement so that NASA can initiate appropriate actions to ensure compliance with U.S. laws/regulations, as well as, all NASA and ISS multilateral procedures, including the non-Partner Participant process. Partner understands that if they choose to sign an agreement prior to receiving approval from NASA, they take the risk that NASA may not approve implementation of the agreement.

We will work to determine whether NASA approval can be granted where NASA has authority for such activities. Additionally, both the commercial crew transportation company and your hotel company, independent of NASA, will each have to determine whether or not they need to submit the required Technical Assistance Agreement (TAA) and/or export licensing paperwork for approval by the Department of State and the Department of Commerce. Approval by export control authorities in these Departments to allow foreign nationals access to export controlled information is a process that can take several months. For ISS visitation, NASA also must acquire an Export License for a category IV designated country if your UAE customer engages in activities beyond the "passenger experience" defined below.

A thorough description of the expected activities for this individual, as well as the individual's specific background, must be documented in the TAA and License. Generally, if the individual is considered a 'passenger,' the following human spaceflight activities are not subject to ITAR or EAR:

- Training on spacecraft access, ingress, and egress, including the operation of all spacecraft doors, hatches, and airlocks;
- Physiological training (e.g., human-rated centrifuge training or parabolic flights, pressure suit or spacesuit training/operation);
- Medical evaluation or assessment of the spaceflight passenger or participant;
- Training for and operation by the passenger or participant of health and safety related hardware or emergency procedures;
- Viewing of the interior and exterior of the spacecraft or terrestrial mock-ups;
- Observing spacecraft operations (e.g., pre-flight checks, landing, in-flight status);
- Training in spacecraft or terrestrial mock-ups for connecting to or operating passenger or participant equipment used for purposes other than operating the spacecraft; or
- Training on donning, wearing or utilizing the passenger's or participant's flight suit, pressure suit or spacesuit, and personal equipment.

Other scenarios and details will have to be carefully considered by all of the applicable NASA and government agencies/departments before approval.

NASA RESPONSE TO PROCESS QUESTIONS:

Agency Coordination:
For the purposes of this sim, this letter will address some possible agency coordination that could occur in such a scenario.

NASA must approve this request, as is discussed in your signed Space Act Agreement. We will need to set into motion NASA internal and other government agency coordination with some of the required organizations related to this request.

The ISS Program will continue the mission-specific technical feasibility work discussed in the Space Act Agreement, coordinating internally among the multiple required offices. The ISS Program is performing an assessment of the technical feasibility of the flight planning (i.e. vehicle traffic) and for accommodating the UAE astronaut temporarily on ISS (e.g. impacts to prop, power, and life support systems capability, consumables and spares, etc.), some of which was performed before agreeing to the SAA. ISS export control experts will discuss the matter with JSC export control, eventually leading to a discussion with NASA HQ export control and other government Departments as appropriate. The NASA Commercial Crew Program Office has also been involved with review and approval of the mission planning and use of USCV resources associated with such a commercial mission, as you are aware since they were involved in the drafting of the SAA. The scenario described in your letter does not address how each crew would always retain a return vehicle capability. The safety risk of having crew separated from their return vehicle is unacceptable to NASA. No guidance has been provided by the government on requirements for private crewed missions but similar to lifeboats on cruise ships, we would expect a requirement for a return capability to be present at all times.

At JSC, the Legal Office and the ISS Export Control Representative (ECR) would be contacted regarding the now-known nationality of the visitor. The JSC Center Export Administrator (CEA) and possibly the agency Export Administrator at HQ will also be involved in the export of ISS technology data (if the UAE astronaut is allowed onboard ISS). The ISS is classified under Category 9 (Aerospace & Propulsion) of the Commerce Control List (CCL) and an export of ISS technology data would likely be classified under EAR99, as would the "use" of ISS data, which does not require a license. The Office of International and Interagency Relations (OIIR) will approve logical and physical access for any users/visitors from a designated country. Additional agreements will likely be required setting forth the rights and obligations of the tourists and Spacelyfe for such activities. However, the JSC CEA is not the main point of contact on the export of the U.S. Crew transportation vehicle data/spacecraft/parts since in this scenario NASA is not making the export. For transportation and for the Space Hotel, it would be the responsibility of SpaceLyfe (or the provider of the transportation vehicle) to make the correct export classification determination, and to seek the required authorizations (e.g., Technical Assistance Agreement).

The NASA Human Exploration and Operations Mission Directorate (HEOMD) was involved regarding this mission prior to signing the SAA, and the nationality of the selected commercial astronaut will likely be discussed within HEOMD and discussed at the highest levels of the Agency at HQ. This likely includes the Administrator, Office of General Counsel (who will discuss it with JSC Legal), Office of International and Interagency Relations, and the Export Administrator.

The ISS International Partners (IPs) would be informed of the request. In accordance with the terms of the IGA, NASA would sponsor the UAE astronaut to the multilateral boards (e.g., Space Medicine) and panels (e.g., Crew Operations) to obtain IP concurrence. The IPs would be responsible for authorizing access to their module(s) if access is desired. If a U.S. commercial module(s) is presently attached to ISS, NASA would inform the commercial module owner/operator of those module(s) that a UAE astronaut would be visiting ISS. The commercial module owner/operator would be responsible for authorizing access to their module(s) and for seeking any required export approval.

It will be the responsibility of SpaceLyfe to seek the appropriate approvals, licenses or waivers from U.S. Government agencies outside of NASA.

Intergovernmental Agreement:
Refer to scenario 1 response.

5.5.7 NanoRacks Analysis

NanoRacks submits the following observations and further questions to the material responses offered by NASA above. NanoRacks would again like to thank NASA for their collaboration and transparency in conducting this exercise.

5.5.7.1 IGA, Investment, CRS-2

Topline Conclusions:

- **NASA *potentially* involves multiple agencies and committees given the novelty of the approach, including possible consultations with the NASA Advisory Council and Regulatory Committee;**
- **NASA in this exercise does not close the door on the request, though the IGA may not be the route to approach liability from, stating that alternative solutions to IGA could be explored;**
- **NASA makes a distinction between the IGA as it is written today and the possibility of evolution of the agreement based on cooperation among the U.S. government, the International Partners, and commercial entities;**
- **Coordination with International Partners is woven throughout;**
- **NanoRacks has not observed a formal or baseline process within or across U.S. government agencies described, but possible points of consultation are left open.**

NanoRacks observes the positive development that NASA recognizes that the coverage afforded by the IGA could potentially benefit future operational areas. Even if not provided in the direct response to the executive, NASA potentially interfacing with the Commerce Department is an extremely important note, no matter the status of the Office of Space Commerce and extent of such consultation. Commerce could provide critical insights into the myriad commercial factors affecting any company, whether in space or aviation or transportation in general. This is especially true within the scope of this simulation, which crosses multiple boundaries for the company involved, from insurance to capital raising to international relations. The inclusion of the just-appointed NAC subcommittee focused on commercial activity should also be noted, as it involves numerous industry representatives working in a consultative manner, which could be useful for NASA considerations. The inclusion of the National Space Council also should be noted as an important inclusion to the widening consultative circle. This inclusion represents a positive step in trust-building between the commercial sector and NASA, and NanoRacks recommends expanded engagement with this advisory body.

Also observed is the breakdown of the request for inclusion into the IGA umbrella into the NASA-funded vehicle and the commercial free-flyer. This question of a hybrid mission is indeed interesting from a policy perspective. NanoRacks could have made the scenario even more difficult by suggesting that the sole customer for this mission be a non-U.S. national space agency—in which case the State Department may well have been consulted by NASA for further advice, but this possibility is not mentioned by NASA. NanoRacks observes that little information is provided as to how as any additional groups—industry or otherwise—would be consulted or notified, so the question is left open as to at whose discretion such consultation would occur, or if it would occur at all. NanoRacks urges that great care should be taken in the process whereby the needs of the commercial sector are accounted for, as this process would greatly affect trust-building between NASA and the commercial sector.

NanoRacks also observes that NASA retains approval authority for the request within the ISS Program Office, but contextualizes this authority with preassigned contractual obligations, adding much clarity to the decision-making channels in question. It is encouraging that NASA does not seek here to pass judgment on the merits of the request, rather working through key decision makers are searching along two pathways: current regulation and possible future developments if warranted, though this discussion is not explicitly mentioned to the executive. Current regulation suggests that the IGA cannot be expanded to include Star Station-1; unclear however is its status with respect to the visiting vehicle, and several pathways are possible that might change the result for the company, such as legislative action. NanoRacks would appreciate an opportunity for further consultation with NASA to explore how different legislative outcomes could affect decision making here, as this question is largely hypothetical at this stage, and difficult to answer as a result.

Similar discussions were undertaken in the early days of NanoRacks and the operation of its first payloads. Operating under a Space Act Agreement, the key question was whether or not the Company payloads would fall under the IGA—then, as today, an extremely important point in terms of legal protection. It was determined that the commercial payloads of NanoRacks (and all who followed) would fall under the IGA, as the commercial payloads came under the NASA umbrella. This proved immensely helpful in enabling commercial activity; otherwise, seeking alternative manners of covering liability as provided under the IGA may have proven too burdensome a requirement. It may well be possible to follow the same route for a free-flyer, where NASA takes a core purchase at a limited dollar value and in return receives certain guaranteed services, and in so doing the platform falls under the presently written IGA. NanoRacks believes that, per NASA's open question concluding the exercise, such a policy and contractual solution could prove an elegant solution to the current question at hand.

NanoRacks does note, however, that the response to the executive did not seem to leave the possibility of further discussion toward this end open, positively identifying and justifying rationale for the current decision open. On a specific level, no answer is given to the executive. However, far clearer is both the widening circle of agencies and groups involved in this new era of commercial space and the desire by NASA to stimulate robust discussion.

5.5.7.2 Use of NASA Resources

Topline Conclusions

- **NASA focuses in this situation on the very specific question of the nature of the Space Act Agreement and its relationship with its commercial partner;**
- **NASA includes a very good array of supporting documents, all of which encourage and support diversity in customers and commercial orbiting platforms in low-earth orbit;**
- **NASA recognizes part of the solution to the company's question involves expertise outside of the space agency;**
- **NanoRacks notes that NASA does not address the challenging question of just how to assure the playing field is level between ISS customers and owners/operators of private free-flyers;**
- **NanoRacks has not observed a formal or baseline process within or across U.S. government agencies described, but possible points of consultation are left open.**

The question of how much NASA supports competition and an ecosystem of LEO services via free-flyers is a critical issue. From the perspective of this report, as options are evaluated for encouraging a commercial ecosystem, rather than a series of one on one commercial relationships, several issues do arise from this answer.

First, NASA recognizes that there is a chance that the costs of use of the ISS resources may present an unleveled playing field and mentions other agencies, such as OMB and Commerce. The letter states: *NASA must ensure it is not offering unfairly subsidized resources through its partnerships with SAA holders*. Left open, however, is the question of what are the proper price points, without clarity on how NASA might achieve this. In this case, further clarity might be required on how NASA can be sure that SSME is not at a competitive advantage to MegoRacks because of the use of government facilities. This letter no doubt satisfies SSME, but how would MegoRacks respond if it read this note? Or MegoRacks investors? Further investigation and engagement would be required to reach a conclusion on this element.

Second, NanoRacks notes the appearance of Reimbursable Space Act Agreements, as well as No-Funds Exchanged Space Acts. A significant question arises as to which resources exactly would be paid for, but the exact details of that agreement are not made clear in this simulation. An assumption may be made regarding potential operational upkeep costs like power and data, but this cannot be confirmed without also having a hypothetical Reimbursable SAA to compare it against. In either case, the ultimate arbiters of SAA policy are not necessarily made clear in NASA's response to the Process Questions, especially in relation to *Policy Directive 1050.1-Parntership Guide.* In part, this means that while the answer does provide a "reason tree" for showing policies and actors to be consulted, it does not fully convey the point-of-decision at which reimbursement would be determined other than referencing the original agreement. In the absence of a hypothetical agreement, it is difficult to draw conclusions about how these reimbursements were organized in the first place.

The question of which body determines the types of allowable SAAs is left largely open. Who, for instance, does NASA consult (either internally or externally) to determine what elements of collaboration or reimbursement—or indeed the means of reimbursement—are possible? Again, this is a difficult question to resolve without another round within the simulation built on knowledge of what the SAA between the Company and NASA contained. NanoRacks assumes that, in part, such determinations would be made by NASA Legal, but then another actor or group of actors would need to determine that implementation of such a partnership would be consistent across all commercial players. NanoRacks observes that in such a case, what is allowable under the SAAs may not end up being a stable policy, in which case it potentially could become difficult for businesses to build plans on assumptions contained therein, as they may perceive that competitors could get a better deal.

Within the scope of the above, the degree of coordination required with the International Partners to this end is also noteworthy. Their inclusion in determining continued use of NASA resources would be an interesting point for further study.

Third, further clarity may be required on how the commercial relationship with SSME correlates with the policy quoted by NASA in this letter, to *Increase platform options in LEO to enable more ISS transition pathways, security through redundant capabilities, and industrial capability that can support NASA's deep space exploration needs*. How determinations are made regarding the support of commercial capabilities remains an open question, and NASA also seems to leave open the issue of potentially providing no support to the competing free-flyer platform. While NanoRacks does not expect NASA to discuss these matters openly with the company, more thought may be warranted on what can be done to make sure subsidization of costs is not occurring at a level that actively harms the ability of the company's competitor to close a business case. In any case, NASA notes that it will, *"continually assess the health and status of the commercial market during this development phase and will work with industry and our stakeholders regarding the timing and criteria to appropriately transition away from the current government-funded services regime"* but the exact structure of this assessment is not clearly laid out.

As in the previous example, NASA is to be complimented for reaching out to other agencies and other sources of U.S. government expertise, as well as its broad and clear reference to existing policy background for strategic, policy, and agency guidance. The entire question of how to both simultaneously encourage free-flyer private platforms and increase ISS utilization is one of the most challenging questions raised in this report.

5.5.7.3 Allowable Nationalities

Topline Conclusions

- **NanoRacks notes that NASA recognizes other agencies within the U.S. government are involved in questions such as space tourism and commercial space policy, and the**

policy and appropriate authority references regarding export control is extensive and comprehensive;

- **NanoRacks observes that NASA seeks to support the company in executing its space tourist mission, but does point out that there are many challenging hurdles, but takes the time to describe the carve outs and that the door is open. That is encouraging;**
- **It is recognized that the citizenship of the tourist has an impact in terms of U.S. government policy. This is a data point that suggests close coordination between the space tourism companies and NASA and the U.S. government is warranted;**
- **It is unclear is how different the mission profile of a free-flyer is from the ISS itself, and questions regarding the applicability of the IGA when the visiting vehicle is docked are referred back to answers given in Scenario 1, which clearly states that the IGA does not apply in its current form to free flying platforms;**
- **NASA makes clear its concern for certain issues of safety, such as ensuring that all astronauts on commercial stations have access to a return vehicle;**
- **NanoRacks has not observed a formal or baseline process within or across U.S. government agencies described, but possible points of consultation are left open.**

Outlined in NASA's answer are the challenges as well as the areas for which the citizenship is given an exception from ITAR and other regulations. For the Company president, what might be discouraging, and what is not said, is that his competition is in the form of an ISS partner space agency: RosCosmos. This competitor has already agreed to fly a paying UAE astronaut to the ISS. This answer dwells solely on the policy regulations for an ISS visitor—but left out is the realization that an UAE citizen has already signed a contract, as of this writing, to live on board the ISS for a short duration, never mind on a free-flyer. The Company would certainly consider this an important point. One, perhaps, they should have mentioned in their letter and have NASA indicate whether they take into account the commercial nature of the marketplace today. What if the UAE citizen rode up on a Soyuz to an American-flagged free-flyer? Who would have to sponsor, RosCosmos or NASA? And given that this answer, like the previous, believes the free-flyer is not under the IGA, how is that of concern? Such questions, and their associated policy pathways through the NASA and U.S. government bureaucracy, would be critical to understand in forward work.

NanoRacks also observes that NASA discusses the potential of consultation across government agencies, with reference to seeking appropriate licenses, approvals, and waivers, as being herein reduced to the responsibility of the commercial user. NASA does, however, imply that ensuring a free-flying station to which a Commercial Crew vehicle would potentially fly (and subsequently depart from on its way to the ISS) must also have access to an existing crew return vehicle. In further study, this point should be further investigated, in particular regarding if this policy would hold if non-US crew were involved. It would be interesting to explore if NASA or another U.S. government entity, for instance, would be responsible for making these determinations in such cases, or if they would be made exclusively through consultations with international partners. This implication, however, is not marked as a statement of policy, as NASA clearly states that *"no guidance has been provided by the government on requirements for private crewed missions but* *similar to lifeboats on cruise ships, we would expect a requirement for a return capability to be present at all times."*

The policy environment surrounding the status of the UAE itself as a category IV designated country is clearly laid out, and NASA's remark that they will work to determine whether NASA has authority for approval of such activities in the first place. This runs in parallel with the statements regarding the determinations of overall safety environment of the Station, as while NASA can make clear policy determinations and the routes of consultation are well laid out for export control requirements, there exist no guidelines for granting approval, for instance by submitting the Technical Assistance Agreement and/or export licensing paperwork for approval by the Departments of State and Commerce.

Regarding conclusions surrounding the IGA, NASA notes a reference toward the first policy simulation in which the IGA cannot be expanded. The question of whether, and at which points, the hotel would be covered under IGA (for example, while docked to a commercial crew visiting vehicle) remains open. Additionally, potential coverage as a U.S. item under the International Space Treaty is unmentioned.

The Company's question of whether the nationality of their tourist impacts on the visit to their privately owned platform seems to be met with a response that the important consideration is the vehicle. Nonetheless, again the transparency of NASA's answer is encouraging, it allows the Company to think through the answers as is being done here and to consider other pathways that might make more sense to the company commercially. The importance of this sort of detail cannot be overstated.

6 OUTCOMES FOR COMMERCIALIZATION: Conclusions and Recommendations

To document the conclusions gathered from research conducted under this study, and based on interviews with both internal staff, commercial partners, and financial advisory groups, NanoRacks has drafted the below list to document the primary recommendations for energizing the commercialization of low Earth orbit.

Summary List

To document the conclusions gathered from research conducted under this study, and based on interviews with both internal staff, commercial partners, and financial and risk advisory groups, NanoRacks has drafted the below list to document the primary recommendations for energizing the commercialization of low Earth orbit.

6.1 General Conclusions

- **On government competition:**
  - NASA should proclaim the ISS is the final government owned and operated space station in LEO;
  - Commercial providers of ISS hardware, who have invested their funds into that hardware—when that hardware is not required for NASA use—must have free and unfettered access to perform commercial activities on it;
  - NASA must not create competition and redundancies that do not have corresponding demand, such as the funding or granting of permission for myriad similar hardware by differing companies aboard the ISS without regard to the customer base;
  - To secure the future of American leadership in the LEO marketplace, Node 2 should either be made available for multiple commercial companies to dock to, or otherwise both free-flying and attached ISS nodes should be considered;
  - As the commercial sector shows capabilities on free-flyer platforms, NASA should not allow on board the ISS the same services for free-flyers in the station orbit.

- **On Upmass, CRS, and Commercial Crew:**
  - NASA should not change policy as of 2018 on upmass or station resources;
  - CRS-2 contracts should be continued, with adding new destinations as appropriate;
  - Commercial Crew vehicles should visit multiple destinations within the ISS orbit to prompt and encourage the development of a demand and infrastructure to support future commercial human spaceflight, and excess seats should be sold off to the commercial sector.

- **On ISS Processes and Resources:**

- Simplify safety and verification requirements to allow more activities aboard ISS, within reasonable limits. Current practices aboard the ISS hold CubeSats to the same standard as larger complex vehicles doing proximity operations. This process must be simplified; barring major concerns like flammable material, CubeSats do not pose equivalent risks to the ISS. Expanding these verification requirements would strangle LEO commercialization in its infancy. And, in general, major and proven users of the ISS should be allowed greater control and management of their own safety verification system, much like ISS partner agencies today.
- The ISS, and all partially government-operated space platforms wishing to attract commercial investment and support commercial activity, must adopt a predictable and repeatable policy process necessary to allow businesses to create plans that can attract investment. At the same time, such policy processes must evolve adequately to account for changing commercial realities, and must do so only after consultation with the private sector.

- **On international partners, both ISS and otherwise, and IGA:**
  - Expand the IGA to potentially include both commercial and international partners—indeed all national space station owners and operators—at their discretion and their choice, with the understanding that certain platforms may not be candidates to join the Agreement. Commercial partners would benefit from the lowering of resultant insurance rates. The U.S. would benefit from international partners, like China, abiding by the IP restrictions in the IGA, but also potentially being beholden to future international agreements that get transmitted through the template of the IGA;
  - Enforce anti-dumping measures on international partners overtly subsidizing lowered prices for services on board the ISS or in similar orbits, as allowing such practices to continue heavily dis-incentivizes investment in the commercial LEO sector;
  - Engage and collaborate with China generally on commercial rules of the road for space utilization—once their station is operational, U.S. international partners may seek to utilize it due to lower, or heavily subsidized pricing. One way to avoid this uneven playing field is by direct engagement and commercial collaboration;
  - Invest via procuring commercial services via free-flying space station modules both in the ISS and other LEO orbits, and route potential partner collaboration through those if the ISS can no longer sustain such partnerships or if partners seek to pull out;
  - Gain agreement with international partners on 1 or 2 orbits that will be the government sector focus for crewed activity. This will give industry a guide on how to channel their eco-systems to support such crewed activity and likely to place more commercially oriented habitats. Creating "destination" orbits may allow more efficient use of infrastructure resources including launch vehicles, return vehicles and in-space tugs. Such orbits may include the existing 51.6 orbit and a polar orbit or otherwise a lower inclination orbit. If balanced correctly against orbital

crowding, having multiple crewed destinations at the same orbital inclination would increase safety margins.
  - Protect intellectual property aboard the ISS—NASA must not allow customers' IP to be shared with non-US partners;

- **On export control:**
  - Free-flying platforms, in LEO or otherwise, should be subject to the same export control provisions and exceptions that apply to the ISS, at the very least, but such provisions should be expanded to further enable international collaboration within the scope of a well maintained global intellectual property regime.
  - Unless an increase of resources is granted to the Department of State to enforce associated regulations efficiently, ITAR, like EAR, should be overseen by the Commerce Department.

- **On contracts, government versus commercial revenue streams, and government investment:**
  - The government should move toward firm-fixed priced (FFP) contracting, because such contracting structures set clear expectations and allow service providers to standardize processes between customers;
  - Government investment in infrastructure like the ISS, which should be considered critical to enabling continued commercialization, should not be reduced. The commercial sector cannot yet sustain operations without both government demand and infrastructure investment. This investment should follow an "airport" model where the public and private sectors work together to deliver services and capabilities they are uniquely suited to provide;
  - The government must step in early to invest in infrastructure that the nascent private sector is incapable of investing in, and correctly signal the markets that, aside from the taxation of resulting revenue, assistance in the maintenance of that infrastructure, and basic regulatory functions, government policy shall remain consistent;
  - The government should consider LEO infrastructure a public-private partnership, with benefits accruing to the government, the private sector, and taxpayers.

6.2 Conclusions Specific to Financial Model

- **Base Conclusion:**
  - Within reasonable ranges of investment and revenue, Outpost and similar platforms are financially viable.

- **Specifically, On Outpost Financing – Based on cost allowances that the model needs to assume to attain required returns for financing. Findings are NOT reflective of estimated investment costs for actual Outpost Station:**

- Under base case assumptions for crewed, free flying stations, the IRR hurdle rate (i.e. 20% to 30%) is met under a non-recurring investment (i.e. upfront DDT&E) range of $250M-$350M and a recurring investment per station of $150M-$400M. Also under base case assumptions, an Outpost station operator could make a profit with investment requirements of up to $1.1 billion in non-recurring and up to $650 million in recurring investment (i.e. per station).
  - If the U.S. government can help provide more certainty, then the required IRR hurdle rate will go down, and the allowable range of recurring and non-recurring costs can be allowed to increase.
- Under base case assumptions, payback period (approximately 3 years) and 5- and 10-year IRR's are in line with private equity investors (and to a slightly lesser extent VCs)

- **On Launch Costs:**
  - Returns are highly sensitive to launch costs (see sensitivity analysis). Marginal pricing approach to crew launch significantly improves a private space station's ability to achieve targeted financial return metrics, and thus encourage investment from private sector financing sources.

- **On Business Cases:**
  - No single-product-line business case closes, with "additive manufacturing" category coming the closest with the largest gross profit contribution of $1.7 billion over 10 years. Servicing multiple business lines and customers is thus critical to a successful privatization.
    - There exists a trade space between customized environments for various product lines, versus multiple platforms, versus the non-recurring and recurring costs for those platforms.
    - Operators of commercial space stations would benefit from identifying synergistic activities that could both expand the overall commercial capabilities of an individual station, without interference between required activities.
    - Predicating the future of commercialization on a single human rated module does not lead to sustainability. It may be positive to have some autonomously controlled modules to build up the ecosystem and therefore interest from venture infrastructure and private equity sources.
    - Designing an architecture that, from the start, assumes multiple platforms, can allow amortizing non-recurring costs across multiple platforms.

6.3 Conclusions Specific to Liability and Risk

- **On Third Party Liability Insurance:**
  - Insurance for commercial space outposts in orbit offers a huge opportunity. Although markets are available, there has never been an insurance placement for these types of risks in orbit. The slow development of legal and regulatory policies does not allow for quick solutions. Business models, monetization strategies,

technologies, and tools to implement commercial space outpost insurance have to be created.

- There are only a handful of underwriters knowledgeable about in-orbit liability risks. Involving insurers as early as possible about new programs and educating them throughout the process is crucial to their support. These efforts will help develop a core group of insurers and will hopefully result in better terms being offered when the formal placement negotiations are initiated.
- Government assistance may be needed at the outset to reduce some of the liability hazards and offset limited availability of capacity. Eventually as the industry grows successfully the hazards will lessen and risks become more attractive to underwriters.

- **On development of third party liability regimes:**
  - This report has reviewed the various launch liability regimes internationally, which all pertain to the launch phase only of a commercial space outpost. A liability regime for the subsequent phases would have to be developed. This regime would use contractual provisions and risk management tools to manage the risks, such as Maximum Probable Loss (MPL) amounts, Third Party Liability insurance up to the MPL, Indemnification and Reciprocal Interparty Waivers, and Government Indemnification Excess of Insurance.
    - Possible structures for Third Parties include:
      - First dollar Governmental Indemnification of third-parties.
      - Liability insurance followed by full Governmental Indemnification of third-parties. (Two Tier)
      - Liability insurance followed by limited Governmental Indemnification of third-parties. (Three Tier)

- **On Contractual Provisions Regarding Space Risks (Third Party Liability):**
  - Various agreements are used to allocate risk in space between contracting Parties:
    - <u>First and Second Parties</u>: Reciprocal Interparty Waivers of Risk where each party bears risk of loss to its property and injury to its personnel. No risk of loss liability to other party.
    - <u>Overall Limitation of Liability</u>: Liability for breach of contract may be limited to the size of the contract or could be sized at different phases of contract. Liability for related companies could be explicitly disclaimed.
    - <u>Performance Warranties and Incentives:</u> Shared or no risk for mission failure.
  - The final outpost configuration and combination of partners will influence the inter-party contractual arrangements. These could include:
    - <u>Docked to the ISS</u>: All the ISS Partners rely on Intergovernmental Agreements (IGAs) and Interparty Waivers to allocate liability arising out of activities on the station. NanoRacks currently has a lab on the ISS. NASA requires Interparty Waivers for all subcontractors to the ISS.
    - <u>Space Habitat (a combination of Outpost modules connected in orbit):</u> A space habitat including a number of nations and related parties would initiate the need for a new framework to allocate liability while promoting

commercial space and protecting the various nation states' people and property.

- **On Insurance Process Management (First Party Insurance):**
    - Early engagement in risk management practices and the insurance industry is essential to help reduce the overall program risk and to ensure the best insurance placement results. For such an innovative program as Outpost, early insurer engagement also will assist in obtaining feedback from the market regarding the insurance possibilities for this type of risk and will help guide the final risk solution. Other specific examples of early engagement include:
        - Reviews of vendor and financing contracts from a risk/insurance perspective prior to signature, which can greatly assist and simplify future insurance buying needs.
        - Implementing a structured program of engaging insurers in all applicable markets as early partners in the program and educating them throughout the process. This will also help develop a core group of supporting insurers that hopefully will result in better terms being offered when the formal placement negotiations are initiated.
        - Creating an insurance strategy early in the process to ensure all aspects of the risk profile are correctly 'marketed' to the insurers in the most effective manner.

- **On Insurance Structures (First Party Insurance)**
    - The final financing and contractual arrangements will define which parties are required to consider and possibly purchase the various types of insurance policies presented within the report. In addition to the required insurances, NanoRacks and other parties with financial exposures to a launch delay or an Outpost Launch / in orbit failure should also consider insurance to cover additional business expenses or lost revenues triggered by a physical loss, or damage to the Outpost or launch vehicle, subject to availability of insurance capacity.

- **Insurance Financial Model (First Party Insurance)**
    - Future premium rates are estimated and budgeting recommendations presented in the Financial Insurance Model. However, premium rating is difficult to predict accurately for budgeting purposes at this stage of the program. This is mainly due to the volatile nature of the space insurance market, but also the uncertainties of the future risk profile and insurance coverage requirements. Premium payment terms for space insurance are generally relatively benign from a cash flow perspective, since the majority of the overall premium spend for Pre-transit, transit, pre-launch and launch plus 1 year in orbit insurance is due close to launch.
    - The capacity of today's insurance market to cover a multiple platform ecosystem must be investigated further.

7 ATTACHMENTS

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7.2 Partner Proprietary Data

PARTNER DATA NOT AVAILABLE FOR RELEASE

7.3 Supplemental Partner Content

PARTNER DATA NOT AVAILABLE FOR RELEASE