ASTROBOTIC: COMMERCIAL SERVICE FOR LUNAR RESOURCE PAYLOAD DELIVERY. J. Thornton[1], S. Huber[2], K. Peterson[3], D. Hendrickson[4], [1]John.Thornton@astrobotic.com, [2]Steven.Huber@astrobotic.com, [3]Kevin.Peterson@astrobotic.com, [4]Dan.Hendrickson@astrobotic.com. Astrobotic Technology, Inc. (2515 Liberty Ave., Pittsburgh, PA 15222).

Introduction: This paper describes how Astrobotic's commercial lunar delivery service is enabling access to the Moon for activities such as lunar resource development payloads. Topics addressed here include current impediments to lunar resource development, commercial approaches to delivering resource development payloads to the Moon, and traction already seen with the commercial market for payload delivery.

Impediments to Lunar Resource Development: The prospect of utilizing lunar resources for future space exploration is promising, and could reduce the cost of missions beyond Earth orbit by a factor of four. [1] Realizing these savings however, requires first the determination of lunar resource availability, and the demonstration of resource extraction, refinement, and utilization. The prior high-cost of robotic missions to the Moon has placed an extraordinary barrier to these activities getting started. The physics and economics behind lunar missions investigating Strategic Knowledge Gaps has restricted activity on the Moon to large national governments that invest in some cases $500 million or more per mission. The associated cost and complexity has also severely constricted the frequency with which missions can occur. There has been only one Moon landing since the Apollo era, despite the Moon's close proximity as a planetary destination.

Bringing lunar resource development from a state of prospecting to full utilization will require a host of missions, and an eventual infrastructure on the lunar surface. As a result, the high cost and low frequency of missions under the current paradigm for robotic missions to the Moon is ill suited to make lunar resource development a reality.

Commercial Delivery for Lunar Resource Payloads: Alternatively, commercial lunar delivery service provides a viable path to the Moon for resource development payloads that is less expensive, less onerous, and faster. Rather than waiting for a conventional government-only mission to the Moon that is both large and costly, resource development instruments such as drills, neutronspectrometers, and other volatile analysis instruments could fly sooner on a multi-customer commercial mission.

Commercial missions are much cheaper (for instance, an Astrobotic mission flies payloads for $1.2 million per kilogram), and require no wide-sweeping government mandate on lunar exploration. By including resource instruments on multi-customer missions to the Moon, resource development investigations can be launched and iterated at multiple sites on the lunar surface. Small instruments can be sent to numerous destinations, on many small rovers. This approach allows resource payloads to fly without complicated and tenuous bilateral space agency partnerships. Multi-user commercial missions can also provide important precursor feasibility assessments of resource development without a major financial commitment by one or more space agencies.

Figure 1: Astrobotic's lunar payload delivery model is an end-to-end commercial delivery service ideal for lunar resource-focused payloads.

Figure 2: Astrobotic's precision landing and hazard avoidance system has been successfully tested on three Masten flight tests in the Mojave Desert.

The Global Exploration Roadmap has rightly identified that "to gain an understanding of whether lunar volatiles could be used in a cost-effective manner, it is necessary to understand the nature and distribution of the volatiles…[and] The first step is robotic prospecting to take measurements on the lunar surface."[2] Utilizing rapidly maturing commercial lunar delivery services is the best means of carrying out this first step, without an onerous commitment from space agencies upfront.

Astrobotic's Approach: Astrobotic is one such commercial operator that provides an end-to-end lunar payload delivery service suitable for the delivery of distributed resource development-focused payloads. Astrobotic customer payloads are integrated onto a single lunar lander, and then launched collectively on a commercially procured launch opportunity. After deployment from the launch vehicle, the lander enters lunar orbit using its onboard lander propulsion system. The lander then makes a powered descent to the surface using its propulsion system and precision landing and hazard avoidance system. Once on the surface, payloads are deployed

and activated. After landing, the lander operates as a local utility for customer payloads, providing power and communication as needed. Data from the payloads are relayed through the lander back to Earth, and then transmitted to customers.

This end-to-end delivery service model is an ideal means for delivering the first lunar resource prospecting and utilization payloads at a fraction of the traditional cost. Astrobotic's service approach is outfitted to carry a host of mission types to the Moon – from a single mission that carries a collection of smaller payloads, to missions that have one primary payload with a unified set of scientific and exploration objectives.

For example, Astrobotic could carry precursor instruments in advance of NASA's upcoming Resource Prospector (RP) mission, to test instrument techniques, demonstrate technology, and begin prospecting ahead of the full RP mission in the future. Thereafter, Astrobotic could carry the full RP rover and its entire suite of instruments on a dedicated commercial service mission. Astrobotic could be an end-to-end payload delivery provider for RP, in much the same way that NASA commercially procures cargo delivery service to the International Space Station.

Model for Resource Development Payloads:

Already the delivery model for carrying payloads has shown great traction among international space agencies. For instance, Agencia Espacial Mexicana (AEM), the Mexican Space Agency, which has not yet staged a mission beyond Earth orbit, can now build a niche national expertise, and field the first payload from Latin America. AEM has signed a payload service reservation on Astrobotic's first mission to the Moon, and issued a "request for proposals" from Mexico's science and exploration community to determine the nature of the payload. The winner of this RFP will build the payload, and Astrobotic will deliver it to the Moon. It is precisely this model that could be used by other space agencies to carry out resource development objectives outlined in the Global Exploration Roadmap.

Figure 3: Agencia Espacial Mexicana, the Mexican Space Agency will be sending its first payload beyond Earth orbit using Astrobotic's lunar payload delivery service.

Developments Enabling Commercial Delivery: Low cost delivery for lunar resource development payloads is made possible because of three recent developments – reduced launch costs, innovations in electronics and robotics, and inventive new public-private partnerships.

Public-private partnerships are especially important to this new era of lunar activity. NASA's commitment to fostering new commercial service to the Moon is a telling indicator of its promise. This year the agency kicked off its Lunar CATALYST Program, which directly pairs agency expertise and NASA center infrastructure with commercial lunar delivery companies. CATALYST is similar to the highly successful Commercial Orbital Transportation Services (COTS) program that resulted in the development of two, independent commercial launch vehicle services that NASA now uses for regular delivery of vital supplies to the International Space Station.

Market Traction: The most telling indicator of the lunar delivery market's promise is found in the sales that have already taken place before lunar service has commenced. Already, seven contracts have been signed to deliver payload on Astrobotic's first mission. Two signed payloads on this mission come from Japan: the private company rover from Team Hakuto, and the marketing time capsule from the Japanese drink company Pocari Sweat. As noted from Mexico, AEM has booked a payload reservation, with a "request for proposals" to further define the payload. From the United Kingdom, Lunar Mission One has booked a data storage payload ahead of their larger future mission. From the United States, two private companies are booked to send memorial cremains, and dozens of individuals are sending personal mementos in the form of passive payload through a direct-to-consumer program called *MoonMail*™.

Based on market traction and trends, additional missions carrying payloads like these are planned beyond the first mission. A regular cadence of commercial lunar delivery missions opens access for resource prospecting at multiple locations on the Moon, and the diversity of commercial payload collections underwriting multiple missions creates numerous opportunities for small resource development payloads to fly. A manifest of multiple commercial missions could also be a cornerstone to eventual lunar resource development infrastructure in the future.

Conclusion: Low-cost access to the Moon is now open to the host of space agencies and entities that have identified resource development as a priority, both in the Global Exploration Roadmap and beyond. Thanks to commercial lunar delivery, the Moon is available to all entities that seek to prospect and demonstrate lunar resource utilization.

References: [1] Economic Assessment and Systems Analysis of an Evolvable Lunar Architecture that Leverages Commercial Space Capabilities and Public-Private-Partnerships. NextGen Space. July 13, 2015. http://www.nss.org/docs/EvolvableLunarArchitecture.pdf.
[2] The Global Exploration Roadmap. August 2013. https://www.nasa.gov/sites/default/files/files/GER-2013_Small.pdf.