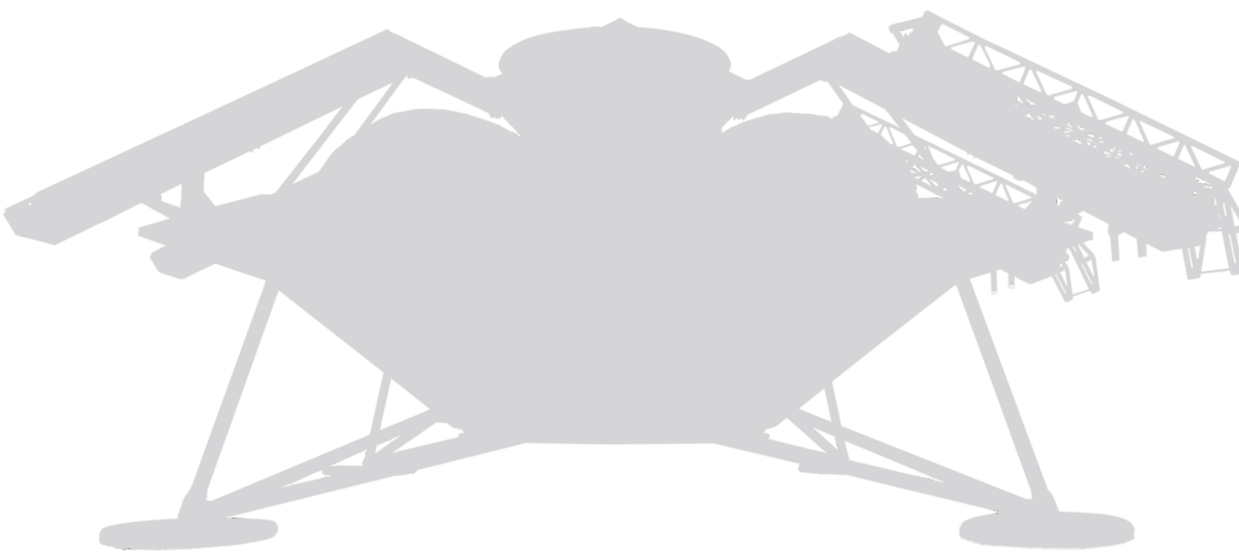
MOON PROSPECT

DEMAND FOR COMMERCIAL LUNAR SERVICES

JULY 2013



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Executive Summary

With a focus on cost reduction the emergence of commercial launch providers is dramatically increasing access to space, enabling new markets like lunar transportation. SpaceX, for example, has already lowered the cost of mass to orbit by a factor of 10 and is projecting another 40 to 60 percent reduction. Additionally, the $30 million Google Lunar X Prize has initiated competition to reach the lunar surface by 2015, and like many competitions before, is spurring the creation of an entirely new industry, this time for lunar services. Of the 23 companies competing there are two established front runners: Astrobotic and Moon Express. Each of these companies are in the competition for more than just the prize money. With long-term aspirations, both companies are looking to capitalize on 40+ years of pent up demand for lunar science and services. Additionally, at least two government agencies in addition to NASA are developing lunar landers with aspirations of reaching the lunar surface. A market for lunar services is already emerging and while some companies are focused on developing longer-term plans to return humans to the lunar surface, there are also many companies with nearer-term needs for lunar services.

This study estimates the current and forecasted demand for lunar services through 2020. The goal of this study is to provide information to Astrobotic decision makers on the emerging market for lunar activity by analyzing customers, market size, trends, and areas of uncertainty in eight distinct potential markets. This study was conducted without pay by Chad Anderson.

Enabling Technology

There are eight lunar landers that are currently in active planning, development, or operation by six different companies or government space agencies. The payload capacity of these landers ranges from tens of kilograms to hundreds, with the largest proposed lander capacity at 500 kilograms.

Company / Institution	Technology	Mass (kg)	Payload Capacity (kg)	Price	Purpose	Announced Operational Date
Astrobotic	Griffin Lander	525	270	$1.2m / kg	Commercial	Q4 2015
	Polaris Rover	150	120	$2.0m / kg	Commercial	Q4 2015
	Red Rover	100	30	$2.0m / kg	Commercial	Q4 2015
China	Chang'e 3 Lander	1,200	?	?	Tech Demo, Science	Late 2013
	Chang'e 3 Rover	120	20	?		Late 2013
ESA / Astrium	Lunar Lander	2,000	?	?	Tech Demo	2018
Moon Express	Common Spacecraft Bus	130	50	$3.0m / kg	Commercial	Early 2015
NASA	Mighty Eagle Lander	320	n/a	n/a	Tech Demo	?
	Morpheus Lander	1,000	500	n/a	Tech Demo	?
Penn State	Lunar Lion Lander/Rover	?	?	?	Tech Demo	?
Russia	Luna 25	?	?	?	Tech Demo	2015
SpaceIL	Sparrow Nano-ship	?	?	?	Tech Demo	?

TABLE 1: LUNAR LANDER STATUS DETAILS

Lunar Payload Markets

This study analyzes the demand for lunar services in eight markets, which were identified and grouped by similarity of applications, purpose, activities, and customers. Figure 1 summarizes and defines those markets.

FIGURE 1. LUNAR MARKET DEFINITIONS

This study has identified six different services that Astrobotic can offer to capitalize on the market demand for lunar services (see Table 2: Overview of Services Demanded by Market). Lunar orbit is notoriously unstable, which leads to a relatively short life for lunar satellites. Therefore, demand for Satellite Deployment includes delivery to lunar orbit for shorter-term projects (the NASA Lunar Reconnaissance Orbiter (LRO) has an extended mission of up to five years), as well as delivery to lunar Lagrange points. Stationary/Mobile LunarCubes denotes a cubesat type of payload affixed to the lander or rover. This is different from "Surface Delivery" which represents more customized payloads, such as customers' proprietary robots or other hardware to support personally directed missions on the surface. The Advertising service includes demand for the purchase of naming rights and logo placement, while Data Sales constitutes the sale of information collected by Astrobotic through its own lander and rovers.

Markets & Services:	TLI/ Lunar Orbit	Stationary LunarCubes	Mobile LunarCubes	Surface Delivery	Advertising	Data Sales
Resource Extraction	X		X	X		X
Tourism	X	X	X	X		
Technology Test & Demonstration	X	X		X		X
Defence & Security	X			X		
Science & Exploration	X	X	X	X		
Education	X	X	X			
Infrastructure, Support, Supplies	X			X		
Media & Advertising	X			X	X	

TABLE 2: OVERVIEW OF SERVICES DEMANDED BY MARKET

Methodology

This study combines primary research and open source materials to build a full and objective picture of market dynamics for lunar services. The results of forecasted volume are reported in "payload unit equivalents" (see Table 3: Payload Unit Equivalents).

One payload unit equivalent (PUE) can equal =	1 LunarCube
	1 kg of surface payload delivery
	$1.2 million in advertising
	$1.2 million in research budget

TABLE 3: PAYLOAD UNIT EQUIVALENTS

Demand in each market was forecast for three scenarios:

- **Baseline scenario**: assumes considerable interest in commercial lunar activity, much of which comes from mining and the development of lunar infrastructure. There is significant interest in establishing a lunar outpost and utilizing local resources, and mining is catalyzed by NASA's successful RESOLVE prospecting mission in 2017. Human missions occur in 2025 and a small amount of preparatory work is demanded within the forecast period.
- **Growth scenario**: successful mining and research missions spur increased demand for commercial lunar activity. Science & exploration, infrastructure and supplies, and resource extraction all begin to ramp up earlier in the forecast period and to a greater extent.
- **Constrained scenario**: delays in technology development, reduced funding, strained government budgets both domestically and internationally, and possible launch and other mission failures all combine for a lower demand scenario. Manned missions to the lunar surface are postponed and very little preparatory work is included in the forecast period.

Results

Total projected demand for lunar services across all markets grows from around 74 payload unit equivalents (PUEs) in 2015 to 1,574 PUEs in 2020 according to the baseline case. Demand under the growth scenario, which reflects increases due to factors such as awareness, scientific breakthrough, and mission success, grows from about 107 PUEs to 2,644 PUEs through 2020. The constrained scenario, which reflects significantly reduced consumer spending and government budgets, shows demand from 41 to 822 PUEs per year (see Figure 2: Baseline, Constrained, and Growth Demand Scenarios for Total Lunar Market).

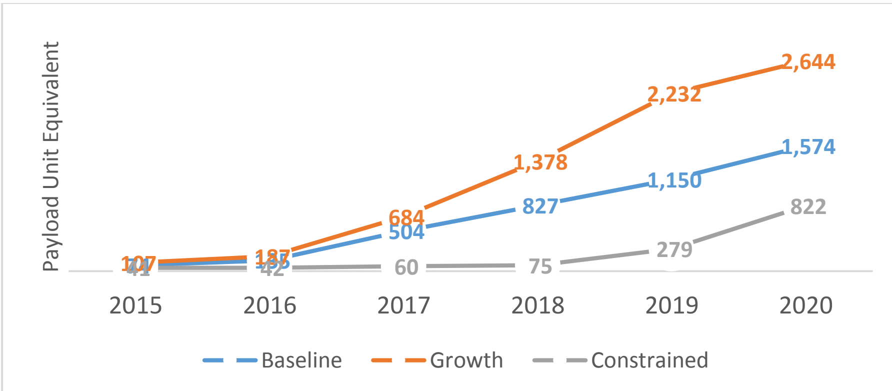


FIGURE 2: BASELINE, CONSTRAINED, AND GROWTH DEMAND SCENARIOS FOR TOTAL LUNAR MARKET

Demand by Market

As shown in Figure 3: Total Baseline Demand by Market below, demand for lunar services is dominated by two key markets: Infrastructure and Mining.

The analysis in this study indicates lunar surface payload delivery for infrastructure, support, and supplies will be the greatest source of demand for lunar services at 45% of the total. This market will support the establishment of a lunar outpost as well as in-situ resource utilization (ISRU).

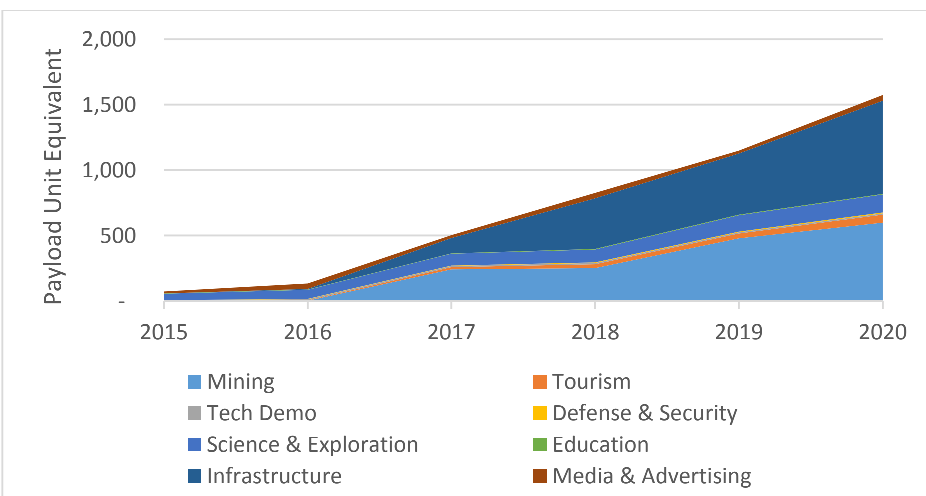


FIGURE 3: TOTAL BASELINE DEMAND BY MARKET

The second largest area of demand is mining at 38% of the total. As this study will attempt to demonstrate, resource extraction will play a key role in the development of the lunar economy. The demand is primarily driven by surface payload delivery of prospecting and mining robots. Because commercial mining has a clear operating process, path to profitability, and competition, this industry is likely to be a key customer for lunar services.

The third largest area of demand comes from Science & Exploration at 9% of the total. As you will see in greater detail in the market segmentation section of this report, demand in this market is driven primarily by surface payload delivery for exploration and basic and applied research.

The remaining 8% of demand is generated by Tourism (for data gathering and preliminary construction), Media & Advertising (through what we have predicted to be a small but influential number revenue dollars for naming rights, advertisements, film, and novelties), Technology Test and Demonstration (driven by government contracts), Defense & Security (for asteroid detection and deflection, and military reconnaissance), and Education (for universities).

Demand by Service

As shown in Figure 4: Total Baseline Demand by Service below, the demand for lunar services is dominated by customized surface payload delivery (95% of baseline in 2020). The analysis in this study indicates that the markets for Infrastructure & Supplies (for both Phase I and Phase II projects), Mining (for prospecting and mining robots), and Science & Exploration (primarily for exploration, space physics, and materials sciences) will be the greatest drivers of demand for lunar services.

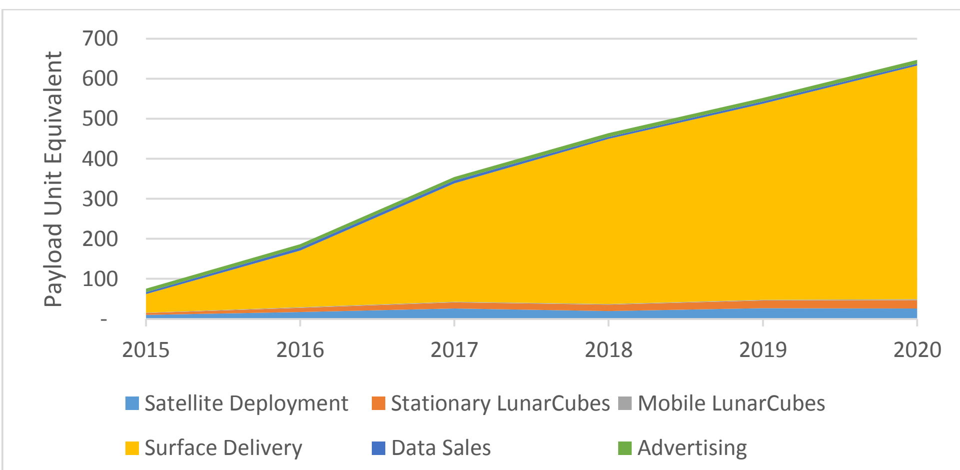


FIGURE 4: TOTAL BASELINE DEMAND BY SERVICE

The second largest area of demand (2% of baseline in 2020) comes from satellite deployment to lunar orbit and lunar Lagrange points, driven by the science & exploration market (primarily space physics and astronomy funding by NASA and DoD).

The remaining 4% of demand is comprised of stationary LunarCubes, advertising, data sales, and mobile LunarCubes.

Revenue

This forecast roughly translates to a total of $4.9 billion in revenue over six years in the baseline case, growing from annual revenue of $80 million in 2015 to $1.9 billion in 2020. The growth scenario increases from $112 million in 2015 to $8.4 billion in 2020, and the constrained scenario grows from $44 million to $971 million. These revenue figures do not reflect prize money from the $30 million GLXP.

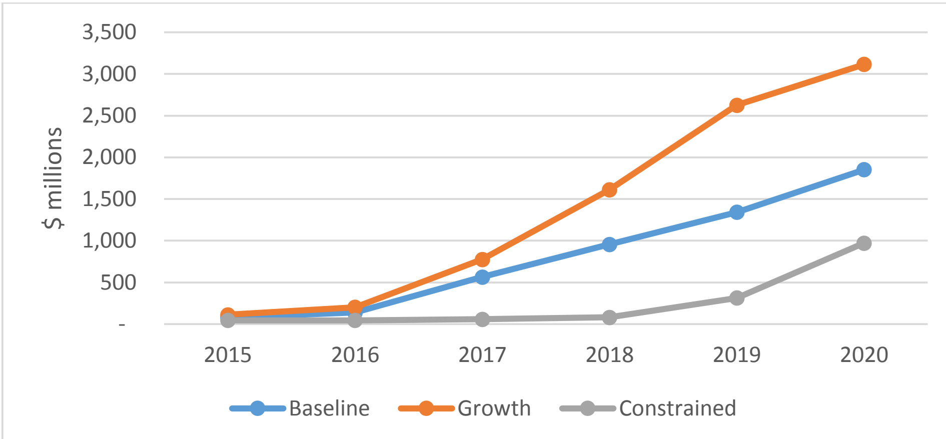


FIGURE 5: TOTAL LUNAR MARKET REVENUE POTENTIAL

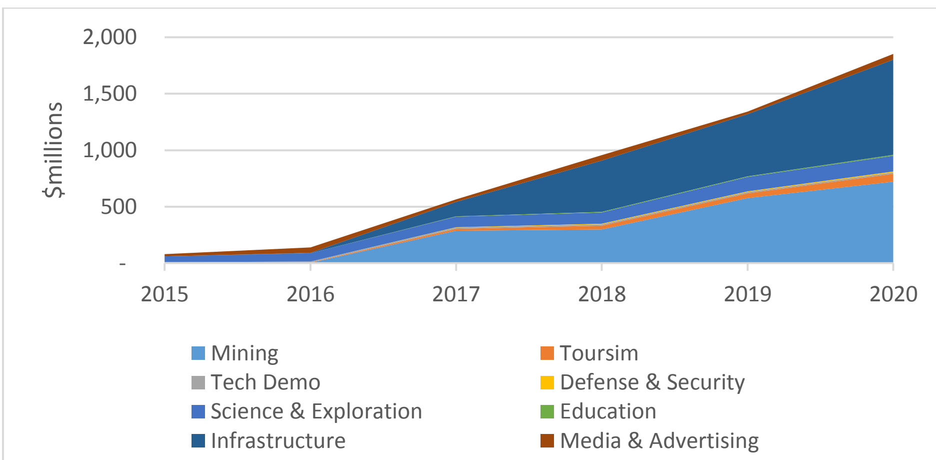


FIGURE 6: TOTAL BASELINE REVENUE BY MARKET

Critical Dependencies

Potential launch/land/mission failures. Extensive testing aboard Masten's Xaero. While insurance is a potential mitigation strategy, it is also very costly. This FAA report on Commercial Space Transportation points out that space insurance is typically the third largest cost component of a commercial satellite system, after the cost of the satellite and launch services. The space insurance market is categorized by low frequency and high severity of losses. As a result, the number of insurance companies willing to commit capital to space insurance has always been limited: there are currently about 30 companies worldwide providing such insurance. While recent good experience in space insurance and a recovery in financial markets has reduced prices considerably, it will still amount to significant cost to a mission with already thin margins. While it is always a good idea to get quotes and understand the figures before making a decision, this report recommends carefully considering the risk / reward of this assurance.

Is Moon mining legal? As resource extraction makes up such a large portion of demand volume and revenue, any policy complications or other slowdowns in exploration/operation could have adverse effects on the business of Astrobotic. The policies that govern space and celestial property rights were developed during the Apollo era and the original space race. During the past 40 years there hasn't been much progress in terms of commercial space activity and the existing space policy reflects that. We are at a pivotal moment in the development of commercial space, where definitions of space treaties are being debated and revised. Favorable space policy to support celestial property rights is essential for the development of a lunar mining industry and the transport infrastructure services that support them.

Conclusion

Demand for lunar transportation services is sustained and appears sufficient to support multiple service providers. Total baseline demand through 2020 is expected to grow to 1,574 PUEs annually, exceeding $1.9 billion in total annual revenue, which at present day capacity would support multiple missions per year. The baseline reflects steady and increasing demand based on current trends and interest from governments, commercial business, and academia. The growth scenario, which reflects mining and research successes as well as expedited construction and expansion of a lunar outpost, could generate $3.1 billion annually by 2020. In a constrained scenario, where government and enterprise spending is cut, multiple annual missions to the Moon still manage to generate $1.5 billion over six years. Further potential could be realized through unpredictable achievements such as major research discoveries, major mining success, identification of new commercial applications, the emergence of global brand value, and new government uses for the Moon.

Market Segmentation

Market Overview

Our scientific knowledge of the Moon is incomplete. Our previous missions to the Moon, both human and robotic, encompassed a geography limited to a number of sites for a limited time, with little surface range. Much remains to be learned. And with the last visit to the Moon over 40 years ago, there is a lot of pent up demand for understanding and experimentation.

Widespread interest in the Moon, from both public and private sectors, as a source for knowledge, security, recreation, or scarce resources combines to create a number of commercial opportunities for private enterprise - whether through pure commercial activities or through government contracts as NASA, with limited budget, relies more heavily on private enterprise for research and exploration.

A great quote about infrastructure and "last mile" solutions comes from a founder of Moon Express. "With the internet there are the people that built the fibers and those that made the last mile solutions," said entrepreneur Naveen Jain. "But the people who made the most money in the internet were the people who provided the services [...], so we want to build the last mile solution." Successful commercial ventures will be those that leverage market principles to control costs by effectively utilizing both terrestrial and lunar resources. Doing business in space is complicated and many early entrants will fail, but the potential payoff is huge.

According to the National Lunar Science Institute (NLSI), when NASA goes back to the Moon we are going to stay, we are not going for a few days or a week, and that will require a brand new approach. There is a great deal of initial work required to prepare us for a sustained presence on the lunar surface by researching and testing technologies and operational concepts and by making observations that will benefit future human activities in space. The market for delivering supplies to support those efforts will be great over the next 5 to 10 years.

Interestingly, there are a number of countries with emerging space ambitions. One or more of these countries with no current launch capability may pay to fly to the Moon in order to facilitate rapid development and leapfrog to the front of the emerging space programs. While the broad market for lunar products and services is still in early stages of development, there appears to be early interest from a number of these national governments. Golden Spike has identified a number of potential government customers: ESA, Brazil, India, Saudi Arabia, Australia, South Africa, and South Korea.

The following sections divide the broader market for lunar services into subsets of consumers who would be interested in lunar industry. To determine the list, this report evaluated potential interest from all industries in the list of Standard Industrial Classification (SIC) to determine what industries the early entrants would likely come from, with a focus on the near- and intermediate-term industry opportunities. *(See Appendices A-D for more detail)*

Resource Extraction

RESOURCE EXTRACTION

Extraction of lunar resources (mainly water) primarily for use as fuel and life support for continued lunar and deep-space activity

Prospecting

Intelligence gathering / feasibility

Mining machines & tool delivery

Over the last four billion years the Moon has been bombarded with millions of asteroids, depositing their resource rich contents onto the lunar surface. Due to an absence of plate tectonics that usually deform and swallow up surface material, many of these resources should theoretically be easily reachable. Perhaps more importantly, according to this Wired article, the Moon has water, which can be broken down to its constituent hydrogen and oxygen and turned into propellant for spacecraft. Water can be used to develop human life support systems such as oxygen for breathing and water for washing. Because of its versatility and importance, water will likely be the first and primary lunar resource to be mined. Gasses such as oxygen, hydrogen, and methane are all prevalent on the Moon and can be used to build fuel depots for self-sustained lunar activity or further deep space explorations (*more about this in the Science & Exploration section*). Additionally, the Moon is known to have Helium-3, a non-radioactive nuclear fusion fuel considered by some to be the safe energy source of the future. While rare on Earth, the abundance of Helium-3 is thought to be greater on the Moon.

Mineral mapping by NASA has shown that the Moon is geologically diverse, with a range of minerals present including those considered "rare Earth minerals". Among them are yttrium, lanthanum, and samarium, which are increasingly critical in the making of high-tech products for civilian and military use: be it tablets, missiles, or wind turbines. Titanium occurs in some lunar rocks at 100 times the rate of rocks on Earth. The mineral is efficient at retaining solar wind particles such as helium and hydrogen, gasses which would likely be vital resources in the construction of lunar colonies and for exploration. Additionally, the Moon is known to have platinum, iron, ilmenite, and pink spinel. While this study does believe that there will be some demand for extracting "rare Earth minerals", it does not consider it to be a large driver of total demand for lunar mining, which will be focused primarily on resources that can be used locally such as the water and gasses mentioned above.

At Australia's first off-Earth mining conference in February 2013, it was noted that advances in robotics in particular mean that investors, entrepreneurs, and research institutions are taking off-Earth mining more seriously. This article points to the Mars Curiosity Rover and Japan's successful sampling of an asteroid some 300 million kilometers away. Because of the high cost of transportation to and from the Moon, mining local resources can completely transform the financial viability of even a small scientific station. Therefore, there are potential windfall profits from mining the Moon and a number of early entrants are already beginning to focus on this the market.

Caterpillar's Automation Systems Manager, Eric Reiners, was quoted as saying, "Caterpillar makes sustainable progress possible by enabling infrastructure development and resource utilization on every continent on Earth. It only makes sense we would be involved in expanding our efforts to the 8^{th} continent, the Moon." Demand for lunar mining will come primarily from two types of private businesses: existing commercial enterprises looking to expand their terrestrial activities (Caterpillar partnered with NASA to develop machines Moon-moving operations, and Bechtel Corp partnered with Planetary Resources to mine near-Earth asteroids), and new commercial enterprises with the sole purpose of mining celestial resources (Shackleton Energy Company, Planetary Resources, Golden Spike).

While there has been commercial interest expressed, there has so far been little financial backing to support commercial lunar mining missions. NASA is currently developing the RESOLVE (Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction) rover, which is seen as the next step in lunar exploration. Slated to fly November 2017, RESOLVE is designed to prospect for water by mapping the distribution of water ice and other useful compounds discovered in the LRO and LCROSS missions. RESOLVE will also drill into the lunar surface and heat the collected material to measure the amount of water vapor and other compounds present. The RESOLVE mission is expected to demonstrate how future commercial missions could gather and then use these valuable resources.

According to the mining development lifecycle mining activities follow a particular order: 1) prospecting to find and define value, 2) resource estimation of the size and grade of the deposit, 3) feasibility study to evaluate financial viability, 4) mine planning & evaluation, 5) removal of waste material - the actual mining process, 6) mine buildings & processing plants for resource recovery, 7) reclamation to make land suitable for future use.

Because human spaceflight and exploration is currently so much more expensive than robotics, it is safe to assume that most steps of the mining process that can be handled by robots and rovers will be. Therefore, following this lifecycle, the first lunar mining expeditions will likely be prospecting and information-gathering robots. In fact prospecting could be done either by a proprietary rover, lunar satellites, or a mobile LunarCube. Most of the analysis and evaluation can be conducted remotely from Earth. These robots will likely then be followed by mining robots, for waste removal, that can be controlled remotely from Earth (Lunabotics). Eventually (step 6), full scale mining activity may need to be supported by human presence. This is where things get really interesting as commercial enterprise looks to build a lunar habitat, because we are now talking about a number of peripheral support services which could stem from this demand in terms of fueling, additive manufacturing, and life support. The first resources mined are expected to be those that have immediate value on the Moon and don't require cost-prohibiting transportation back to Earth - primarily water. While Astrobotic does not have plans at the moment to provide return transport to Earth, this may be a partner activity building upon the transport infrastructure developed by Astrobotic.

Astrobotic can meet the needs of the lunar mining industry throughout the development lifecycle. Firstly, by delivering commercial payloads to the lunar surface to support prospecting efforts (step 1). This could be in the form of the customer's own proprietary rover, or a mobile LunarCube aboard an Astrobotic rover could prove a more cost effective option. Additionally, capital constrained startup companies might be willing to purchase data that Astrobotic gathers itself from its "Ice Breaker" mission which will already be prospecting for water. The large amount of specific data required for resource estimation and a feasibility study (steps 2 & 3) will likely require a rover, so companies that don't already have a proprietary presence on the lunar surface will likely need one at this stage. Mine planning and evaluation (step 4) could probably be performed by the same rover, but they will likely need completely new robots for the actual mining operations (step 5). Mining requires a number of complex and specialized robots including: mining, crushing, sifting, sorting machines and parts. There will be demand for transport to the lunar surface at this stage from mining companies themselves as well as 3D printers for parts manufacturing. The mining stage of development will likely require a human presence. Commercial companies have a huge opportunity here in terms of infrastructure development and it is reasonable to expect that a number of them will compete in the lunar land grab. In addition to lunar transport, Astrobotic will have gathered a large amount of information about the lunar terrain and potential cave habitats from its “Skylight” mission, which it could sell to commercial buyers looking to win the infrastructure development race. Because commercial mining has a clear operating process, path to profitability, and competition, this industry is likely to provide key customers for Astrobotic.

Location will be key for these customers. Frozen water at both lunar poles will no doubt be the primary locations as this resource will provide water, oxygen, and hydrogen to support activities, life support consumables, and allow low-cost transportation back to Earth. There are also several areas near the south pole (Shackleton crater) that receive near constant sunlight, which would make an excellent site for associated solar power systems. Nearly continuous source of power eliminates the need for long-term energy storage, and temperature is more consistent than other locations with extreme shifts. Therefore, companies will likely need proprietary robots on the surface to prospect and mine their specific locations of interest.

Demand Forecast

This study assumes that Astrobotic will transport NASA’s 230 kg RESOLVE rover to the lunar surface in 2017. This mission will serve as a catalyst for commercial mining missions, which are expected to ramp up following that initial prospecting mission. The baseline forecast is driven primarily by surface payload delivery, as companies send their own robots and rovers to the surface to prospect and mine. This forecast assumes that two mining companies are competing in the lunar land grab, likely Caterpillar and Bechtel. This scenario assumes that each company will prospect and mine according to the following timeline: At first the companies show limited initial interest in lunar mining through the purchase of data from Astrobotic’s “Polaris” mission in 2016/17. To prospect, the first company will proactively purchase a 3 kg mobile LunarCube and put a 6 kg imaging satellite into lunar orbit to coincide with the RESOLVE mission in 2017. Following the RESOLVE mission, that company will then send their own 80 kg prospecting rover to the lunar surface in the next launch, followed by delivery of work horse robots for mining, crushing, sifting, and sorting (weighing 120 kg each) in 2018. This company will continue to send the equivalent of two to three lunabots to the lunar surface throughout the forecast period as they ramp up production and prepare for the human support phase of mining. The second company is expected to enter the market following a similar timeline, however on a one-year lag.

The growth scenario assumes that after the two companies in the baseline scenario enter the market, two additional competitors enter in 2018 and 2019, likely international. These two new entrants enter the market in very different ways. The first is a smaller company, with limited capital, that enters the market in a slow and measured way. They first purchase data from Astrobotic and mobile LunarCubes for prospecting in 2018. In the following year they send a prospecting rover to the surface, followed by mining robots in 2020. The fourth company enters the market strong, purchasing prospecting data from Astrobotic’s “Polaris” rover in 2017 before sending two prospecting rovers to the surface in 2018, and three mining robots to the surface each year for the remaining two years of the forecast period.

The constrained scenario assumes that only one company enters the market in the forecast period and they do so with a slower and more cautious approach.

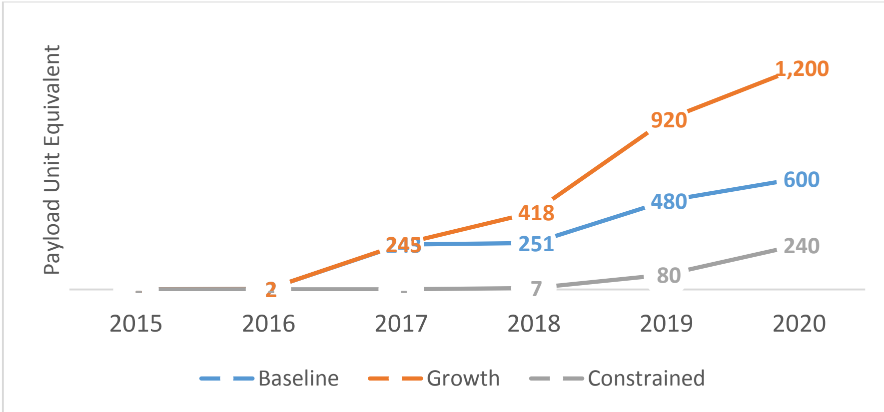


FIGURE 7: BASELINE, CONSTRAINED, AND GROWTH SCENARIOS FOR RESOURCE EXTRACTION

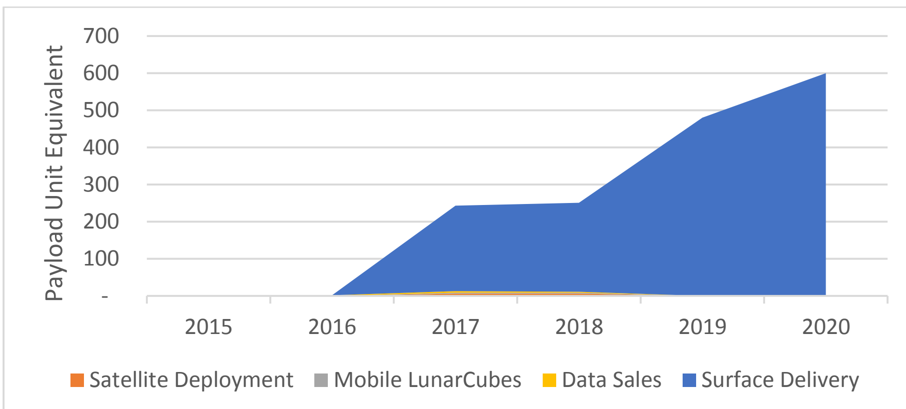


FIGURE 8: RESOURCE EXTRACTION BASELINE COMPOSITION

Uncertainty

This study assumes that NASA's RESOLVE prospecting mission will serve as a catalyst for commercial involvement in lunar resource extraction. Any mission failure or delay in timing could adversely affect the demand estimates for this market.

For the surface delivery of prospecting and mining robots, an average size/weight of 80kg was used. This estimate was based on the average size of NASA's current small lunar rovers, Cratos and K-10, and also agrees with the 80 kg guidelines of NASA's lunabotics competition. However, these estimates may vary from the actual size of robots used by mining companies. Additionally, this report assumes that on average each mining company will send one prospecting and two to three mining robots per year through the forecast period. Actual interest in lunar mining may vary greatly depending on success of prospecting and ability of early entrants to extract resources. Additionally, there may be much greater upside in surface delivery than forecasted if facilities are needed for processing and deconstruction of lunar water. (*see Materials sciences in the Science & Exploration market section*)

Tourism

The demand for lunar tourism will be driven primarily by commercial enterprise. Space Adventures is offering private spaceflight packages to visit lunar orbit and fly within 100 kilometers of the lunar surface for $150 million, beginning in 2015. They will not likely be a customer for lunar payloads, however they could emerge as a competitor should they decide to launch secondary payloads such as a lunar lander or satellite while in lunar orbit (similar to Virgin Galactic's LauncherOne, XCOR's Lynx Mark III, Swiss Space Systems' proposed spacecraft).

TOURISM

The moon as a destination for adventure seekers

Lunar hotel / outpost developers

Manned lunar missions (Government & civil)

Plans for lunar hotels are already being designed by manufacturers of space habitats such as Bigelow Aerospace. Robert Bigelow has invested more than $250 million his own money to develop the BA 330, and NASA has signed a $17.8 million contract with Bigelow Aerospace to build the module, which could reach the ISS as soon as 2015. In conjunction with the announcement of that contract, Bigelow also announced pricing for exclusive use of the 110 cubic meter station: $25 million for 60 days. This is a major milestone for the space destination/space habitat market and a tangible step toward eventual on-surface lunar tourism. The subsequent NASA / Bigelow space act agreement also demonstrates serious attention to lunar tourism as it establishes a partnership to explore the construction of a lunar base which could be used as a military or civilian outpost and/or hotel. As of July 22, Orbital Technology has entered the market and given Bigelow some competition. The Russian company plans to open an orbital space hotel in 2016, and reportedly has customers lined up as well as funding from Russian and American investors. While Bigelow might be farther ahead in terms of technology development, this study assumes that Orbital will follow a similar development path to Bigelow and will ultimately target the Moon as their next hotel destination. Both companies are in the business of building space habitats and will need transportation to the Moon to gather valuable data for planning. Astrobotic can meet the immediate needs of Bigelow and Orbital Technology through satellite deployment, data sales, and on-surface LunarCubes. Subsequent missions will likely include payload delivery to the lunar surface as these companies begin transporting resources to initiate construction.

Golden Spike is a collective group of a number of different commercial space partners, including Masten, Paragon, Biosphere, and others with plans to fly manned crews to the Moon and back for a price of $1.5 billion per flight by 2020. With this long timeline it is reasonable to expect that they will have interest in obtaining data, before 2020, from the lunar surface or from a satellite at lunar orbit or a lunar Lagrange point. However, they might not be an ideal customer as they don't yet have funding, earning just $20k of their $240k goal on Indiegogo. However, with solid strategic partnerships and an experienced team it is not hard to imagine them gaining some momentum in the near future. What this does point out though is that while it appears there is strong demand for lunar data, it is entirely possible for many of these customers to form partnerships to share the cost of payload delivery and essentially cannibalize Astrobotic's potential revenues.

Demand Forecast

The baseline scenario reflects interest from Bigelow in building a lunar habitat for tourism and/or as a government outpost. While this analysis assumes that actual human missions will fall outside the forecast period, it does assume that preparatory work will begin to pick up in 2018. The baseline assumes that beginning in 2016, Bigelow will be interested in purchasing data from Astrobotic, as well as a lunar satellite and 3 kg stationary and mobile LunarCubes. This forecast assumes that in 2018 they will begin to deliver 25 kg of cargo (tools & materials) to the surface to initiate construction of the first lunar habitat, continuing through the forecast period. Depending on Bigelow's technology development progress, this demand could also represent a subcontracting opportunity for Astrobotic to support development of landing (or other) systems. While this analysis assumes that Orbital Technology will ultimately be interested in establishing a Moon outpost/hotel, it is expected that this will fall outside the forecast period.

The growth scenario assumes that another company, likely GoldenSpike, will follow a similar path to that of Bigelow. However, this report assumes that due to financial constraints they will opt to purchase more data from Astrobotic and will have a longer development lead time before delivering any tools or construction equipment to the surface.

The constrained scenario assumes that no other company beyond Bigelow enters the market during the forecast period, and that Bigelow activity occurs on a two year lag from the baseline.

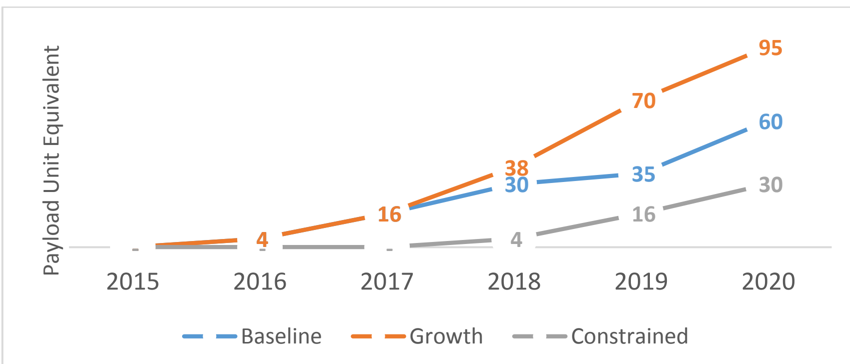


FIGURE 9: BASELINE, CONSTRAINED, AND GROWTH SCENARIOS FOR TOURISM

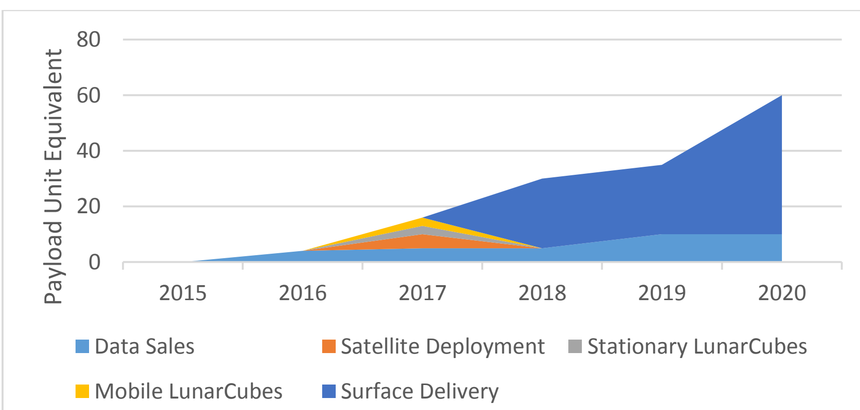


FIGURE 10: TOURISM BASELINE COMPOSITION

Uncertainty

Currently, there is only a very general timeline of when we will see manned missions to the Moon. The optimistic estimates fall somewhere around 2020, while the less-optimistic estimates are around 2025 or later. There are no clear plans yet of how the exploration and exploitation of the lunar surface for space habitats will go. The timeline outlined in this study is based on extrapolated data from a number of different sources, which give a general idea of what activities would be necessary to develop a lunar habitat (see Appendix B for more detail).

This forecast assumes that following 2-3 years of research, a company will be able to begin excavation and construction. This timeline may prove to be unrealistic and the required timeline might be much longer. Additionally, the demand for this market is dependent upon customers that are also starting up and operating in nascent markets, which compounds the uncertainty of projections. While Bigelow has every intention of developing a lunar outpost, they may get bogged down with the orbital BA 330 and the ISS and might have to postpone their lunar plans until later in the forecast period. Additionally, Golden Spike has still not received funding and their initial crowdfunding efforts were anemic. While there may be more startup companies in its place, if Golden Spike does not get funded that could be a real setback to the lunar tourism market.

Technology Test & Demonstration

The lunar surface and lunar orbit are likely to be attractive environments to advance technology maturity or achieve space and off-Earth demonstration, qualification, or certification.

Space agencies currently conduct technology test and demonstration activities using terrestrial facilities and spaceflight. NASA, for instance, has created a number of programs to test and demonstrate technology in relevant environments. Below is a list of current NASA programs in order of increasing technology readiness and with associated investment where known:

TECHNOLOGY TEST & DEMONSTRATION

Aerospace engineering to advance technology maturity or achieve lunar demonstration, qualification, or certification

Demonstrations requiring lunar environment

Hardware qualification and test

- Space Technology Research Grants (STRG) program accelerates the development of push technologies by investing in innovation and encouraging high risk/high payoff efforts. NASA expects to make 10 awards of $250,000 each for a total program cost of $2.5 million.
- NASA Innovative Advanced Concepts (NIAC) nurtures visionary ideas that could one day "change the possible" in aerospace. In 2011, NASA selected 30 proposals which each received $100,000, for a total program cost of $3 million.
- Center Innovation Fund (CIF): to stimulate and encourage creativity and innovation within NASA centers. Funds are distributed to each NASA center to support emerging technologies and creative initiatives that leverage center talent and capabilities.
- Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STTR): provide an opportunity for small, high-tech companies and research institutions to participate in

government sponsored R&D efforts in key technology areas. The combined award total for the 44 Phase II contracts announced on April 2013 is expected to be $30 million.

- Game Changing Development (GCD) invests in mid-TRL technologies using focused 2-3 year development efforts that will produce dramatic benefit to the Agency's science and/or space exploration missions. In 2013 the program will manage more than 50 projects with investment ranging from $50k - $500k for an estimated total of $11 million.
- Centennial Challenges (CC) program offers incentive prizes to generate revolutionary solutions to problems of interest to NASA. The current budget for this program is $10 million, spread across five different challenges.
- Flight Opportunities (FO) program develops and provides flight opportunities for space technologies to be demonstrated and validated in relevant environments. The technology areas of focus are outlined in Figure 11: Flight Opportunities Program Technology Area Alignment below. To provide these opportunities, NASA has partnered with commercial service providers Armadillo Aerospace, Masten, Near Space, UP Aerospace, Virgin Galactic, Whittinghill Aerospace, XCOR, and Zero Gravity signing two year contracts worth a combined total of $10 million. In 2010, NASA also awarded $475,000 to two companies allowing them to perform flight tests of their experimental vehicles.

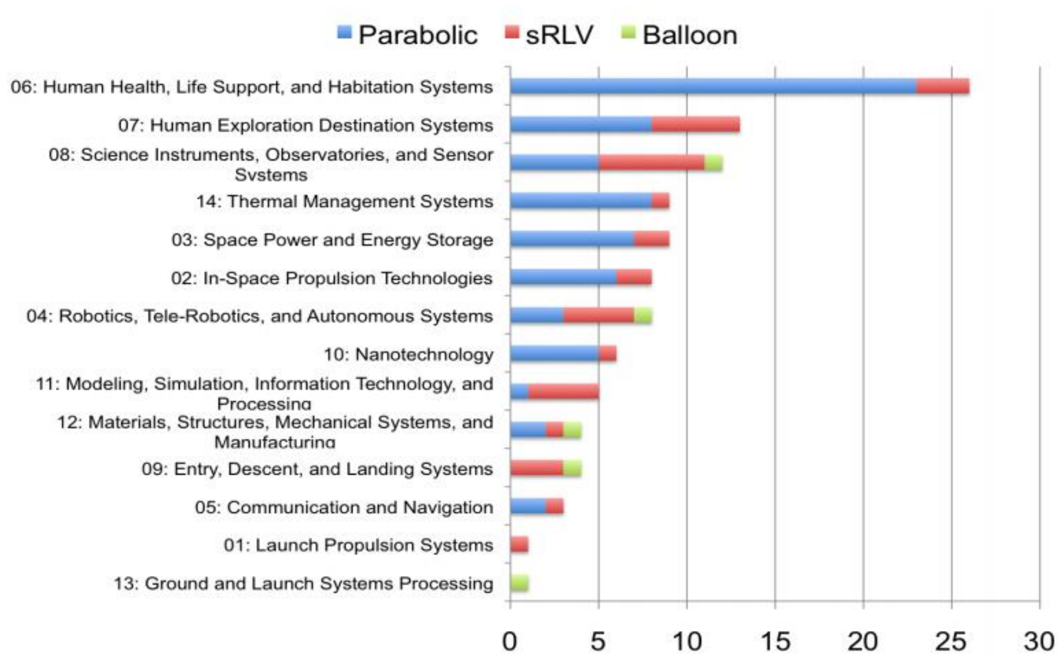


FIGURE 11: FLIGHT OPPORTUNITIES PROGRAM TECHNOLOGY AREA ALIGNMENT

- Small Spacecraft Technologies (SST) program develops and demonstrates new capabilities employing the unique features of small spacecraft for science, exploration, and space operations. The program currently has four active flight demonstration projects, and NASA is currently seeking proposals for Smallsat tech demonstration for a total investment of $1 - $1.5 million as well as an additional $2 million for suborbital flight technology proposals.

- [Technology Demonstration Missions (TDM)](#) program is focused on bridging the gap between need and means; scientific and engineering challenges and innovations to meet them; lab development and space demonstration.

While not by any means an exhaustive list, these programs combine to show NASA investment for current or actively sought technology demonstration projects in excess of $70 million. Additionally, NASA's Science Mission Directorate is soliciting proposals for instrument and technology test/demonstration under SALMON-2 (Second Stand Alone Missions of Opportunity Notice). The program has combined funding of $250 million to be put toward the following three areas of focus: Earth Venture Instrument (EVI) $90 million, ESA JUpiter ICy moons Explorer instrument (JUICE) $100 million, and High-altitude scientific balloon missions $60 million. NASA has a history of investing significantly in technology testing and demonstration. From 1998 to 2006, NASA's Mars Instrument Development Project (MIDP) was successful in developing space qualifiable hardware for Mars missions, bridging the gap between instrument R&D programs, and integrating mature instruments with the Mars rover. This program invested $34 million over an eight year period.

This market analysis assumes that due to the high cost of payload delivery to the Moon, many technology tests and demonstrations will use terrestrial facilities to simulate a lunar environment where possible. Payloads can be at any level of maturity, but are likely to be at the higher technology readiness levels (TRLs) of 5, 6, and 7, which require test or demonstration in relevant environments. NASA, in association with ISS partner nations, is the largest potential customer in this market. Average annual rates for NASA and ISS partner technology tests and demonstrations on these platforms are roughly 4 per year on sounding rockets, 24 per year on the ISS, and 10 per year on the Shuttle (no longer in service). These rates have grown each year at an average of about 7 to 8% for the Shuttle and ISS.

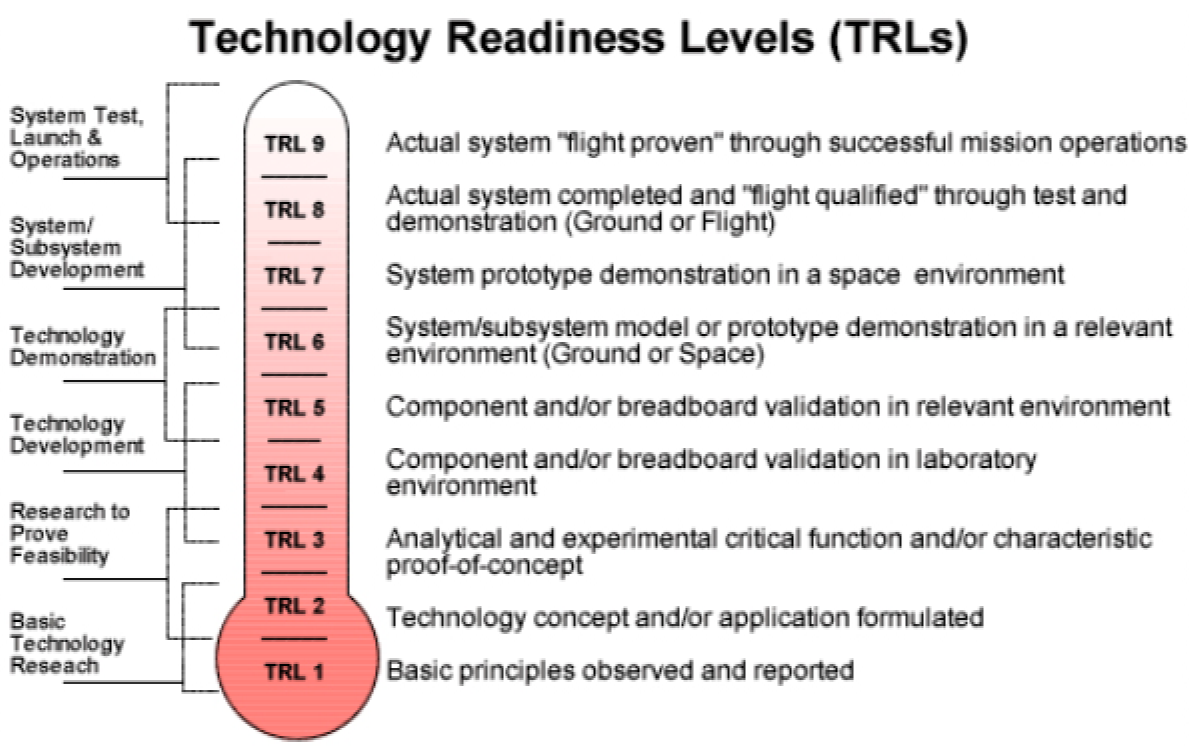


FIGURE 12: TECHNOLOGY READINESS LEVELS. SOURCE: NASA

In April 2013, field experiments were conducted at the US Army's National Training Center (NTC) at Fort Irwin, California, to evaluate geotechnical methods and systems that will enable humans to be productive explorers in the low gravity environment of small rocky bodies. Near Earth Asteroids, Phobos, and Deimos are among destinations currently considered by NASA for future human missions into Deep Space. As the technologies progress along the TRL scale, the Moon will likely be an ideal environment for more advanced testing and technology demonstration. This would bring additional demand from customers such as SETI Institute, Honeybee Robotics, and NASA.

In October 2010 NASA awarded Innovative Lunar Demonstrations Data (ILDD) contracts to six companies for the purchase of technical data resulting from industry efforts to develop vehicle capabilities and demonstrate end-to-end robotic lunar landing missions. The data from these contracts will inform the development of future human and robotic lander vehicles and exploration systems. The total value of the firm-fixed price indefinite-delivery/indefinite-quantity contracts is $30.1 million over a period of up to five years. Each selected contractor has an opportunity to earn between $10,000 and $10 million of that total. In December 2010, NASA issued a delivery order to Astrobotic worth $500,000.

Astrobotic's technologies enabling exploration of lunar skylights, lava tubes, and caves was a Phase I selection for NASA Innovative Advanced Concepts (NIAC). In 2011, Astrobotic received an additional $599,000 two-year contract to develop a scalable gravity offload device for testing rover mobility in simulated lunar gravity under NASA's Small Business Technology Transfer Program (STTR).

Demand forecast

NASA and other space agencies will likely be the major users of the lunar environment for test and demonstration, particularly for the next generation of human exploration systems, the development of a lunar colony, or exploring planetary bodies with extremely low gravity. NASA has shown an interest in this area by awarding multiple contracts to Astrobotic and others. This forecast assumes that other space agencies will have similar aspirations and that Astrobotic's position as a cost leader would make it an attractive alternative to domestic national transport systems, if they exist.

The baseline forecast assumes no change to the current level of funding for data purchased through ILDD and NIAC programs, and that the same level of funding carries on through the end of the forecast period. One CubeSat per year through the forecast period is deployed into lunar orbit or to a lunar Lagrange point. At least one stationary LunarCube is launched in 2015, growing steadily to three per year at the end of the forecast.

The growth forecast assumes 30% growth above the baseline scenario for data sales, satellite deployment, and stationary LunarCubes. This scenario includes the addition of 5 kg payload delivery beginning in 2017, which continues throughout the forecast period reflecting government agencies increased reliance on private industry (see NASA Budget Changes Moon Plan).

The constrained scenario assumes that when funding for the NIAC program ends after two years and the ILDD after five years, there is no more additional funding for the purchase of data. However, there is still a small amount of commercial interest whereby one stationary LunarCube is deployed per year.

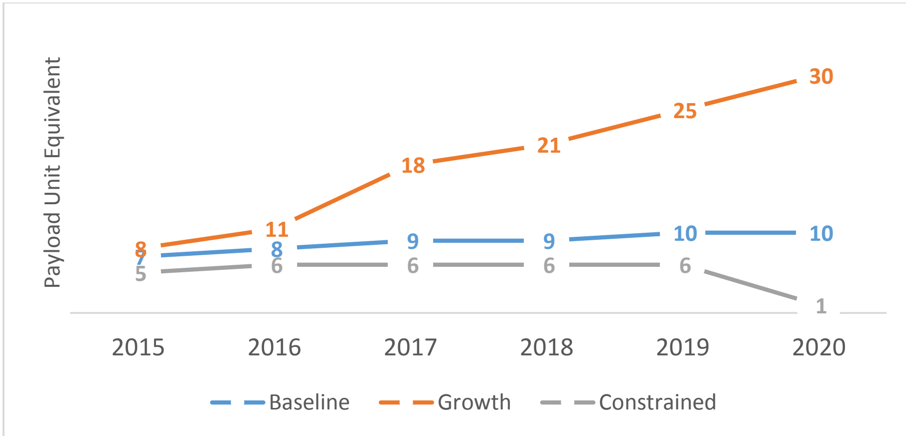


FIGURE 13: BASELINE, CONSTRAINED, AND GROWTH SCENARIOS FOR TECH DEMONSTRATION

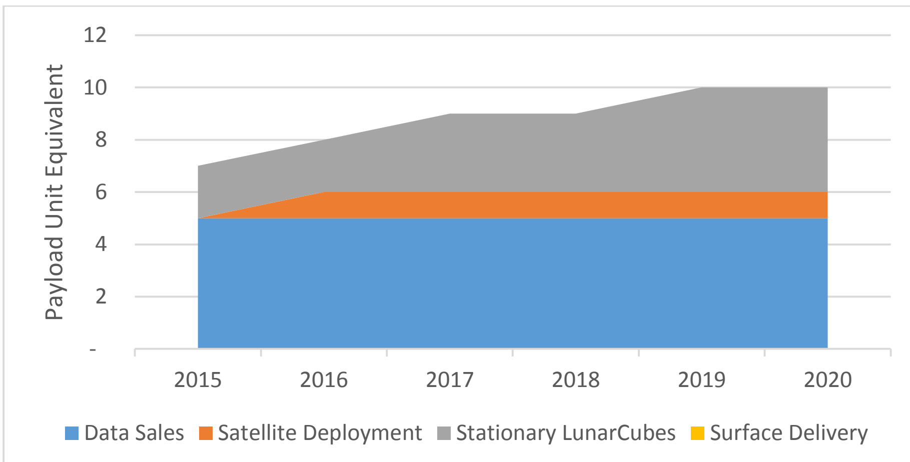


FIGURE 14: TECH DEMONSTRATION BASELINE COMPOSITION

Uncertainty

The market for technology test and demonstration in an entirely new and unique environment is uncertain. The baseline forecast includes only current contracts and therefore does not reflect any increased interest that may arise from successful tests. Additionally, because the primary customers for these services are government agencies, the demand is subject to budgetary provision.

There are limitations on some of these funding schemes, whereby one company can only receive a predetermined fraction of the total contracts. Therefore, while this study attempts to size the entire market for lunar technology demonstration, the amount available to any one company might be significantly less.

Defense & Security

The proximity of the Moon to Earth make it a natural target for asteroid identification, detection, and deflection. This information could be useful for a number of customers including the US government, other governments with large defense budgets, as well as asteroid mining companies. Additionally, with the increased interest by international governments in lunar activity, such as China, India, and Russia, this study assumes that the US military will be in the market for reconnaissance through Moon-based telescopes and other detection and communications equipment.

DEFENSE & SECURITY

Intelligence gathering of Near Earth Objects and reconnaissance of lunar surface activity

Asteroid Identification, detection, deflection

Military reconnaissance

Asteroid Intelligence

The Association of Space Explorer's 2008 report to the United Nation's Committee on Peaceful Uses of Outer Space said that as new telescopes come online, in a little over a decade we are likely to be tracking as many as one million near-Earth asteroids (NEAs), of which 10,000 may have some probability of impacting Earth in the next 100 years, and 50 to 100 will appear threatening enough to require active monitoring and/or deflection.

In that same year, some members of US Congress wrote House Resolution (HR) 6003, which tasked the Director of the President's Office of Science and Technology Policy to develop a policy for notifying federal agencies and relevant emergency response institutions of an impending near Earth object threat, if near-term public safety is at stake, and recommended a federal agency or agencies be responsible for protecting the nation from a near-Earth object that is anticipated to collide with Earth and implementing a deflection campaign, in consultation with other international bodies.

The threat is now generally accepted to be of significant importance among policy makers. The house resolution mentioned above states clearly and upfront that "near-Earth objects pose a serious and credible threat to humankind, as many scientists believe that a major asteroid or comet was responsible for the mass extinction of the majority of the Earth's species, including the dinosaurs, nearly 65,000,000 years ago […] and asteroid and comet collisions rank as one of the most costly natural disasters that can occur."

How much is being spent/projected to be spent in this effort? In the 1990's, US Congress held hearings to consider the risks and what needed to be done about them. This led to a $3 million budget for programs like Spaceguard and the near-Earth object program, as managed by NASA and USAF. A subsequent NASA study in 2003 of a follow-on program suggested spending US$250-400 million to meet the Congressional requirement to detect 90% of all near-Earth asteroids 140 meters and larger by 2028. Peter Garretson, transformational strategist at Headquarters US Air Force, estimates that "the US government will have an encouraging policy to source asteroid-related space-situational awareness from private industry." With a ready buyer of such information, you can be sure that private industry will step up to the challenge.

This study reflects an interest in asteroid and deep space data from governments and asteroid mining companies. This demand can be met by deploying satellites to lunar orbit/Lagrange points or delivering astronomical instruments, such as telescopes and communications hardware, to the lunar surface.

Military Reconnaissance

Chang'e 3 is the lander for a lunar exploration mission operated by China National Space Administration, incorporating a robotic lander and a rover. Chang'e 3 is scheduled for launch in late 2013 as part of the second phase of the Chinese Lunar Exploration Program. It will be China's first lunar rover, and the first spacecraft to make a soft landing on the Moon since the Soviet *Luna 24* mission in 1976. The first Chinese lunar orbiter, Chang'e 1, was launched in 2007 and the Chinese lunar program has been progressing steadily ever since.

As noted in *Asia's Space Race: National Motivations, Regional Rivalries, and International Risks*, a book by James Moltz, China's dramatic entrance into civil, commercial, and military space activities over the past decade has played a major role in sparking the ambitions of Asia's other space players. A number of rivals have expanded their space programs as a result, in some cases dramatically. India has enhanced its satellite reconnaissance capabilities, announced plans for a military space command, and launched its first in a series of planned lunar probes, while hinting at future human spaceflights to match China's. Japan has invested in costly lunar missions, maintains an active astronaut corps, and has built new modules and transport spacecraft for the International Space Station (ISS). Of special concern to its neighbors is Japan's recent decision to scrap its forty-year-old Diet Law on space activity to allow military uses for the first time. South Korea, meanwhile, is moving forward with advanced imaging, communications, and scientific satellites, purchasing space-launch technology from Russia, and paying for a South Korean astronaut's flight to the ISS. Pakistan, North Korea, and Indonesia are all aiming for independent space-launch capability as well, and Australia, Malaysia, Singapore, Taiwan, Thailand, and Vietnam are all working to expand their space capabilities.

Russia launched its last lunar mission, *Luna 24*, in 1976 which returned samples from the Mare Crisium region. Today, Russian space scientists are scripting a new plan to reconnect with the Moon. Russia is developing a renewed robotic Moon exploration program, building upon the history-making legacy of orbiters, landers, rovers, and sample-return missions the country launched decades ago. Russia is no newcomer to Moon exploration. Russia is planning an aggressive schedule of potential Moon missions through 2020 including: Luna 25 – Glob Lander (2015), Luna 26 – Glob Orbiter (2016), Luna 27 – Resource-1 (2017), Luna 28 – Resource-2 (2019), Luna 29 – Resource-3 (2020).

This study reflects significant interest from international governments in lunar science, exploration, and resource extraction. It then assumes that each government with an economic or strategic interest in the Moon will be interested in monitoring activities on the surface, to protect those economic interests. This demand will be met through satellite deployment to lunar orbit/Lagrange points.

Demand Forecast

The baseline forecast assumes that private industry, companies such as Planetary Resources, will receive a modest amount of government funding in an effort to manage, detect, and deflect the threat of NEOs. The baseline reflects three payload unit equivalents of asteroid detection hardware delivered to the surface per year beginning in 2017, growing to six PUEs per year from 2018 through 2020. This forecast also assumes that at least one government, likely the US, would be interested in having military reconnaissance capabilities to protect its economic and security interests. This demand will be met through a mix of one satellite at a lunar Lagrange point and a small amount of on-surface surveillance/communications equipment, building to a total of five reconnaissance points by the end of the forecast period.

The growth scenario assumes greater emphasis and urgency from the US government in the area of defense and security. The US military speeds up deployment of its reconnaissance capabilities, beginning with a satellite deployment in 2015 and followed by delivery of six payload unit equivalents of surface delivery through the remainder of the forecast period. Asteroid security begins earlier with the delivery of a surface telescope in 2016, followed by 6 payload unit equivalents of astronomy and communications equipment delivered to the lunar surface through the remainder of the forecast period. Continued demand will be supported by other nations and international commercial customers.

The constrained scenario assumes that tight government budgets and limited funding for commercial enterprises reduce the total demand for lunar reconnaissance to virtually nothing, just one satellite deployed in 2019 and one small payload delivered in 2020. Additionally, this scenario assumes that funding for asteroid security is postponed and just one surface payload is delivered for a commercial customer in 2018.

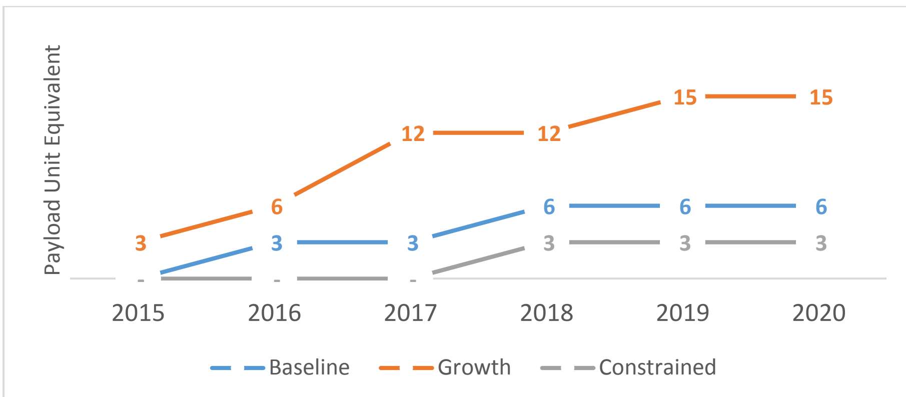


FIGURE 15: BASELINE, CONSTRAINED, AND GROWTH SCENARIOS FOR DEFENSE & SECURITY

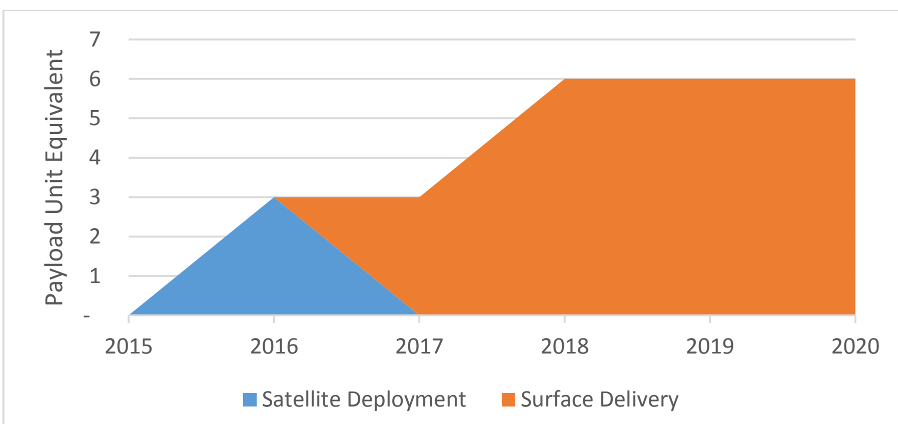


FIGURE 16: DEFENSE & SECURITY BASELINE COMPOSITION

Uncertainty

We are just beginning to see money be put behind efforts to track NEOs. Since 2003 there has been serious talk of dramatically increasing the budget to something more like $250-400 million, although this has not happened yet. This forecast assumes that interest will continue to increase, albeit gradually over the forecast period. A significant increase or decrease in budget for this type of activity will effect demand.

This forecast assumes that interest in the Moon from international space agencies will drive action from the US government and in turn drive demand for reconnaissance satellites. Therefore, any success or failure, or increase or decrease in interest will have a corresponding effect on demand.

Science & Exploration

Our scientific knowledge of the Moon is incomplete. Our previous missions to the Moon, both human and robotic, encompassed a geography limited to a number of sites for a limited time, with little surface range. Much remains to be learned. And with the last visit to the Moon over 40 years ago, there is a lot of pent up demand for understanding and experimentation. Additionally, the Moon provides an ideal plaltform for local and deep space exploration.

SCIENCE & EXPLORATION

Basic & applied research in a number of disciplines, leveraging the unique properties of and access to the lunar environment and microgravity

Earth & deep space imagery
Space physics
Biological and physical research
Human research
Lunar exploration

A resurgence of US and international interest in the Moon has led to seven new missions and paradigm-shifting research from returned data. New theories on the formation and evolution of the Moon, our Solar System, and other planetary systems, new discoveries of water and volatile emplacement around and in the Moon, and new missions to characterize the Moon and its immediate space environment all point to an exciting and vibrant scientific world with vast exploration potential. The National Lunar Science Institute (NLSI), supported by NASA's Science Mission Dictorate and Exploration Systems Dictorate, brings together competitively selected research teams to focus on questions to understand the formation, evolution, composition, and potential of the Moon. Lunar Quest, a subset of NASA's 2013 Planetary Science budget, has $61.5 million in funding.

The recent increased interest in the use of CubeSats can be leveraged to estimate the market for LunarCubes as well (see Appendix A). Nano/microsatellite development continues to be led by the civil sector (universities, federally funded research & development centers), but the defense/intelligence community is showing increased interest and involvement. Until 2012, the majority of smallsats were developed for technology demonstration, but are becoming more diversified with increased use. They are increasingly being used for science, Earth observation, and reconnaissance missions - see *Trends & Growth* section of this report for more detail. But based on this data, it appears that we can extrapolate a healthy demand for lunar science and lunar reconnaissance. Therefore national governments and academia are clearly potential customers in this demographic. To give an idea of the level of demand, Table 4: US Government Space Budgets 2009 below shows the budgets for space science and exploration by government agency as of 2009 (including stimulus).

Agency	Budget
Department of Defense (DoD)	$ 26.53 B
National Aeronautics and Space Administration (NASA)	$ 18.78 B
National Reconnaissance Office (NRO)	$ 15.00 B
National Geospatial-Intelligence Agency (NGA)	$ 2.00 B
National Oceanic and Atmospheric Administration (NOAA)	$ 1.25 B
National Science Foundation (NSF)	$ 0.80 B
Department of Energy (DOE)	$ 0.04 B
Federal Aviation Authority (FAA)	$ 0.01 B
Total	**$ 64.41 B**

TABLE 4: US GOVERNMENT SPACE BUDGETS 2009

Of NASA's FY3013 budget, a total of $8.8 billion has been set aside for science & exploration. The following table shows a breakdown of the budget components for science (blue) and exploration (grey). Additional budget detail can be found in Appendix H.

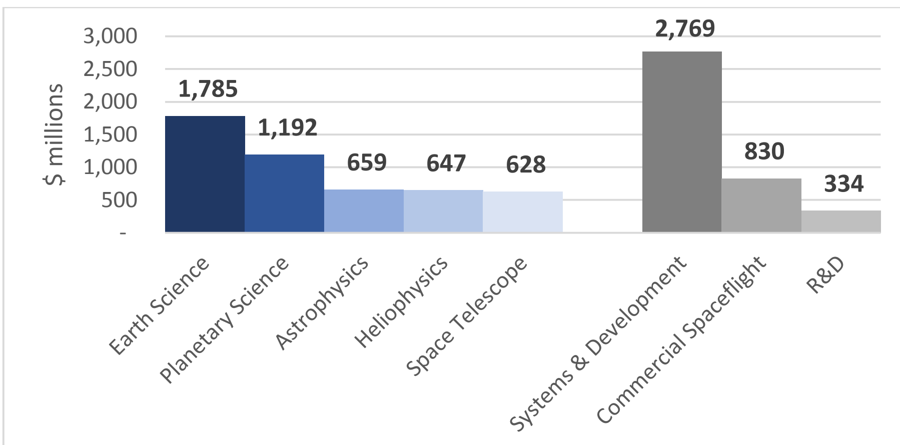


FIGURE 17: NASA FY2013 BUDGET FOR SCIENCE & EXPLORATION

Additionally, the high number of certain types of scientific experiments conducted aboard the ISS could be an indicator of where the demand for lunar science will come from. For instance the very high number of biological and biotech experiments signal that customers of LunarCubes would likely come from the agriculture and medical sectors. The high number of physical science experiments could also signal strong demand from academia, R&D centers, and commercial enterprises such as additive manufacturing. All of these institutions have considerable potential demand for smallsat delivery to lunar orbit as well as LunarCubes.

Science

The Moon can be used to conduct basic and applied research in a number of disciplines, leveraging the unique properties of, and access to, the lunar environment and microgravity. The lunar surface can support many types of space-related research, generally grouped into five disciplines:

Earth Observation	Space Physics	Astronomy	Materials Sciences	Life Sciences
• Remote sensing	• Space weather • Magnetosphere	• Space telescopes	• Lunar regolith • Micro-gravity	• Human physiology • Radiation

Most space-related research is currently conducted on orbital platforms such as the International Space Station, high-altitude balloons, sounding rockets, drop towers, other terrestrial alternatives, and emerging commercial sub/orbital vehicles. However, the lunar surface and lunar orbit provide an entirely new and unique research environment.

Earth Observation

There is already a market developing for deep space and Earth observation from the lunar surface. The mission of the International Lunar Observatory Association (ILOA) is "[…] to expand human understanding of the cosmos through observation from our Moon." The ILOA currently has four active lunar missions. The first of which will see a two-meter dish observatory placed near the south pole of the Moon. The mission will conduct radio astronomy and commercial communications, while serving as a beacon for lunar base build-out. ILOA is working with MDA of Canada to develop the scientific payload. ILOA is working with Golden Spike to achieve a human Moon mission within a decade. As a precursor to both of these missions, ILOA is teaming up with Moon Express to place a 10-cm optical telescope on the team's lunar lander scheduled for 2015(?). Additionally, the Chang'e 3 lunar lander will carry an astronomical telescope making it the world's first lunar-based astronomical observatory. While this is just a couple of examples of organizations with ambitions and traction toward real lunar science, it does demonstrate the demand and collaboration with industry partners to achieve its goals. Organizations like this could be customers for surface payload delivery.

Space Physics

Space physics is the study of plasmas as they occur naturally in the universe. As such, it encompasses a far-ranging number of topics including the sun, solar wind, planetary magnetospheres and ionospheres, auroras, cosmic rays, and synchrotron radiation. Space physics is a fundamental part of the study of space weather and has important implications not only to understanding the universe, but also the operation of communications and weather satellites. Astrobotic can meet the demand for research in space physics by deploying satellites to lunar orbit and delivering scientific payloads to the lunar surface.

Astronomy

The lunar surface and lunar orbit will allow researchers to conduct high-quality infrared (IR) and ultraviolet (UV) observations from outside Earth's atmosphere. There are a number of useful IR and UV spectra that do not penetrate Earth's atmosphere, so they cannot be viewed by ground-based telescopes. These spectra can be viewed by orbital observatories, but most orbiting telescopes have long queues, making them less suited for quick response applications, like flybys of newly discovered NEOs. The demand for astronomy research can be met through lunar satellite deployment and surface payload delivery.

Materials Sciences

The lunar surface provides the possibility for long-term microgravity environments, which is only possible today aboard the ISS. With limited space aboard the ISS, the Moon may provide an outlet for pent up demand as well as a more authentic environment for researching other celestial bodies. The lunar surface itself will be a hotbed of research activity as governments, universities, and commercial enterprise race to understand this newly available resource.

According to new budget details for the NLSI, future missions may use robotic technology to demonstrate a lunar factory that can process lunar asteroid materials for various purposes.

Life Sciences

Researchers can leverage the lunar surface to understand the physiological responses to many situations including extreme and prolonged microgravity, lunar surface radiation, and radiation belts while traveling through Earth's magnetosphere. There may be research activities designed to investigate pharmaceuticals or techniques to minimize the harm and discomfort that lunar travelers may experience.

The Orion Multi-Purpose Crew Vehicle (MPCV) is being developed by Lockheed Martin for NASA and Astrium for the ESA for crewed missions to deep space, including the Moon. Orion is expected to cost NASA $4.3 billion and the UK Space Agency $25.6 million. If NASA is planning to spend this kind of money to send humans back to the Moon, then it is reasonable to believe that they will want to mitigate any risk by doing some serious due diligence about the environment first. NASA could be a significant customer for any of the services provided by Astrobotic.

<table>
<tr><th>Organization</th><th>Earth Observation</th><th>Space Physics</th><th>Astronomy</th><th>Materials Sciences</th><th>Life Sciences</th></tr>
<tr><td rowspan="2">NASA - Lunar Science Institute</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td colspan="5">NASA funds research primarily through its Science Mission Dictorate. Human and microgravity research is conducted through ISS research programs or terrestrial analogs. Astronomy research is conducted through the Earth, Heliophysics, Astrophysics, and Planetary Science divisions.</td></tr>
<tr><td rowspan="2">National Science Foundation (NSF)</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td></tr>
<tr><td colspan="5">NSF supports several relevant grants per year for applicable projects. Currently, these primarily include data analysis and modeling for UV and IR astronomy conducted on orbital telescopes. NSF also supports terrestrial observatories.</td></tr>
<tr><td rowspan="2">National Institute of Health (NIH)</td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td colspan="5">In collaboration with NASA, NIH researches explore fundamental questions about health issues such as how bones and the immune system get weak in microgravity.</td></tr>
<tr><td rowspan="2">Department of Defense (DOD)</td><td></td><td>X</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">DoD conducts atmospheric and space research using military aircraft, evolved expendable launch vehicles, missles, and DoD-procured sounding rockets.</td></tr>
<tr><td rowspan="2">Non-profits</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td colspan="5">A small number of non-profits provide funding for basic and applied research applicable to the Moon. The ILOA, which has teamed up with Moon Express, is the most prominent example.</td></tr>
<tr><td rowspan="2">Universities</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td colspan="5">Government research funding for basic and applied research in these areas primarily flows to universities and university-affiliated laboratories. Universitites often have a relatively small budget from non-federal sources that augments government research funding. Universities currently conduct basic and applied research using sounding rockets, terrestrial facilities, and orbital facilities. Since 2006, 58 universities have launched a sounding rocket payload: 21 in the United States, 23 in Europe, and 14 elsewhere.</td></tr>
<tr><td rowspan="2">International</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td colspan="5">Europe supports relevant research across all of these areas using the ISS, parabolic flights, and sounding rockets. The European Space Agency (ESA) sponsors experiments on 30 parabolic flights and about 4-5 sounding rockets per year, with the largest number of projects studying physics, especially micro-gravity experiments. Additional relevant research is conducted by agencies in Canada (Canadian Lunar Research Network), Russia, China, Japan, India, and other nations.</td></tr>
</table>

TABLE 5: MAJOR FUNDERS/CUSTOMERS OF BASIC & APPLIED RESEARCH MAPPED TO FIVE RESEARCH APPLICATIONS WELL SUITED FOR THE LUNAR ENVIRONMENT

Exploration

Slightly more intermediate- and longer-term are the supplies and infrastructure needed to support human exploration of the lunar surface and using the Moon as a propellant depot and launch pad for further deep space exploration. As mentioned, the ILOA is working with Golden Spike to achieve a human mission to the Moon within the decade. The purpose of this mission is primarily for on-surface science experiments and Earth observation.

In 2009, President Obama outlined a plan for NASA that included two key objectives: Moon & Mars. This 2009 NASA report section 7.3, states the need for *in situ* propellant production, or the need to produce fuel on the lunar surface, from lunar rocks and regolith. A variety of chemical processes to extract oxygen from lunar material has been demonstrated in Earth-based labs. These propellant production methods must next be demonstrated on the lunar surface through robotic missions. Collecting lunar material and bringing it to a lunar-based processing station presents a great challenge and the actual building of fueling depots and launchpads is a longer term goal. However, Astrobotic can meet the short-term demand for robotic exploration, technology demonstration, and physical science experimentation through LunarCubes, surface payload delivery, and Astrobotic collected data.

In 2010, the White House canceled NASA's Constellation program, however NASA continues to show considerable interest in lunar research. Researchers with the Keck Institute for Space Studies in California have confirmed that NASA is mulling over their plan to build a robotic spacecraft to grab a small asteroid and place it in high lunar orbit. The mission would cost about $2.6 billion – slightly more than NASA's Curiosity Mars rover – and could be completed by the 2020s.

It is important to note that NASA's new budget does not end US ambitions to explore the Moon. Robotic precursor missions to the Moon will scout targets for future human activities, and identify the hazards and resources that will determine the future course of the expansion of human civilization into space. According to the NLSI, when NASA goes back to the Moon we are going to stay, we are not going for a few days or a week, and that will require a brand new approach. This precursor work will prepare us for a sustained human presence on the lunar surface by researching and testing technologies and operational concepts and by making observations that will benefit future human activities in space. Future missions will likely include landing on the Moon with a robot that can be tele-operated from Earth and can transmit near-live video. NASA will likely be the primary customer for surface payload delivery of robots for purely exploratory purposes, with a small amount of funding coming from non-profits.

Demand Forecast

A mix of government agencies, universities, and non-profits, domestically and abroad, will support basic and applied science on the Moon. The primary service demanded by the science & exploration market is surface payload delivery as this supports telescopes for Earth observation and astronomy, machines for material manipulation and analysis, biological experiments, and exploratory robots.

The baseline forecast reflects existing organizations' current budgets for space research, with an assumption for how much will be directed toward lunar research. The baseline assumes that 0.2% of NASA's $19bn budget will be directed toward lunar science & exploration beginning in 2015 and growing to 0.4% of budget by the end of the forecast period. This is calculated roughly as a $76 million budget for lunar science in 2020, which is grounded in the $67 million that was budgeted for the Lunar Science Project in 2012. The baseline assumes that the NSF will direct 0.1% of its $6.9bn budget toward the Moon beginning in 2016, growing to 0.3% of budget by 2020. This reflects NSF interest in UV and IR astronomy as well as deep space observation from the lunar surface. The NIH will direct 0.03% of budget to lunar surface payload delivery beginning in 2016 and increasing modestly to 0.05% by 2020. Biological experiments in space typically weigh 5.5 kg, so this NIH budget reflects 1-2 experiments per year throughout the forecast. The total Department of Defense budget for space satellites is roughly $3.4bn (mostly for GPS, space-based IR, and Advance Extremely High Frequency), and this baseline forecast assumes that just 0.1% will be directed to lunar satellite deployment and surface payload delivery in 2015, increasing to 0.5% of budget by 2020. This reflects DoD interest in space weather, IR, and precision tracking systems. The baseline assumes that non-profits and universities direct a small budget of $5mn in total to lunar science & research, increasing it to $10mn by the end of the forecast. International interest in the baseline scenario reflects primary interest in exploring the lunar environment, with dedicated budgets of $7mn to $12mn over the forecast period.

The growth scenario assumes a 20% increase in Earth observation, astronomy, and materials sciences. Space physics and exploration increase to 150% over the baseline, based on the assumption that the most likely agencies to increase their lunar budgets would be NASA Lunar Science Institute, DoD, and the NSF in order to better understand space weather, radiation, the lunar environment. In the growth scenario the NIH increases its budget to 200% over its relatively small baseline assuming that manned missions to the Moon are expedited.

The constrained scenario reflects constrained domestic government budgets and consequently, no lunar research funding by NSF, NIH, non-profits, or universities.

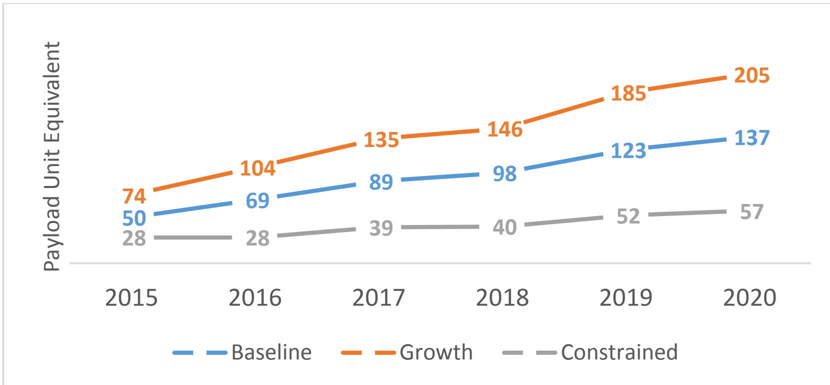


FIGURE 18: BASELINE, CONSTRAINED, AND GROWTH SCENARIOS FOR SCIENCE & EXPLORATION

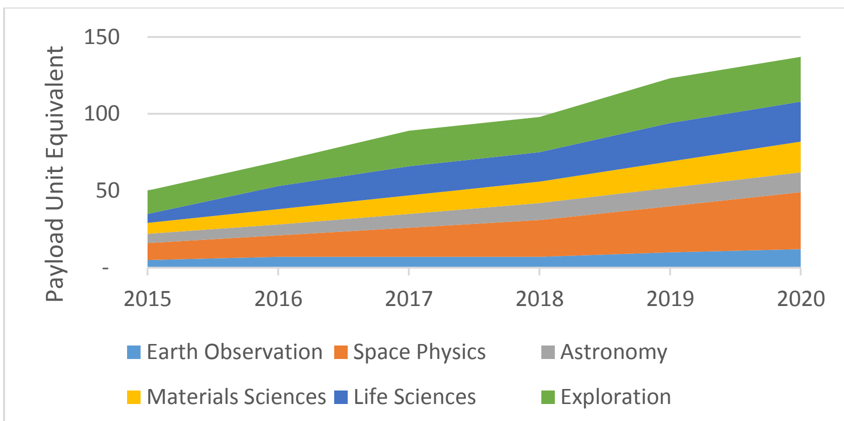


FIGURE 19: SCIENCE & EXPLORATION BASELINE BY SUBMARKET

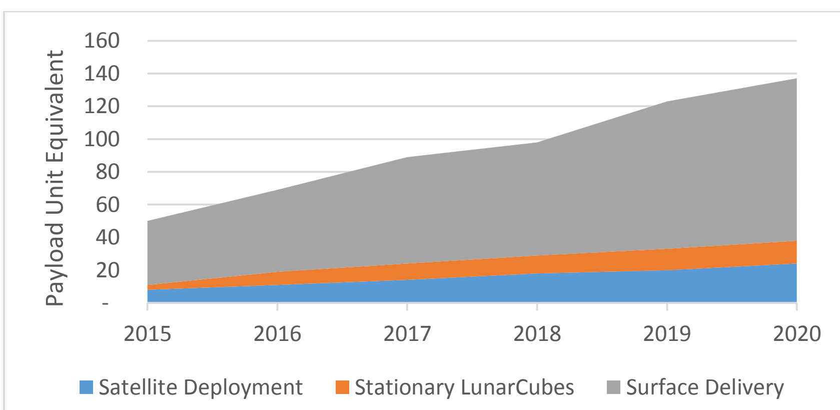


FIGURE 20: SCIENCE & EXPLORATION BASELINE BY SERVICE

Uncertainty

Research success and increased interest could increase funding beyond the forecasted amounts, while loss of interest in speculative research or poor performance by lunar payload providers could limit commercial exploratory funding below these levels.

The future relationship between lunar research and alternatives such as terrestrial simulations or ISS payloads is unclear. While the lunar surface provides a unique research environment, the alternatives likely provide a less expensive option and it is unclear how much budget will be redirected to the Moon.

Education

EDUCATION

Providing opportunities to universities to increase access to and awareness of space and the moon

University educational missions

Access to lunar orbit and the lunar surface provide opportunities for universities to increase access to and awareness of space, especially through the delivery of student-built payloads. This study focuses primarily on universities, as the cost for lunar payload delivery is likely outside the reach of most colleges or K-12 schools. Even still, the key advantage for Astrobotic in this market is its position as cost leader for small lunar payloads.

Existing space-related education build projects use small and large rockets, balloons, parabolic flights, amateur rockets, and the ISS. Student-built payloads are typically small, from ping-pong-ball-sized experiments to CubeSat form factors. The costs range from $500 to as much as $300,000 for universities. High costs in the upper range for universities include launch costs for CubeSats, although universities are often able to take advantage of government-sponsored complimentary rides to orbit as secondary payloads. Based on these numbers a LunarCube is likely out of the reach of most universities acting alone, but six could combine resources to transport a LunarCube with Astrobotic. Additionally, costs to universities could be lowered through space agency educational program subsidies. Figure 21: Universities Utilizing Space-Related Educational Programs by Region (Tauri Group, 2011) below shows considerable university interest in space-related education.

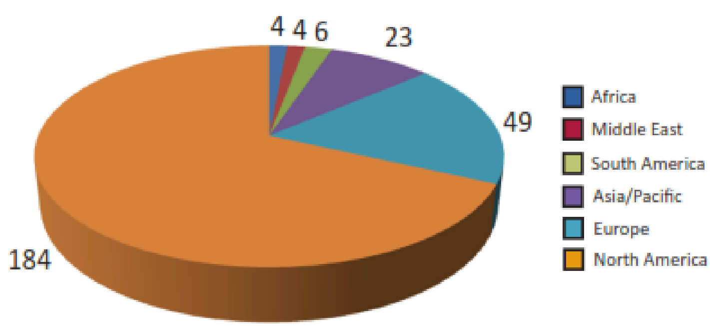


FIGURE 21: UNIVERSITIES UTILIZING SPACE-RELATED EDUCATIONAL PROGRAMS BY REGION (TAURI GROUP, 2011)

Demand Forecast

Baseline forecast reflects use of lunar landers and rovers for delivering education payloads to lunar orbit and the lunar surface growing in line with the overall growth trend estimates for nanosatellites (see Figure

31: Attempted Nano/pico-satellite deliveries). The six payload unit equivalents at the end of the forecast period reflects an assumption that roughly one quarter of universities' space-related spend will be directed toward the Moon or deep space, which ignores the potential for more schools to develop an interest in space or the potential for space-related education budgets to increase.

The growth scenario reflects strong use of lunar payload delivery due to high interest from students, given comparatively low and declining costs. Total demand grows to 11 LunarCubes at the end of the forecast period, as an assumed 20% of all 200 universities with indication of interest in space-related education eventually join financial resources.

The constrained scenario reflects light use of lunar payload delivery for education due to free alternatives for space education such as NASA-sponsored balloon flights or CubeSat launches. This forecast includes no growth beyond estimates of current demand.

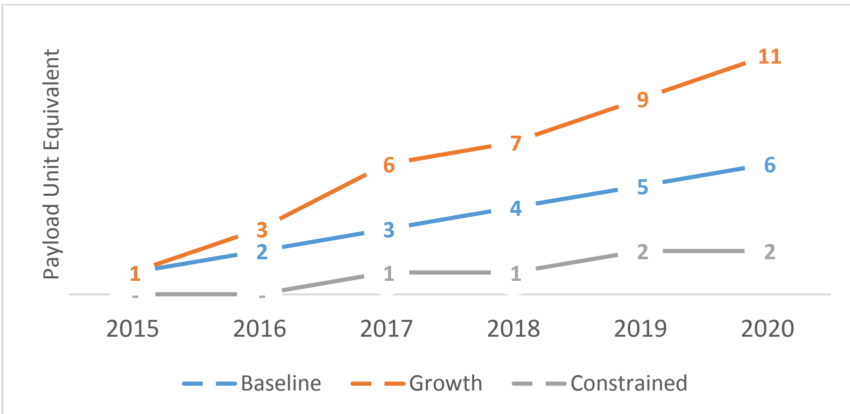


FIGURE 22: BASELINE, CONSTRAINED, AND GROWTH SCENARIOS FOR UNIVERSITY PAYLOADS

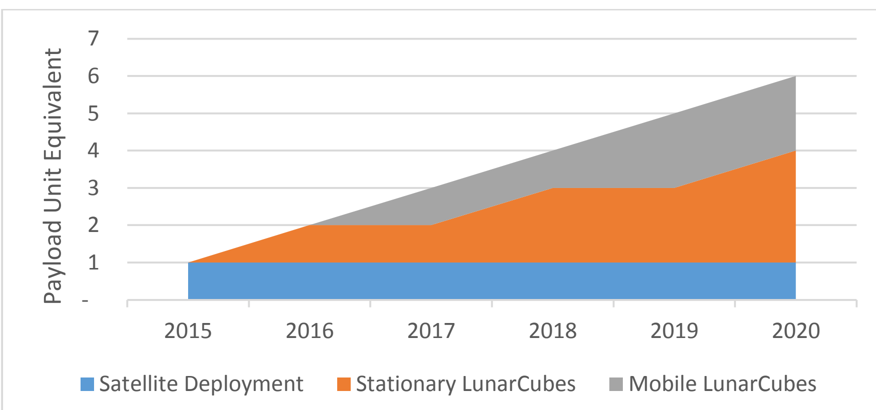


FIGURE 23: EDUCATION BASELINE COMPOSITION

Uncertainty

Due to the high cost of lunar payload delivery, it is unclear how well this service will be adopted for educational purposes. The ability or willingness of educational institutions to pool resources is also unclear and is a driver of demand. Additionally, no government subsidies are included in the forecast, however they have the potential to increase demand for the education market.

There are, however, indications of increased private spending to support space-related education. Galactic Unite (a collaboration between Virgin Galactic and Virgin Unite) has recently announced multiple full tuition scholarships for students pursuing degrees in physics at the University of Oxford. The recent Kickstarter campaign for ARKYD drew $1.5 million (50% more than its $1 million target) in funding with a prize for pledge levels of $5,000 providing educational institutions access to control the ARKYD telescope, plus teaching tools. Additionally, NanoSatisfi has recently partnered with Spaceialist to collaborate on Science, Technology, Engineering, and Math (STEM) education, allowing students from middle school onward to access an online curriculum, design experiments, and control NanoSatisfi's in-orbit Arduino nano-satellite using an interactive we interface for only $250. We are beginning to see more private funding go toward space science education, however the effect of this is not included in this analysis as it is still too early to tell where it will go from here.

Infrastructure, Support, Supplies

Infrastructure on the Moon, just like on Earth, will be the life-blood of industry, providing support services to all other markets. This study assumes that the first infrastructure project on the Moon will be to develop outpost alpha, followed by a period of growth and expansion. For any type of sustained lunar activity an outpost will be essential – a place to consolidate effort, amass resources, and build upon so as not to start from scratch each mission. Also, a well-developed transport and communications infrastructure will reduce the effect of distance between areas of interest, thereby allowing rapid development and utilization of multiple lunar regions. This study expects that the outpost will initially be used to support robotic missions, developing in-situ resource utilization (ISRU) capability.

INFRASTRUCTURE, SUPPORT, SUPPLIES

The market for products and services to support sustained commercial lunar activity

Energy, manufacturing, construction

Life support, medical care, sanitation

Transportation, communications

Beginning with no infrastructure to speak of, the tools, robots, and supplies necessary to develop this initial outpost must be transported from Earth and will make up a large part of the demand for this market in the early years (ie. the forecast period). After the forecast period, demand is expected to taper off to a more consistent, long-term demand curve as a more permanent presence is established. As mentioned previously, ISRU can dramatically increase the financial feasibility of even a small scientific project. Therefore ISRU will be a focus for both governments and industry as the cost savings attributed to local energy production, processing, and storage would greatly increase the sustainability of all lunar activities.

While not expected within the forecast period, establishing a permanent human presence on the Moon with a minimal need for supplies from Earth is an economic inevitability of sustained lunar activity. In this 2012 article, Dennis Wingo, author of Moon Rush, says, "Even with all of the advances in automation, humans are 100% required on the Moon. Murphy lives and no matter how many ways that you look at hardware failure and work out methods to preclude it, failure always finds a way to outsmart you. With enough infrastructure in place humans can also use their creativity to work out new things and new ways of doing things in that environment. Taking humans in the early days of lunar manufacturing outpost development may be expensive but humans are much more easily programmable than a machine and human problem solving skills will be necessary."

The following lists represent the technology and systems required to establish a quality and extensive lunar infrastructure. It is separated into three phases: Phase 1 represents the required systems for development of the initial outpost, Phase 2 represents infrastructure required to grow and expand the outpost, and Phase 3 represents necessary life support systems to prepare for eventual human settlement (see appendix B for more detail):

Phase I: Establish Outpost

- Site characterization and resource mapping (facilitated by RESOLVE, see *Resource Extraction*)
- Regolith excavation: small and large rovers, reactor burial
- Polar volatile extraction: drilling rover
- Regolith processing: mobile/stationary machines
- Power source: electric, solar array, nuclear reactors
- Landing pads, landing aprons, blast walls for protection of equipment at landing sites
- Communications / Navigation: locally and beaming back to Earth

Phase II: Expand Outpost

- Manufacturing & repair: parts, tools, 3D printing (additive manufacturing)
- Surface construction: robots, rovers, 3D printing (contour crafting)
- In-situ energy generation and storage: cryocoolers, liquid O2 storage, thermal management
- Surface transport: roads, rovers, hoppers
- Non-regolith resource processing: extraction and processing plants
- Spaceports: transport resources and people to/from Earth

Phase III: Life Support

- Habitats & shelter (elements, radiation): fitness, human centrifuge, climate control, air filtration
- Water supply: harvesting, oxygen generation
- Agricultural services, food production
- Product storage
- Refuse, sanitation, hazardous waste disposal, dust filtration systems
- Hospital / pharmacy / medical care
- Space (EVA) suits

The development and implementation of these systems will need to be tested and qualified according to the technology readiness levels (TRL) outlined in the *Science & Exploration* market section. The development timeline roughly follows these four steps: demonstrate feasibility, evolve system with improved technologies, develop system to TRL 6, and flight development for outpost. Fortunately, a number of these technologies are at or near TRL 6 in time for the first Astrobotic launch in Q4 2015. For instance, NASA has a number of small and large rovers in a mature stage of development including RESOLVE, Cratos, K-10, Pressurized Lunar Rover (SEV), Robotic Centaur, ATHLETE, and Chariot; Russia has a rover for its Luna missions; China has Chang'e 3 and Chang'e 4; India has a mini-rover for the Chandrayaan-2 mission; Astrobotic has Polaris, Red Rover, and Tybot; a number of other GLXP teams have rovers in mature stages of development as well. Made in Space's 3D printer, part of NASA's Flight Opportunities Program, has passed a series of microgravity flight tests and will now be going to the ISS for further testing. This has the potential to revolutionize the manufacturing and repair, as well as construction, capabilities on the lunar surface. Bigelow has signed a space act agreement with NASA to study the feasibility of an inflatable human habitat on the Moon. A NASA space suit program, supported by ILC Dover, is currently testing a Lunar/Mars Suit Prototype (I-Suit). The I-Suit has taken part in NASA's annual D-RATS field trials, during which suit occupants interact with one another, and with rovers and other equipment. Other emerging space suit prototypes include the Mark III, Bio-Suit, MX-2, and Aouda.X. Today NASA actively pursues technical innovation and scientific discoveries to advance human exploration of space. To help prepare for the challenges, NASA relies on Earth-based missions that are similar, or analogous, to space. Through D-RATS, NASA has matured a great deal of technology developed for lunar environments. While there is much development and qualification yet to be done to establish an extensive lunar infrastructure, these examples serve to point out that there has been a great deal of progress made to date and that there are qualified payloads that are ready to be sent to the lunar surface now.

Demand Forecast

This study assumes that the primary demand for the infrastructure market will come from government and industry efforts to utilize local resources and build a lunar outpost. This analysis expects that transportation for qualified rovers and other robotics to carry out these efforts will begin in the same year as NASA's RESOLVE prospecting mission (2017) and will be carried out according to the approximate timelines outlined in NASA's own ISRU reports (see Appendix F for detail). Through industry partnerships, NASA has matured a great deal of technology and systems in analogous environments through the D-RATS program. The baseline scenario uses the specifications of these systems and technologies to determine what will be transported to the lunar surface beginning in 2017, starting with a small 80 kg excavation rover and 25 kg of inflatable solar contractors as a power source. This is followed by additional Phase I infrastructure deliveries in subsequent years. In 2018 a large regolith excavator (230 kg), polar volatile extractor (120 kg), and more solar contractors (25 kg) are delivered. Robotics for Phase II infrastructure begin to be delivered in 2019, made up primarily of a 3D printer (50 kg), construction robot (Robonaut, 150 kg), energy storage (50 kg), and a small surface transport rover (80 kg). In 2020, similar deliveries of Phase I & II infrastructure continue, with the addition of the 425 kg ATHLETE transport rover constituting nearly half of the years demand. After 2020 the payload sizes are expected to continue to increase as the larger 1,000 kg Chariot and 4,000 kg Pressurized Rovers are delivered to the lunar surface in deconstructed/manageable sections. Phase III infrastructure hardware and systems to support human life are not expected to be delivered during the forecast period.

The growth scenario follows a similar development path to the baseline scenario, with Phase I infrastructure deliveries beginning in 2017 and ramping up in 2018. However, the growth scenario ramps up more quickly and NASA opts for a larger polar volatile extraction rover initially, similar in size to the RESOLVE rover. Phase II infrastructure hardware begins earlier in 2018 with the delivery of a 3D printer representing accelerated qualification. In 2019, Phase II deliveries pick up rapidly and continue into 2020. The growth scenario assumes deliveries of construction, repair, and surface transport robots will continue through the last year of the forecast period and there is an increased urgency for energy generation, storage, and non-regolith resource processing. Similar to the baseline, Phase III hardware and systems are not expected to be delivered during the forecast period.

The constrained scenario assumes that Phase I infrastructure deliveries are delayed two years from the baseline scenario, not beginning until 2019. The constrained scenario also assumes that no deliveries of Phase II or III infrastructure hardware occur within the forecast period.

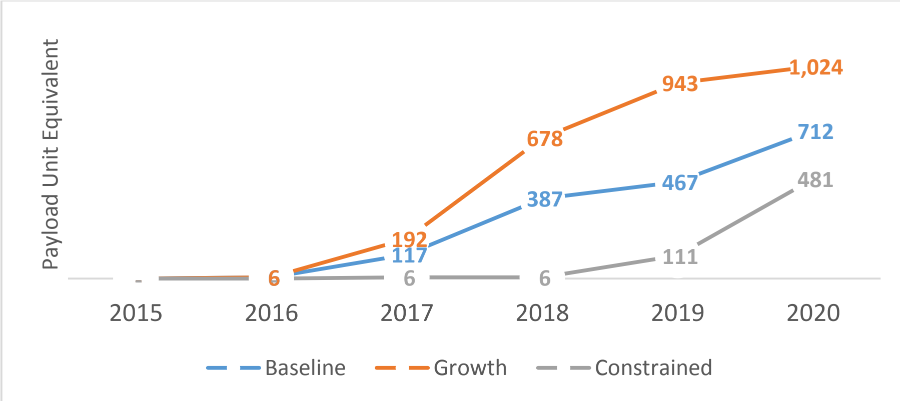


FIGURE 24: BASELINE, CONSTRAINED, AND GROWTH SCENARIOS FOR INFRASTRUCTURE, SUPPORT, SUPPLIES

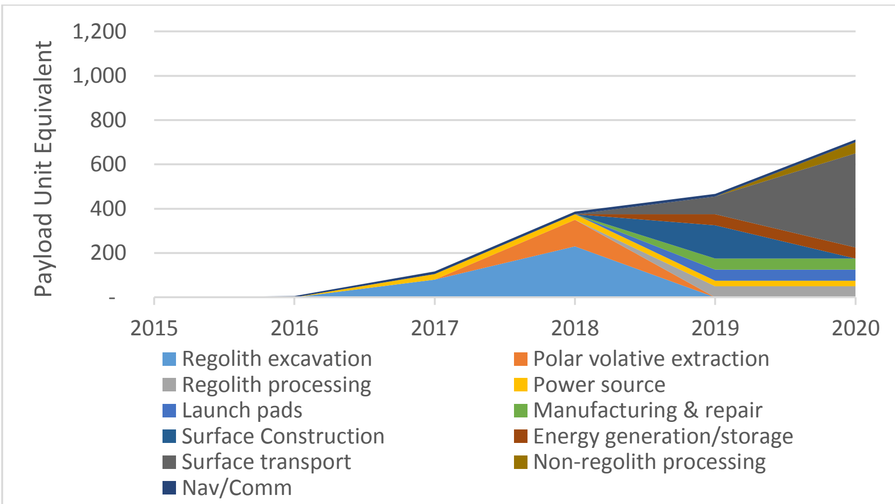


FIGURE 25: BASELINE DEMAND FORECAST BY SUBMARKET

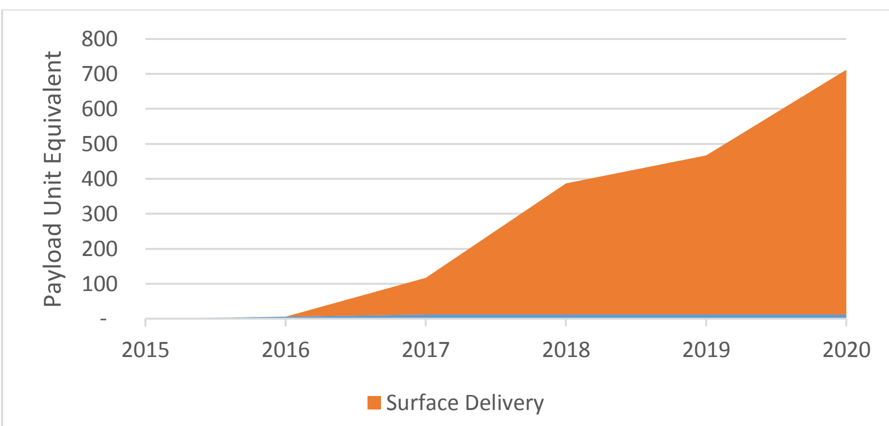


FIGURE 26: BASELINE DEMAND FORECAST BY SERVICE

Uncertainty

Of all the markets outlined in this report, this might be the most uncertain. While the demand forecast relies heavily upon NASA reports for ISRU and outpost development, the timing of when these technologies and systems will be transported is highly uncertain. This report built demand scenarios based on actual hardware mass and estimates of which hardware will be used for each activity, but the proposed activity may change and the actual hardware selected to carry out particular missions may vary. A change in any of these variable would have a significant impact on the demand scenarios.

Media & Advertising

The market for media and advertising includes film & television documentaries, advertising and sponsorship of lunar hardware, and Moon novelties.

MEDIA & ADVERTISING

Using the Moon to promote products, increase brand awareness, or film moon-related content

Media, advertising, and sponsorship

Film & Television

Novelties & Memorabilia

Film

Is there a market for lunar movie production? Since the early 1900's there have been at least 330 movies made which feature extraterrestrial life and another 189 movies made about outer space (there is some overlap). If we account for just the movies made after the historic 1961 launch of Russian cosmonaut Yuri Gagarin, the number of films which feature alien life or are about outer space is 461. While this list includes some smaller studio films, it also includes major studio blockbusters like Avatar and Men in Black. According to TheNumbers.com, the actual cost of making a Hollywood movie, produced by a major studio, is $139 million per film on average. Additionally, a studio may spend anywhere from $1 to 30 million marketing the film. This brings an estimate of total cost per movie to roughly $150 million. Applying some simple math we can see that since 1961, Hollywood has spent $69 billion on space related cinema.

The most recent high-profile example of incredible interest in space-related films is Avatar. Estimates put the cost of that film at about $280-310 million to produce and an estimated $150 million for marketing, approximately $450 million in total. James Cameron is a space enthusiast and is an advisor to Planetary Resources, but he isn't alone in his passion for space. Demand for this type of movie was proven at the box office as Avatar made total world-wide revenue of $2.8 billion. With increasingly larger amounts of money directed to films of this type, and with space advocates like Cameron continuing to make them, there could be a market for lunar movie production.

Cameron also backed the development of a 3D zoom camera system to replace the main fixed focal-length camera on NASA's Mars Curiosity Rover. While unfortunately the project had to be shelved due to a lack of time to get it ready before the mission's launch, Malin Space Systems is continuing to develop the zoom system which is expected to be available for use on future missions, including a mission to the lunar surface.

In addition to films and movies, there is a large number of televised documentaries that focus on the space industry, space exploration, and current space missions. Here are just a couple of examples:

1. It has been reported that the writers from the hit TV series Mad Men have pitched a new show about the early days of the US space program.
2. The field test mentioned earlier in the technology demonstration market section of this report will be featured as part of an upcoming television documentary filmed by First Canyon Media,

Inc., titled Mission Asteroid. Produced by Canadian Broadcasting Company (CBC) and expected to air in fall 2013.

Astrobotic can meet the demands of the film/movie business by delivering high-resolution imaging satellites to lunar orbit/Lagrange points or delivering robot film crews to the lunar surface aboard the Griffin lander.

Advertising

There are a few companies that have worked or are currently working to leverage advertising as a source of funding for space missions. For example, BlastOff! was a small aerospace company that operated from 1999-2001, created to capitalize on the public interest of space travel and exploration. The company's mission was to do entertainment space missions, ie. flights that would pay for themselves through the sales of advertising, media content, action figures, etc. While a majority of the hardware for its only concept mission, Lunar 1, had been ordered and received, it was never completed or launched. Another example is Mars One, a private spaceflight project aiming to establish a permanent human colony on Mars, beginning with a one-way trip for four in 2023. A global reality TV event is intended to provide most of the funds to finance the expedition, which is expected to cost $6 billion. While the project might seem improbable, it gains some credibility from an endorsement by Nobel Prize winning physicist Gerard 't Hooft. Additionally, as of 8 May 2013, over 80,000 people had completed a rigorous application which includes an application fee of up to $75. Simple math shows that Mars One has collected approximately $6 million in revenues already. These examples further demonstrate the significant public interest of space travel and exploration and their willingness to pay.

Advertisers typically work on a near-term time horizon. While Astrobotic has not had success securing advertising revenue to this point, this report expects that this revenue stream will open up as the launch date nears. There is expected to be a lot of media attention surrounding the Astrobotic missions, which the company has an opportunity to capitalize on. Over the past 20 years, there have been an average of 1.25 space-related advertising campaigns per year filmed on space vehicles or balloons. Costs have varied widely, ranging from several hundred dollars on a high-altitude balloon to several million for an orbital flight.

Year	Status	Cost	Type	Platform	Company	Description
1993	Cancelled	$500,000	Logo Placement	Rocket	Columbia Pictures	To promote the "Last Action Hero" movie.
1996	Proposed; never filmed	No available data	TV commercial	Mir	Beefjerky.com	To promote "Final Frontier Jerky".
1996	Proposed; never completed	$750,000	Multi-media campaign	Shuttle	Coca-Cola	Soda Fountain Experiment
1996	Proposed; never completed	$3,000,000	Multi-media campaign	Mir	Pepsi-Cola	Advertisement featuring cosmonauts.
1997	Filmed	$450,000	TV commercial	Mir	Tnuva (milk)	TV ad showing Mir cosmonaut Vasily Tsibliyev drinking Israeli milk.
1998	Filmed	No available data	TV program	Mir	Fisher Space Pen/QVC	Russian cosmonauts appeared live on the QVC shopping channel to promote the $32.75 Fisher Space Pen.
1999	Filmed	No available data	TV commercial	Mir	More.com	Commercial for the More.com online drugstore.
2001	Filmed	No available data	TV commercial	ISS	Radio Shack	Astronauts received Father's Day gifts from Radio Shack.
2001	Complete	$2,300,000	PR and Logo placement	Rocket (Proton) and ISS	Yum! Brands/ Pizza Hut	Pizza Hut delivered to space; also placed a logo on the side of a Proton rocket in 1999.
2001	Complete	$0	PR - Promotion	ISS	Beefjerky.com	To promote "Final Frontier Jerky", flew a small amount of jerkey to the ISS.
2001	Complete	No available data	Logo Placement	ISS	Kodak	A Kodak logo was placed outside of the ISS.
2004	Complete	$6,000,000	Multi-media campaign	Zero-G	Diet Rite	Yearlong campaign including sponsorship of The Biggest Looser, six-city "Go For Zero" tour, commercials, and associated PR.
2005	Filmed	No available data	TV commercial	ISS	Nissin Food Products Co	Commercial for instant ramen, part of Nissin's "Cup Noodle No Border" campaign.
2006	Complete	$5,000,000	Multi-media campaign	ISS	Element 21	Russian cosmonaut hit a golf ball to promote Element 21's line of clubs.
2008	Filmed	$165,000	TV commercial	Zero-G	7-Up	Promoting the "Free Ticket to Space" sweepstakes.
2008	Filmed	$165,000	TV commercial	Zero-G	Mastercard	Briefly shows points for a Zero-G flight.
2009	Filmed	No available data	TV commercial	Balloon	Toshiba	Commercial touts Toshiba's HD cameras and LCD displays as "armchair viewing, redefined".
2011	Filmed	No available data	TV commercial	Balloon	CitiBank	Buying a weather balloon with points.
2011	Filmed	$165,000	TV commercial	Zero-G	Justin Bieber	"Someday" perfume commercial filmed on Zero-G.
2012	Complete	No available data	Sponsorship	Balloon	Red Bull	Sponsorship of the Red Bull Stratos high-altitude skydive
2013	Ongoing	$2,000,000	Multi-media campaign	SXC Lynx	Unilever (AXE)	"AXE Apollo Space Academy" contest, series of "Nothing Beats an Astronaut" commercials
2013	Complete	No available data	Multi-media campaign	SXC Lynx	KLM	Contest to win a flight aboard Lynx by guessing the location of a high altitude balloon at burst.
2013	Ongoing	No available data	TV commercial	SXC Lynx	Luminox	Commercial promoting watch made for space, part of "Essential Gear. Made for Space" campaign.

TABLE 6: EXAMPLES OF SPACE ADVERTISING & PR EFFORTS

This study assumes that the lunar surface will open up new advertising channels and specifically calls out three potential revenue opportunities from advertising: 1) naming rights for lunar landers and rovers, 2) logos and advertisements placed on lunar hardware, and 3) transporting advertising artifacts manufactured by the purchasing company for deposit on the lunar surface.

Naming Rights: Earlier this year Bigelow Aerospace announced pricing of $25 million per year for full naming rights of its Alpha Station, BA 330 inflatable module. This price was reportedly determined based on the pricing for stadium naming rights as a comparable. The value of stadium naming rights increases in proportion to the number of events held at that venue. Content drives higher value of naming rights, so the more that venue appears in the media, the more the sponsoring company’s name is called out to a mass audience. Therefore, in order for Bigelow to secure a similar price for Alpha Station naming rights, they must convince a potential buyer that their station will get equivalent press or reach the same sized audience. This report believes those figures are probably too high, but that there is in fact a significant revenue opportunity in naming rights. There will undoubtedly be a substantial amount of press in the beginning, but a key question will be whether or not it can maintain consistent attention. Astrobotic has an opportunity to sell naming rights as well for the lander, rover, or other hardware.

In the absence of comparables, it is difficult to estimate the price that organizations will be willing to pay for naming rights. The first question is whether or not Astrobotic missions will draw the same number of viewers as sporting events. The answer is probably no, but it is likely still a significant figure. The best and most recent proxy of the reach that companies can expect is Felix Baumgartner's Red Bull Stratos spacedive, which topped 8 million concurrent views on YouTube. While this reach would cause any marketer to sit up and pay attention, it is still less reach than what a sports stadium can bring in over the course of a year. Therefore this report assumes that $5 million would be the going rate for a year's worth of naming rights on a lunar rover and will be based on a contract for as long as the rover will operate. The lunar lander is likely to get a lot of initial attention, but will likely experience diminishing returns as rover missions begin to steal the show through discovery and deeper exploration. This report estimates naming rights of the lander to be half that of the rover, or $2.5 million for one year (could also benefit from a higher price if it will stay on the Moon and be used in some manner in perpetuity). Therefore, naming rights represent a combined $7.5 million opportunity in year one.

One thing to keep in mind is that all other Astrobotic customers will have the ability to sell naming rights of their proprietary rovers and lunar robots. This could affect the market in two ways. One, it create competition for a limited demand and drive the prices lower. Or two, it could increase awareness of naming space hardware as a viable marketing campaign, driving demand and overall profits higher.

Logos & Advertisement: A less expensive option than complete naming rights could come from logos and advertisements placed on the physical lander, rover, and other lunar hardware. These activities have the ability to generate revenue without disrupting mission activities. Potential customers are companies with ambitions to operate in the lunar environment, and Astrobotic could meet this demand by placing stickers on lunar hardware or manipulating the lunar environment. There will likely also be opportunity in sponsorship. In 2007, Caterpillar proved interest in this service by sponsoring Carnegie Melon's winning machine in the Urban Challenge.

In terms of logo placement, think of what an effective marketing tool it would be to paint the Moon red in the style of the Coca-Cola logo, reaching every person on Earth who looks at the night sky. While that might not be sensible or feasible, it does help to make a point. Many corporate customers may wish to imprint a more modest version of their logo on the lunar surface, which Astrobotic could satisfy with its rovers.

Artifacts: In addition to naming rights, companies may find it more cost effective to build their own advertisements/sign posts to be transported and deposited on the lunar surface. Additional demand could come from other nations wishing to put self-erecting flags on the Moon's surface, or corporate customers that wish to send mementos to the lunar surface. Astrobotic can meet the demand for both commercial and government advertising through lunar payload delivery.

Novelties & Memorabilia

Celestis Memorial Spaceflights is a service that will fly a portion of cremated remains into suborbital space, Earth orbit, onto the lunar surface, or into deep space. The company has flown its canisters on 11 launches, carrying the remains of over 800 individuals. The service was inaugurated in 1999, when at the request of NASA, Celestis assisted the colleagues and loved ones of Dr. Eugene Shoemaker to place a portion of his cremated remains aboard the NASA Lunar Prospector mission. Celestis offers one-gram "Flight Capsules" or seven-gram "Flight Modules". Pricing for Luna Service can be seen in Figure 27: Celestis Pricing for Luna Service. The memorabilia market have met with mixed success: including *Space Wed* who flew 50 sets of wedding rings to space in 2011, *To Space* who brokered sending personal items to space, and *Bigelow Aerospace* who flew small personal items aboard Genesis II for a $300 fee.

Luna Service Options	Price
Capsule Option (1 gram total) — Launches cremated remains sample of one person	$12,500
Gemini Capsule Option (2 grams total) — Launches cremated remains sample of two people	+50%
Module Option (7 grams total) — Launches cremated remains sample of one person	+100%
Gemini Module Option (14 grams total) — Launches cremated remains sample of two people	+200%

FIGURE 27: CELESTIS PRICING FOR LUNA SERVICE

Demand Forecast

The media and advertising forecast separately analyzes the markets for film, advertising, and novelties and memorabilia.

The **film** baseline forecast reflects interest in filming documentaries and TV programming from robots on the lunar surface or from high resolution imaging satellites in lunar orbit. Based on historic trends in space-based documentaries, about one movie/documentary will be shot on the Moon or from lunar orbit per year. This assumes that the television and film industry will be interested in documenting the developments on the lunar surface through filming robots and high resolution imagery from lunar orbit. The baseline scenario assumes that one 10 kg filming rover will be launched every other year beginning in 2016 and one 6 kg imaging satellite will be launched to lunar orbit/Lagrange point on alternating years. The growth scenario assumes that the number of filming robots will increase to one each year, while the constrained scenario assumes no filming during the forecast period.

The baseline forecast for **advertising** reflects corporate interest in acquiring annual naming rights of the lunar lander and rover for a combined 4 payload unit equivalents per year ($7.5 million) and logos and sponsorship on the lander and other lunar hardware for an equivalent of 2 payload units per year ($3 million). The baseline also assumes that one artifact weighing 5 kg will be launched each year throughout the forecast period. The growth scenario assumes an increase in price for naming rights for the lander, rover, and logos & sponsorship by 50% per year, and artifact delivery increasing to 20 payload unit equivalents by the end of the forecast period. The constrained scenario assumes a 20% reduction in the price of naming rights and logos & sponsorships, and no artifacts delivered throughout the forecast period.

The baseline forecast for **novelties** is based on the current demand of two payload unit equivalents per year increasing to nine four per year by 2020, while the growth scenario increases demand by 50%, and the constrained scenario remains at one payload unit equivalent throughout the forecast period.

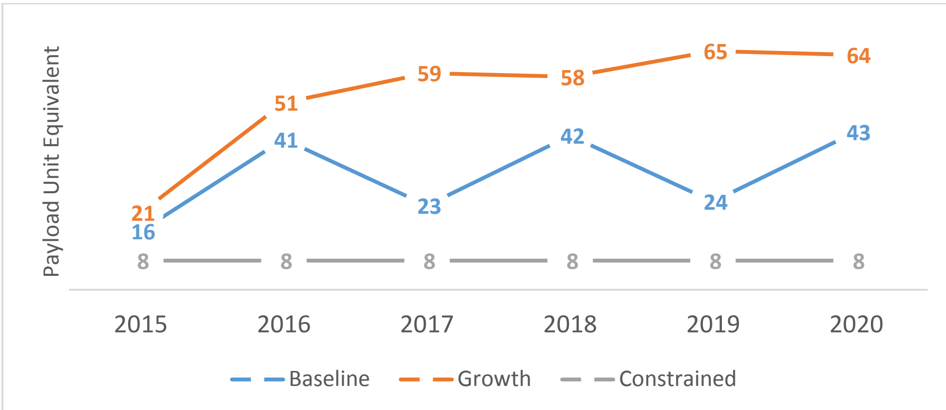


FIGURE 28: BASELINE, CONSTRAINED, AND GROWTH SCENARIOS FOR MEDIA & ADVERTISING

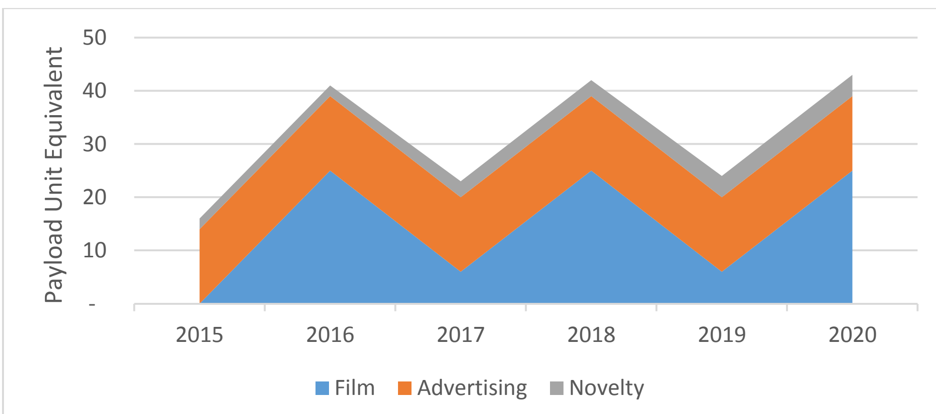


FIGURE 29: MEDIA & ADVERTISING BASELINE BY SUBMARKET

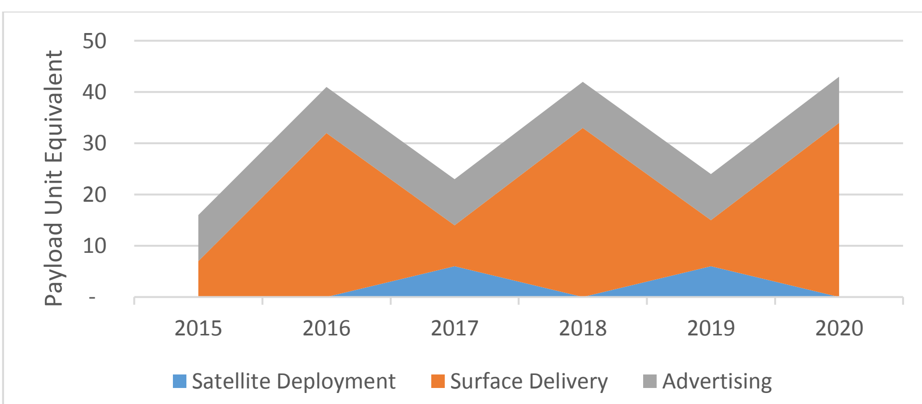


FIGURE 30: MEDIA & ADVERTISING BASELINE BY SERVICE

Uncertainty

The forecast for film and television documentaries on the Moon is based on historical data showing an average of 1.5 films about space produced per year. While the forecast shows steady interest in lunar activity throughout the forecast period as human presence increases, this is highly depended upon viewer interest which may or may not support that volume.

This naming rights in this study are based upon two disparate data points: Red Bull Stratos viewership and Bigelow pricing, which was based on a terrestrial form of advertising. As of this writing Bigelow has not yet sold the naming rights for its Alpha Station and so the market for lunar advertising is still unproven. Stadium deals might not be the best comparable, and the actual amount of revenue that a lunar transport company can get from naming rights might vary greatly. Furthermore, the price of naming rights is extremely dependent on the macroeconomic environment and any changes to the economic landscape could have an impact on demand.

Service Differentiation

The list of current or aspiring players offering lunar payload delivery is short. There are currently 23 teams competing for the $30 million Google Lunar X Prize (GLXP), however the competition appears to be down to Astrobotic and Moon Express. Not trivially, Astrobotic is the only team in the competition with a launch date, scheduled for Q4 2015 aboard a SpaceX Falcon 9 rocket. While many of these organizations involved in the competition are focused on completing the designated tasks by 2015 deadline, their long-term plans are to offer long-term lunar services.

Service Offering

Astrobotic currently has the capability to offer four primary services and two secondary services:

Primary:

1. Trans-lunar injection or satellite deployment to lunar orbit/lunar Lagrange points
2. Stationary LunarCube delivery to lunar surface aboard lander
3. Mobile LunarCube delivery on the lunar surface aboard rover
4. Customized payload delivery to lunar surface aboard lunar lander

Secondary:

1. Data Sales: cost-effective way for customers to obtain contracted Astrobotic data
2. Advertising: naming rights, logos & sponsorship, and artifact delivery

Proprietary Lander

Currently, Astrobotic is the only GLXP team that has a lunar lander to get them from lunar orbit to the lunar surface which has been fully developed, assembled, and tested. Griffin uses the same tested and reliable propulsion technology as the space shuttle, reducing uncertainty and risk. Further testing and more accurate lander success rates will come following drop testing aboard Masten Space Systems' Xaero rocket at 4 kilometers. Building this technology in house has allowed Astrobotic to keep costs low and develop on the cheap. A low cost base is a significant competitive advantage for a company with long-term plans to provide lunar services. Staying ahead of the curve has additional benefits as well. The additional time and testing will go a long way to ensure mission success and reduce mission costs as insurance rates will surely be lower than untested competitors.

The only other GLXP team with a lander in an advanced stage of development is Moon Express, who is licensing NASA's "common spacebus" technology through a space act agreement. In June 2011, Moon Express conducted its first successful test flight of the spacebus prototype dubbed the Lander Test Vehicle (LTV). Moon Express is licensing NASA's common spacecraft bus technology as their lunar lander in the GLXP competition.

Payload Capacity

Capacity is obviously a key competitive advantage as higher volume allows for more competitive pricing. Astrobotic can carry more payload than any other player in the market – 270 kg to the surface.

Pricing

Astrobotic currently has pricing for four different services: 1) payload delivery to trans-lunar injection (TLI), 2) satellite delivery to lunar orbit/Lagrange points, 3) payload delivery to lunar surface aboard the Griffin lander, and 4) payload delivery to lunar surface destination on a robotic rover. Other potential revenue streams are advertising and data sales, which are not currently priced. This is talked about in greater detail in the "market size" section. Pricing for each of the existing options varies. Full pricing for TLI, orbit, lander, and rover payload deliveries can be seen in Table 7. Astrobotic Payload Pricing below.

Astrobotic Pricing ($millions)	**Capacity (kg)**	**1U**	**2U**	**3U**	**6U**
Trans-lunar Injection (TLI)	663	$ 0.10	$ 0.20	$ 0.30	$ 0.59
Lunar Orbit	515	$ 0.20	$ 0.40	$ 0.59	$ 1.19
Lander to surface	270	$ 1.20	$ 2.40	$ 3.60	$ 7.20
Rover (mobile) on surface	120	$ 2.00	$ 4.00	$ 6.00	$ 12.00

TABLE 7. ASTROBOTIC PAYLOAD PRICING

The only other entity that has announced pricing for payload delivery to the lunar surface is Moon Express, for $3 million/kg. The considerably higher price (67%) may be because they are using a government lander and the full cost of their launch mission is still unscheduled and unknown. Astrobotic was able to develop, build, and test their Griffin lander for $450k. Bob Richards, CEO of Moon Express, has said himself that private enterprise can do things much more cheaply and efficiently than governments, and those savings can be seen in Astrobotic's lower price. There is no doubt that at this moment, Astrobotic is the cost and capacity leader for lunar payload delivery.

Launch Mission

Another critical dependency is the ride into space and trans-lunar injection. Again Astrobotic is alone among GLXP contenders as the only competitor with a launch mission scheduled, aboard SpaceX's Falcon

9 rocket. Moon Express reportedly plans to launch aboard a Falcon 9 rocket or another commercial vehicle, but nothing is scheduled as of the time of this writing. While Barcelona Moon Team claims to have a flight scheduled aboard a Chinese rocket, this study has found no reports to substantiate this claim.

-END-

Appendices

Appendix A: Nano-Satellites Trends & Growth

Nano-satellites as a proxy for LunarCubes

An analysis of the market trends for small satellites can serve as a proxy and validation for the demand for LunarCubes. The following section looks closely at the growing market for Nano-satellites to better understand the evolving demand for space science and application, from which this study has extrapolated demand for LunarCubes.

The market for small space payloads is at an exciting and complicated time in its development, with all signs pointing to substantial growth over the coming years. Historically, getting small satellites into orbit has been a challenge. For CubeSats in particular that cost somewhere around $40k or less to develop, it is just too expensive to fly as a dedicated payload aboard a heavy rocket. Therefore, these small satellites typically get to space as secondary payloads, piggybacking on larger launch missions. Larger payloads lease a certain amount of cargo space on the rocket and rent out any remaining capacity to secondary payloads to reduce overall cost. This means that small sat developers are at the mercy of the development timelines of other, larger projects. While there has not yet been enough demand to justify the development of smaller rockets, dedicated to smallsat payloads, reports by the FAA and SpaceWorks project strong growth. SpaceX was developing a smaller Falcon 1 rocket for small sat delivery, however low demand in 2008 caused them to put the project on hold. With demand increasing for nano-satellites, there is increased interest in the smallsat launch space. Commercial space tourism companies are looking to get into this business by using re-usable launch vehicles such as Virgin Galactic's LauncherOne, XCOR's Lynx Mark III, of Swiss Space System's suborbital shuttle to fly dedicated small satellite payloads for much lower cost (and provide much needed revenue as develop human spaceflight capability).

Generally accepted definitions of satellite mass classes under 500 kg are: Small (100-500kg), Micro (10-100kg), Nano (1-10kg), and Pico (<1kg). Many satellites are based on the CubeSat standard of 10 cm^3 and a mass of no more than 1.33kg, developed by California Polytechnic Institute and Stanford University in 1999. CubeSats are measured in "Units" (or "U"), where each Unit is 10 cm^3 and each Unit has a mass close to 1kg, not to exceed 1.33kg. This standard allows for ease of design and integration, and the nano/microsatellite market has grown considerably with its adoption. In an effort to estimate the market demand for LunarCubes, this study leverages the quantitative market analysis and forecasts of the robust and growing nano-satellite market.

Today, nano-satellites are used primarily for Remote Sensing, Scientific Research, Biological Experiments, Military Applications, and Academic Training. Nano-satellite deployment is an emerging market building on success of university payloads and growing interest from government customers. University demand for nano-satellites (especially CubeSats), which traditionally dominates this market, is continuing to grow, especially in the international community. However, civil and defense agencies as well as commercial companies are increasing their use of nano-satellites and developing new capabilities and supporting infrastructure. Over 90% of very small satellites have been deployed as piggyback payloads on existing launch vehicles.

Deployment method	Vehicles	Payload Capability (kg)	Cost
SRV	Planned: Lynx III	Up to 12 kg	$500,000 for 12 kg
Secondary (Piggyback/ Rideshare) Payload	Dneper, PSLV, Falcon 9	Varies	$40,000 for 1 kg; $12.5M for small satellites
Small satellites grouped on a launch vehicle (existing)	One Shtil launch in 1998	Varies	Varies
Small satellite launch vehicles in development	Planned: SWORDS, KSLV 1 (Naro-1), Nanosat Launch Vehicle (NLV)	Generally 10 - 25 kg have been announced	~$1 million

TABLE 8: CURRENT OPTIONS FOR SMALL PAYLOAD DEPLOYMENT

Nano-satellites: Trends & Growth

Market trends for nanosatellites presented in this analysis are based on the Nano/Microsatellite Market Assessment, prepared by SpaceWorks®, February 2013. The nano/micro satellite market has grown considerably with the adoption of the CubeSat standard, technology development, and broader applications. We have seen historical average growth of 8.6% per year over the last 12 years (2000-2012). Estimated average growth of 16.8% per year over the next seven years (2013-2020), with an optimistic estimate of 23.4% over the same period. The graph below in Figure 31: Attempted Nano/pico-satellite deliveries shows signs of an emerging and sustained nanosatellite launch market. This information and is based upon publicly announced projects, so it likely understates the true volume of all projects underway, particularly military and high-profile corporate projects being kept secret. The future of dedicated small satellite delivery is dependent upon this projected growth. It is important to remember that in 2008, SpaceX put its Falcon 1 project on hold because they "could not securely manifest a sustainable amount [of volume] to keep the product line going". Volume has continued to grow modestly since that time, however announced launches in 2013/14 show significant growth in activity.

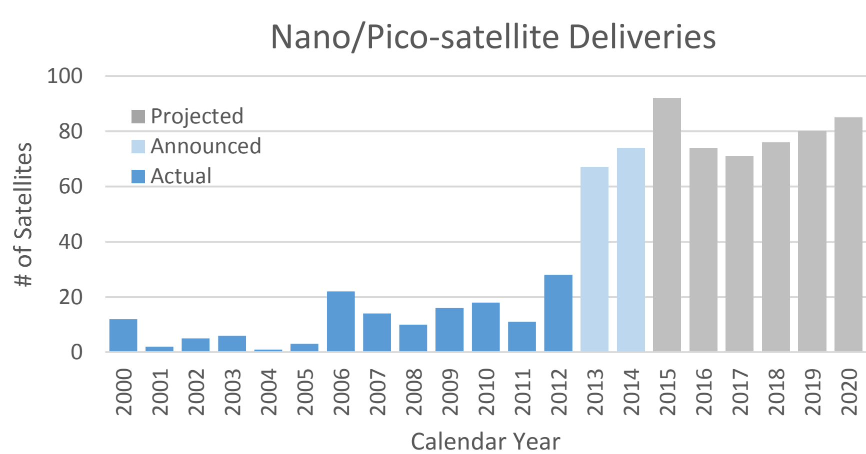


FIGURE 31: ATTEMPTED NANO/PICO-SATELLITE DELIVERIES

The chart below shows continued growth in nano-satellite launch projections through 2019. However, fewer satellites are expected to launch than the actual number projected as these are based on the announced plans of satellite developers, but delays often occur. For instance, as of November 2011 there were 58 announced satellite launches (1-50 kg), but only 35 actually launched. This is merely a timing issue however, as none of the announced projects were canceled or ended. The primary reasons for delay are issues/delays with launch or launch contract (55%) and satellite development issues (32%).

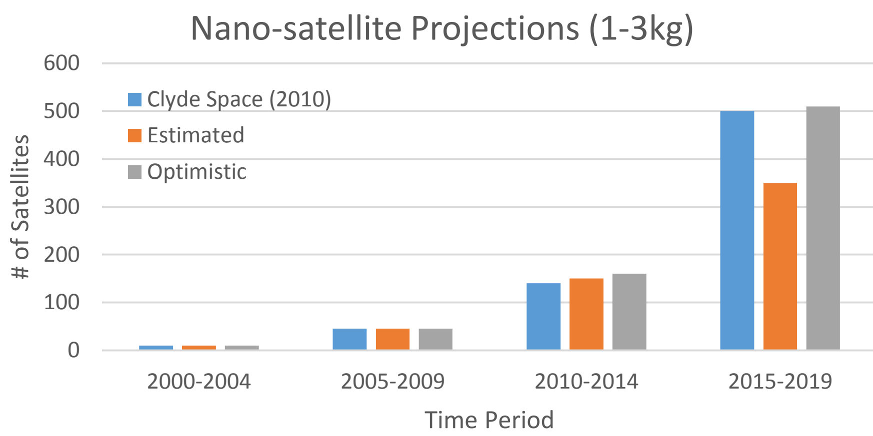


FIGURE 32. NANO-SATELLITE PROJECTIONS (1-3KG)

The number of announced future nano-satellite launches suggests continued growth in the historically popular 1U (1 kg) CubeSat, as well as emerging growth in the 2U and 3U nano-satellites. This demonstrates the increased interest and involvement of the defense/intelligence community. The majority of development of 1U CubeSats comes from academia (AAUSAT, 1 kg), while 2U and 3U nano-satellites are typically used for military applications (SMDC-One, 4 kg), biological experiments (O/OREOS, 5.5 kg), and scientific research (UNISAT, 1.5 kg).

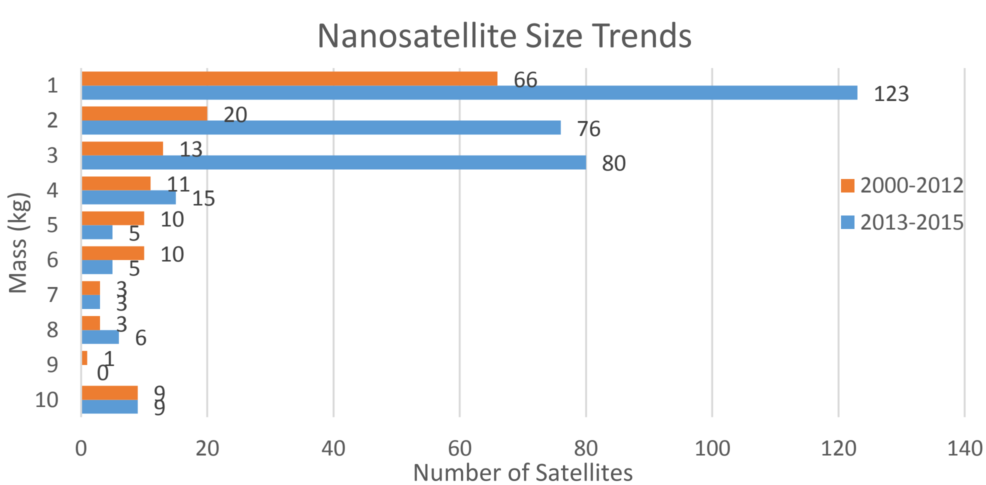


FIGURE 33. NANO-SATELLITE SIZE TRENDS

Applications for nano/micro-satellites are diversifying with increased use in the future for science, Earth observation, and reconnaissance missions. The chart below shows evidence that small satellites are being adopted for applications beyond technology demonstration.

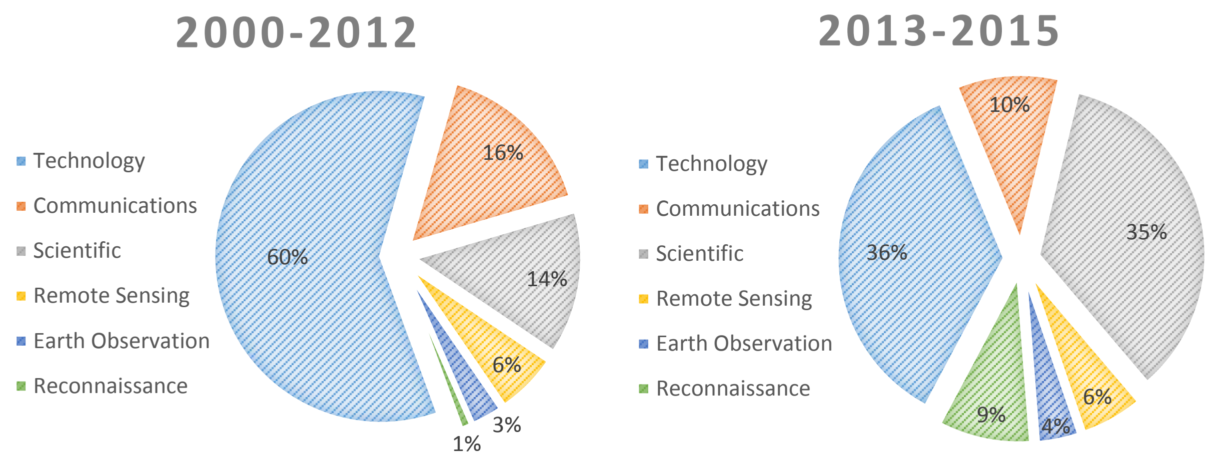


FIGURE 34. NANO/MICROSATELLITE TRENDS BY PURPOSE

Nano/micro-satellite development continues to be led by the civil sector (universities, federally funded research & development centers), but the defense/intelligence community is showing increased interest and involvement.

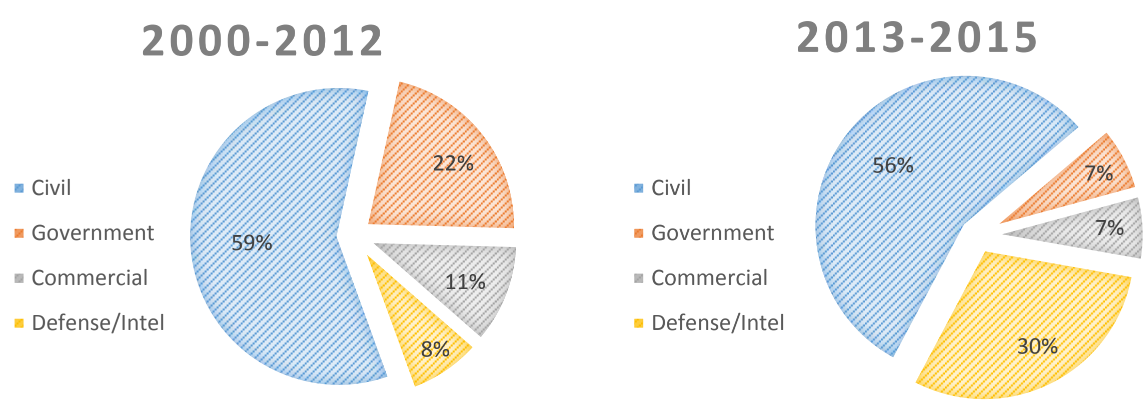


FIGURE 35: NANO-MICRO-SATELLITE TRENDS BY SECTOR

Appendix B: Technology & Systems Required for Lunar Outpost

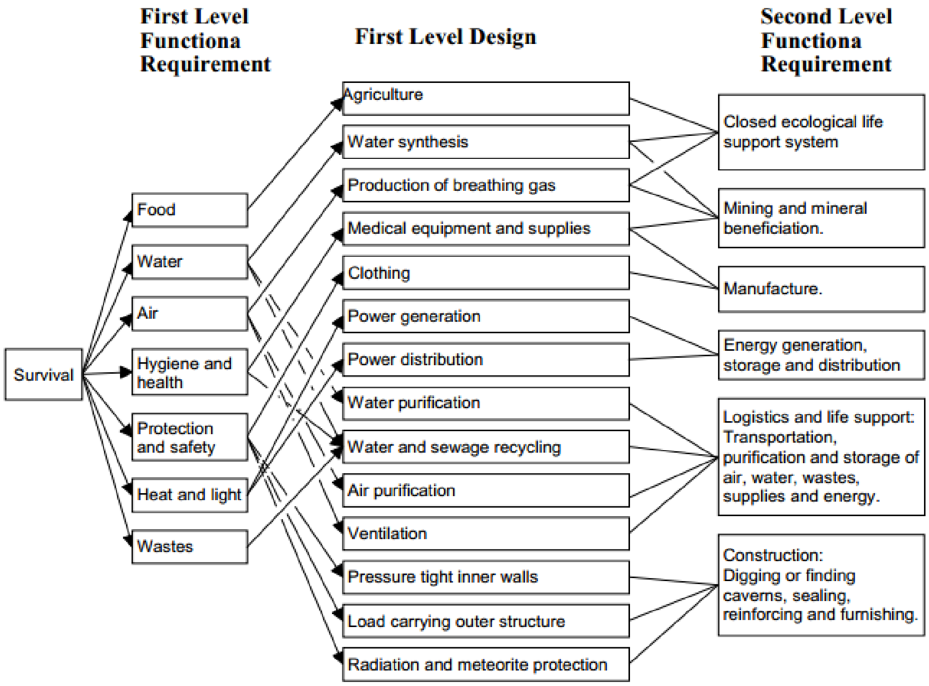


Figure 13. Requirement Breakdown for Human Survival

FIGURE 36: [ORBITEC]: STRATIFIED REQUIREMENTS FOR A HUMAN LUNAR COLONY

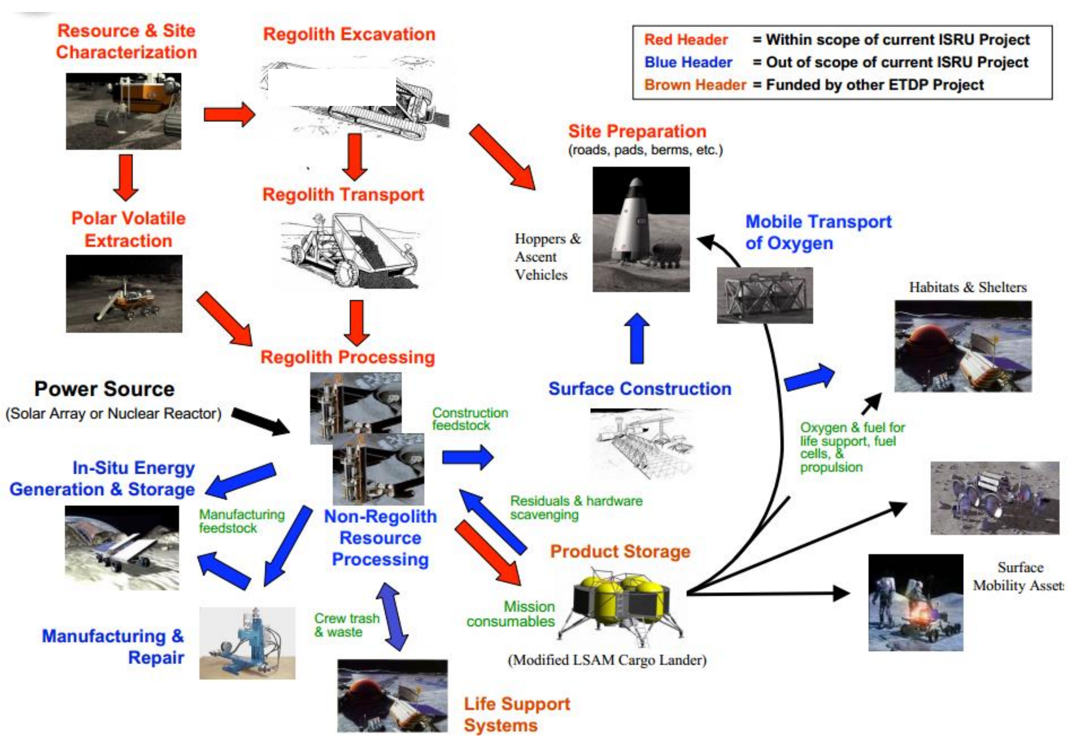


FIGURE 37: [NASA] IN-SITU RESOURCE UTILIZATION (ISRU) DEVELOPMENT & INCORPORATION PLAN

Appendix C: Map of Resources Needed for Lunar Colony

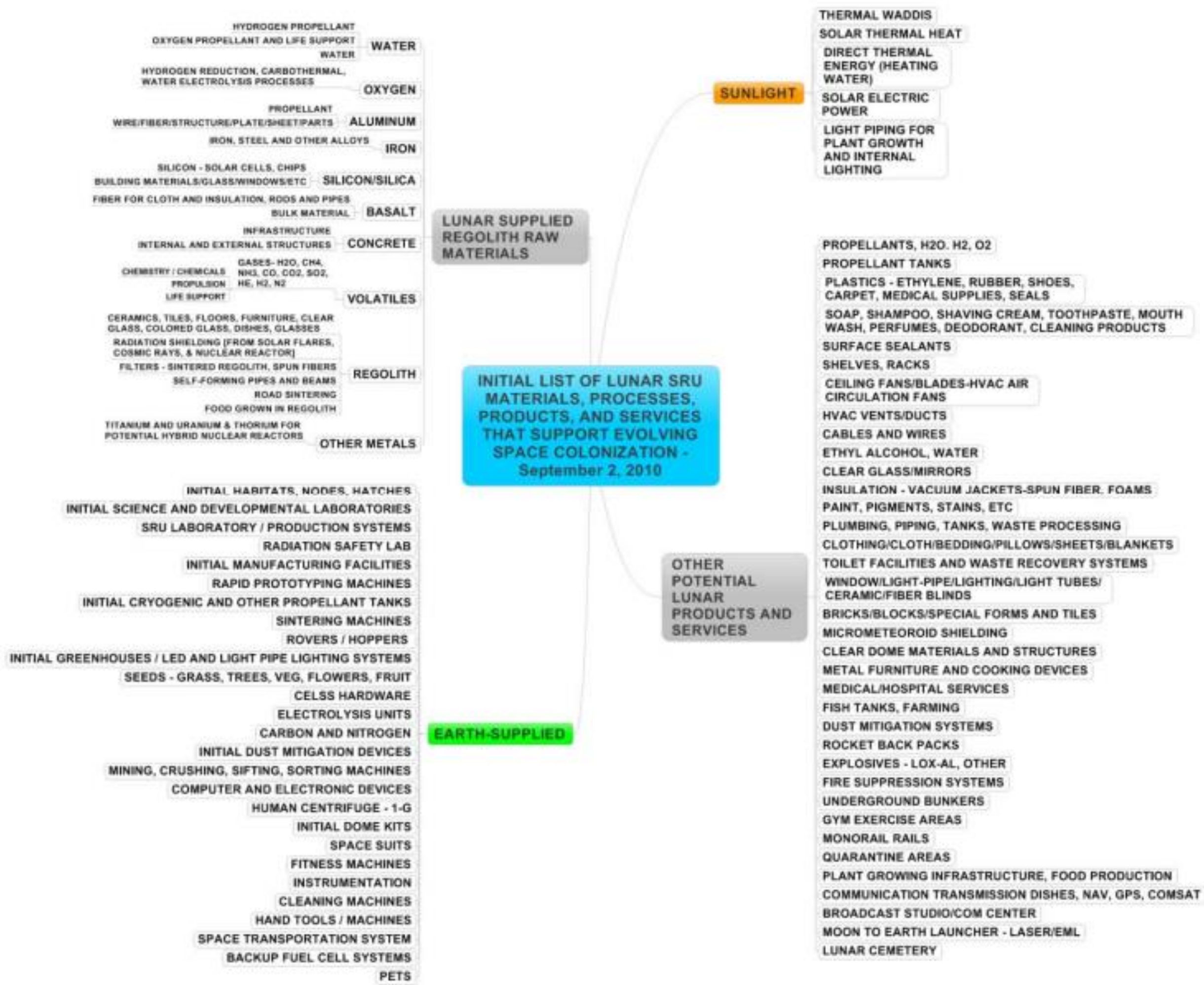


FIGURE 38: ORBITEC PHASE I STECKLER PROJECT

Appendix D: Possible Commercial Activities to Support Lunar Colony

Lunar Sports and Facilities, Amusement Park	Radiation Shields
Energy – Solar Power, Energy Storage, Solar Cell Production	Telemedicine Medical Services, Burn Treatment Services
Propellant Servicing, LOX Production, Water and Hydrogen Production, Volatiles Production	Rail Gun, EML, or Laser Beamed Propulsion Back to Earth, Probe Launching
Communications Services	High-Vacuum Manufacturing
Navigation Services, Flight and Ground	Archival of Data Assets
Entertainment with Rovers	Storage of Nuclear Materials
Movie Production	He3 Production
Advertising	Satellite Refueling and Servicing at the Depots
Transport Services	Water Extraction
Lunar Casino	Life-Support Services/Supplies
Lunar Tourism	Taxi Flight Service - Hoppers
Facilities - Habitats	EVA Systems
Raw Materials	Rovers
Lunar-Produced Products	Logistics Resupply
Space Resource Utilization (SRU)	Road Building and Excavating
Agricultural Services/Food Production	Mono-Rail Construction
Repair/Manufacture/Fab/Assembly	Mining
Microwave Power Transmission	Provision of Building Materials / Forms / Bricks
Large Mirror Manufacture	Self-Forming Pipes and Other Structural Shapes
Launch Lunar Materials Back to Earth	Centrifuge Facilities for Health and Fitness Services
Manufacturing of Solar Cells	Lunar Jewelry and Rocks for Sale
Detectors, Sun Observations, Solar Wind Measurements, Dust Measurements	Earth Power Beaming
Export Special Beverages to Earth	

A List of Possible Lunar Commercial Activities

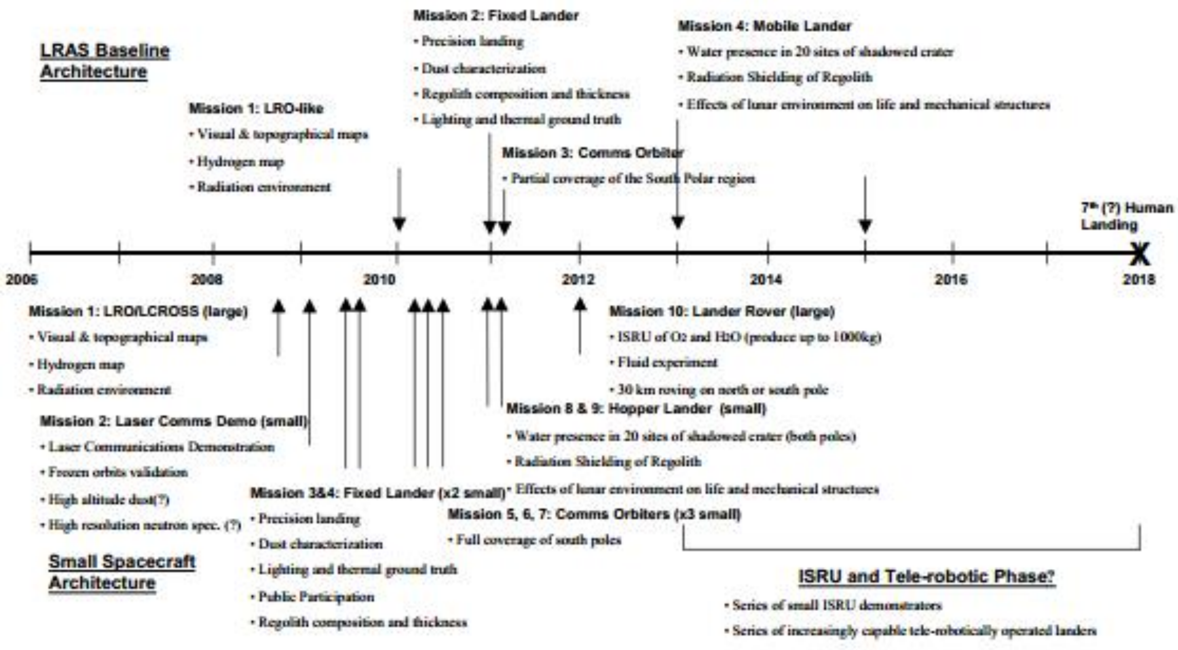
FIGURE 39: ORBITEC PHASE I STECKLER PROJECT

Appendix E: Industry Sector Divisions

Sector	Definition
Primary	This involves the extraction of resources directly from the Earth, this includes farming, mining and logging. They do not process the products at all. They send it off to factories to make a profit.
Secondary	This group is involved in the processing products from primary industries. This includes all factories—those that refine metals, produce furniture, or pack farm products such as meat.
Tertiary	This group is involved in the provision of services. They include teachers, managers and other service providers.
Quaternary	This group is involved in the research of science and technology. They include scientists.
Quinary Sector	Some consider there to be a branch of the quaternary sector called the quinary sector, which includes the highest levels of decision making in a society or economy. This sector would include the top executives or officials in such fields as government, science, universities, nonprofit, healthcare, culture, and the media.

TABLE 9: WIKIPEDIA.ORG

Appendix F: Small Spacecraft Architecture Concept



Small Spacecraft Architecture Concept as compared to the *LRAS* Architecture

FIGURE 40: [NASA/MARSHALL] SMALL SPACECRAFT IN SUPPORT OF THE LUNAR EXPLORATION PROGRAM

Proposed Timeline:

- **Mission 1: LRO-like.** Visual and topographical maps, hydrogen map, radiation environment.
- **Mission 2: Fixed Lander.** Precision landing, dust characterization, regolith composition and thickness, lighting, and thermal ground truth.
- **Mission 3: Communications Orbiter**. Partial coverage of south polar region.
- **Mission 4: Mobile Lander.** Water presence in 20 sites of shadowed crater, radiation shielding of regolith, effects of lunar environment on life and mechanical structures.
- **Mission 5: Lander Rover.** ISRU of O2 and H2O, fluid experiment, 30km roving.

Appendix G: List of Space Agencies and Associated Budgets

Country	Agency	Budget (USD)
United States	NASA (National Aeronautics and Space Administration)	$17,700 million (2012)[71]
Russia	ROSCOSMOS (Russian Federal Space Agency)	$5,600 million (2013)[72]
European Union[show]	ESA (European Space Agency)	$5,380 million (2012)[73]
France	CNES (French Space Agency)	$2,822 million (2010)[74]
Japan	JAXA (Japan Aerospace Exploration Agency)	$2,460 million[75]
Germany	DLR (German Aerospace Center)	$2,000 million[76]
India	ISRO (Indian Space Research Organization)	$1,320 million[77]
China	CNSA (China National Space Administration)	$1,300 million[78]
Italy	ASI (Italian Space Agency)	$1,000 million[79]
Iran	ISA (Iranian Space Agency)	$500 million[80]
Canada	CSA (Canadian Space Agency)	$488.7 million[81]
United Kingdom	UKSA (UK Space Agency)	$414 million[82]
Brazil	AEB (Brazilian Space Agency)	$343 million[83]
South Korea	KARI (Korea Aerospace Research Institute)	$300 million[84]
Ukraine	NSAU (National Space Agency of Ukraine)	$250 million[85]
Belgium	BELSPO (Belgian Federal Office for Science Policy)	$170 million[86]
Argentina	CONAE (Comisión Nacional de Actividades Espaciales)	$148 million[87]
Spain	INTA (Instituto Nacional de Técnica Aeroespacial)	$135 million[88]
Sweden	SNSB (Swedish National Space Board)	$100 million[89]
Pakistan	SUPARCO (Space and Upper Atmosphere Research Commission)	$82 million[90]
Netherlands	SRON (Netherlands Institute for Space Research)	$26 million[91]
Switzerland	SSO (Swiss Space Office)	$10 million[92]
Mexico	AEM (Mexican Space Agency)	$8.34 million[93]
World	All space agencies (Total of listed budgets)	$42,557.04 million
Arab League	PASA (Pan-Arab Space Agency)	Proposal Stage
African Union	AfriSpace (African Space Agency)	Proposal Stage
Sri Lanka	SLASA (Sri Lanka Aeronautics and Space Agency)	Working to launch 2 sats

TABLE 10: LIST OF SPACE AGENCIES VIA WIKIPEDIA

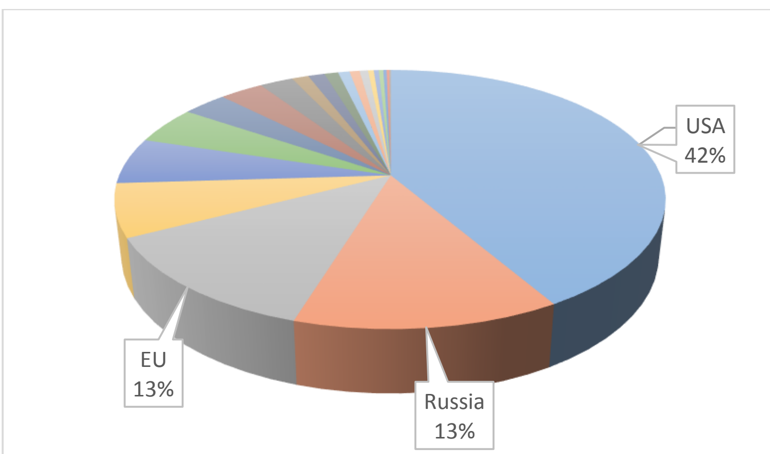


FIGURE 41: RELATIVE SPACE AGENCY BUDGETS

Appendix H: NASA Science & Exploration Budget Detail

	Actual	Estimate		Notional			
Budget Authority (in $ millions)	**FY 2011**	**FY 2012**	**FY 2013**	**FY 2014**	**FY 2015**	**FY 2016**	**FY 2017**
FY 2013 President's Budget Request	**1,721.9**	**1,760.5**	**1,784.9**	**1,775.5**	**1,835.6**	**1,826.2**	**1,772.8**
Earth Science Research	461.1	440.1	**433.6**	461.7	485.1	497.3	508.1
Earth Systematic Missions	841.2	881.1	**886.0**	787.6	813.2	835.6	756.4
Earth System Science Pathfinder	182.8	188.3	**219.5**	270.9	275.6	224.2	234.4
Earth Science Multi-Mission Operations	147.4	163.4	**161.7**	170.2	172.9	176.5	177.6
Earth Science Technology	52.8	51.2	**49.5**	50.1	52.1	54.1	56.1
Applied Sciences	36.6	36.4	**34.6**	35.0	36.7	38.4	40.1

TABLE 11: EARTH SCIENCE BUDGET DETAIL, NASA.GOV

	Actual	Estimate		Notional			
Budget Authority (in $ millions)	**FY 2011**	**FY 2012**	**FY 2013**	**FY 2014**	**FY 2015**	**FY 2016**	**FY 2017**
FY 2013 President's Budget Request	**1,450.8**	**1,501.4**	**1,192.3**	**1,133.7**	**1,102.0**	**1,119.4**	**1,198.8**
Planetary Science Research	158.8	174.1	**188.5**	222.5	233.4	231.7	230.3
Lunar Quest Program	130.2	139.9	**61.5**	6.2	0.0	0.0	0.0
Discovery	192.0	172.6	**189.6**	242.2	235.6	193.8	134.3
New Frontiers	213.2	160.7	**175.0**	269.8	279.6	259.9	155.1
Mars Exploration	547.4	587.0	**360.8**	227.7	188.7	266.9	503.1
Outer Planets	91.9	122.1	**84.0**	80.8	78.8	76.2	76.3
Technology	117.3	144.9	**132.9**	84.6	85.9	90.9	99.6

TABLE 12: PLANETARY SCIENCE BUDGET DETAIL, NASA.GOV

	Actual	Estimate		Notional			
Budget Authority (in $ millions)	**FY 2011**	**FY 2012**	**FY 2013**	**FY 2014**	**FY 2015**	**FY 2016**	**FY 2017**
FY 2013 President's Budget Request	**631.1**	**672.7**	**659.4**	**703.0**	**693.7**	**708.9**	**710.2**
Astrophysics Research	146.9	164.1	**176.2**	189.1	205.1	211.5	218.7
Cosmic Origins	229.1	237.3	**240.4**	228.5	215.1	205.3	205.7
Physics of the Cosmos	108.7	108.3	**111.8**	109.6	96.3	92.7	74.6
Exoplanet Exploration	46.4	50.8	**56.0**	41.6	43.3	42.4	45.6
Astrophysics Explorer	100.0	112.2	**75.1**	134.3	133.9	157.0	165.6

TABLE 13: ASTROPHYSICS SCIENCE BUDGET DETAIL, NASA.GOV

	Actual	Estimate		Notional			
Budget Authority (in $ millions)	**FY 2011**	**FY 2012**	**FY 2013**	**FY 2014**	**FY 2015**	**FY 2016**	**FY 2017**
FY 2013 President's Budget Request	**639.2**	**620.5**	**647.0**	**643.0**	**636.7**	**638.3**	**661.6**
Heliophysics Research	160.8	175.2	**178.9**	162.6	168.5	170.3	171.6
Living with a Star	218.4	196.3	**232.6**	212.2	286.2	336.6	351.7
Solar Terrestrial Probes	168.3	188.7	**189.4**	179.8	64.5	46.7	53.4
Heliophysics Explorer Program	91.7	60.2	**46.1**	88.4	117.5	84.8	84.8
New Millennium	0.1	0.0	**0.0**	0.0	0.0	0.0	0.0

TABLE 14: HELIOPHYSICS SCIENCE BUDGET DETAIL, NASA.GOV

Budget Authority (in $ millions)	Actual FY 2011	Estimate FY 2012	FY 2013	Notional FY 2014	FY 2015	FY 2016	FY 2017
FY 2013 President's Budget Request	**3,821.2**	**3,712.8**	**3,932.8**	**4,076.5**	**4,076.5**	**4,076.5**	**4,076.5**
Exploration Systems Development	2,982.1	3,007.1	**2,769.4**	2,913.1	2,913.1	2,913.1	2,913.1
Commercial Spaceflight	606.8	406.0	**829.7**	829.7	829.7	829.7	829.7
Exploration Research and Development	232.3	299.7	**333.7**	333.7	333.7	333.7	333.7
Change From FY 2012 Estimate	--	--	**220.0**				
Percent Change From FY 2012 Estimate	--	--	**5.9%**				

TABLE 15: EXPLORATION BUDGET DETAIL, NASA.GOV

Appendix I: Acknowledgements and Contact Information

This report was conducted without pay by Chad Anderson for Astrobotic Technology, Inc. This study delivers key insights from a combination of existing research and open source materials to build a full and objective picture of market dynamics for lunar services. In particular, it relied heavily upon research from the following:

Tauri Group: Suborbital Reusable Vehicles 10 Year Forecast

Futron: Commercial Lunar Transportation Study Market Assessment

NASA Ames: Small Spacecraft in Support of the Lunar Exploration Program

SpaceWorks: Nano/Microsatellite Market Assessment

FAA: 2012 Commercial Space Transportation Forecasts

NASA: Seeking a Human Spaceflight Program Worthy of Great Nation

NASA: Using Space Resources

NASA: Contour Crafting Simulation Plan for Lunar Settlement Infrastructure Build-up

NASA Ames: Asteroid and Comet Impact Hazards

NASA: In-Situ Resource Utilization Development & Incorporation Plans

NASA: NASA's Analog Missions – Paving the Way for Space Exploration

Orbitec: Phase I Steckler Project

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