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Statement of
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before the

Subcommittee on Space
Committee on Science, Space, and Technology
U. S. House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss NASA's support of private sector exploration of the Moon. In support of its efforts to expand the frontiers of spaceflight capabilities in this new era of space exploration, NASA is working to foster the fullest possible commercial use of space and engagement with the broader community. Building on the progress of NASA's partnerships with the U.S. commercial space industry to develop new spacecraft and rockets capable of delivering cargo, and soon, astronauts, to low-Earth orbit, the Agency recognizes the U.S. industry's interest in reaching and exploring the Moon. Commercial robotic lunar lander capabilities could address emerging demand by private customers who wish to conduct activities on the Moon and could also enable new science and exploration missions of interest to the larger scientific and academic communities. These emerging commercial capabilities, in turn, have the potential of providing important enabling capabilities as NASA expands human presence into deep space, including to the surface of Mars.

NASA lunar science has helped to map the Moon, determine the presence of water ice, and understand Earth's satellite's irregular gravity field. NASA lunar missions are increasing global understanding of the origins of our solar system, informing future exploration efforts of the Moon and other planetary bodies, and bringing the Agency closer to having the infrastructure and technologies needed to explore future destinations like Mars. Future missions could help characterize the internal structure of the Moon and characterize ancient impact basins, in addition to demonstrating key technologies necessary to support future robotic and human exploration infrastructures.

Lunar CATALYST: Promoting Private Sector Robotic Exploration of the Moon

As part of the Agency's overall strategy to conduct deep space exploration, NASA is also supporting the development of commercial lunar exploration. In 2014, NASA introduced an initiative called Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST). The purpose of the initiative is to encourage the development of U.S. private-sector robotic lunar landers capable of successfully delivering payloads to the lunar surface using U.S. commercial launch capabilities.

In September 2014, NASA signed three-year Space Act Agreements (SAAs) with three U.S. firms: Astrobotic Technologies of Pittsburgh, PA; Masten Space Systems of Mojave, CA; and Moon Express Inc., of Cape Canaveral, FL. These companies were competitively selected on the basis of their proposed

technical approach, financial plan, and commercialization strategy. Through Lunar CATALYST, NASA has provided partners with in-kind contributions including technical expertise, access to test facilities, software, and the loaning of equipment. Initial flights of commercial lunar landers may begin as early as 2018, and as a result one or more of these companies will be able to market lunar payload delivery services for small instruments and technology demonstrations. Future commercial lunar transportation capabilities could support science and exploration objectives such as sample returns, geophysical network deployment, resource utilization, and technology advancements.

The Advanced Exploration Systems (AES) Division in NASA's Human Exploration and Operations Mission Directorate manages Lunar CATALYST. AES pioneers new approaches for rapidly developing prototype systems, demonstrating key capabilities and validating operational concepts for future human missions beyond Earth orbit, and Lunar CATALYST represents another step in the Agency's effort to spur growth in the commercial space sector. The NASA side of the Lunar CATALYST team is made up of lander development expertise from NASA's space science and human exploration communities, primarily from Marshall Space Flight Center and Johnson Space Center.

NASA recognizes that private-sector investment in technologies intended to enable commercial lunar activities, at least initially with respect to U.S. and other nations' exploration activities, has been increasing and anticipates that industry will eventually be able to provide commercial cargo transportation services to the lunar surface to both public and private customers. Commercial robotic lunar lander capabilities could address emerging demand by private customers who wish to conduct activities on the Moon, even while providing cost-effective transportation services for NASA's science and exploration missions, thereby benefitting the larger scientific and academic communities.

A Diversity of NASA Lunar Exploration Efforts

Along with our commercial and international partners, NASA has a continued interest in lunar exploration and is working to continue scientific investigations of our celestial neighbor that will also inform the Agency's deep space human exploration plans. The Science Mission Directorate, Space Technology Mission Directorate, and Human Exploration and Operations Mission Directorate (SMD, STMD, and HEOMD, respectively) are currently assessing possible robotic mission concepts, acquisition approaches, and associated payloads for a potential series of lunar cargo (i.e., uncrewed) missions to the surface of the Moon starting as early as 2020 and extending through at least 2024. NASA is considering a variety of objectives that could be addressed sending stand-alone instruments, experiments, or more complex payloads to the lunar surface. These would consist of NASA primary, secondary, or NASA hosted payloads and include the potential to gather data from commercial lunar surface missions and/or return payloads or samples to the Earth.

In support of these objectives, NASA issued a Request for Information (RFI) seeking ideas from industry for the Agency to possibly participate in existing or future commercial missions to the Moon. The Agency is interested in assessing the availability of a commercial launch from Earth to the lunar surface to provide landing services as early as Fiscal Year 2018, and through the next decade. This approach offers the Agency the potential to simultaneously address high-priority science, critical strategic objectives related to exploration, and technology demonstration, using commercially provided domestic space services and hardware.

Near-term robotic missions to the lunar surface offer an opportunity to achieve priority objectives for science and exploration. An early mission comprised of one or two instruments could reduce cost and risk for high priority science, and ensure the robustness of the lunar science community. A mission focused specifically on lunar polar volatiles may be the key to future exploration architectures, and

characterizing volatiles entrainment in regolith could be game-changing. Critical technologies can be demonstrated to enable improvements in precision landing, power generating, and low-temperature environments, to name a few areas. These missions might also serve as advance planning for Mars and other destinations or to enable deep-space architectures.

Other NASA lunar exploration efforts include:

- The selection of the Lunar Polar Hydrogen Mapper (LunaH-Map) through NASA's Small Innovative Missions for Planetary Exploration (SIMPLEx) program. LunaH-Map is a NASA Planetary Science Division CubeSat mission designed by Arizona State University to sense the presence of hydrogen in craters and other areas on the Moon using a neutron spectrometer. When completed, it will be one of 13 CubeSats set to launch on Exploration Mission 1 (EM-1) – the first integrated flight of NASA's Space Launch System (SLS) and Orion spacecraft. Upon arrival, the LunaH-Map spacecraft will produce the most detailed map to date of the Moon's water deposits, unveiling new details about the depth and distribution of the ice that has been identified from previous missions. Confirming and mapping those deposits in detail will help NASA understand how much water might be available and will help inform NASA's strategy for sending humans farther into the solar system.

- AES also selected three lunar research CubeSats set to be launched on EM-1:

    - Lunar Flashlight will map the lunar south pole for volatiles and demonstrate several technological firsts, including being the first CubeSat to reach the Moon, the first planetary CubeSat mission to use green propulsion, and the first mission to use lasers to look for water ice. It will shine light into the shaded polar regions with near-infrared lasers, while the on-board spectrometer measures surface reflection and composition. Lunar Flashlight is developed by NASA's Jet Propulsion Laboratory, with contributions from Marshall Space Flight Center.

    - Lunar IceCube will prospect for lunar volatiles and water during its six months in lunar orbit, investigating the distribution of water and other volatiles as a function of time of day, latitude, and regolith age and composition. IceCube's miniaturized Broadband InfraRed Compact High Resolution Explorer Spectrometer (BIRCHES) instrument will prospect for water in ice, liquid, and vapor forms from a highly inclined elliptical lunar orbit. Morehead State University in Kentucky is leading the mission, with contributions from the Busek Company and NASA's Goddard Space Flight Center.

    - Lockheed Martin's LunIR mission is hosting a mid-wave Infra-Red (MWIR) sensor LunIR will perform a lunar flyby to capture and downlink images of the lunar surface and its environment. It will help address strategic knowledge gaps related to surface characterization, remote sensing, and site selection observations. The data collected on thermal environments will add to the body of knowledge on the composition, structure, interaction with the space environment, and interaction with solar particles and the lunar regolith.

- AES has partnered with the Korea Aerospace Research Institute (KARI) on the Korea Pathfinder Lunar Orbiter (KPLO) – the country's first lunar exploration mission in 2020. Pursuant to a cooperative international SAA, NASA will provide Deep Space Network communication and lunar navigation and design expertise in exchange for flying one of AES's science instruments in development, the ShadowCam, on the KPLO mission. This instrument is a highly sensitive optical camera that will peer into the Moon's permanently shadowed areas at the lunar poles that

we suspect holds large amounts of volatiles, including water that may be useful for future exploration missions. KARI and NASA will also share data from KPLO's other instruments and, with support from the Planetary Science Division (PSD), are planning to add additional international scientific expertise to all the KPLO instrument teams.

- NASA Planetary Science Division's Lunar Reconnaissance Orbiter (LRO) is a mission whose seven different instruments are mapping the surface of the Moon and its surrounding environment. LRO has produced the highest quality, global topographic map of any planetary body and continues to share its data with the public through the Planetary Data System (PDS). Data is uploaded on a 3-month cadence and the public can suggest future targets for high-resolution imagery (which are prioritized by scientific objective or completed on a non-interference basis). Most recently, LRO has been acquiring imaging and topographic data for candidate Chandrayaan-2 landing sites, making these data available to the Indian Space Research Organisation (ISRO) through PDS. The PDS data has also been utilized by the Google Lunar X-Prize foundation for locating potential landing sites.

- NASA has also studied a potential Resource Prospector (RP) mission to provide information that could transform how the Agency approaches long-duration exploration. NASA's efforts to date have been focused on developing a suite of instruments to locate resources in regolith, specifically volatiles, particularly in the lunar polar regions. Building on the findings of the Lunar Crater Observation and Sensing Satellite (LCROSS), Gravity Recovery and Interior Laboratory (GRAIL), Lunar Atmosphere and Dust Environment Explorer (LADEE), LRO, and Chandrayaan-1 missions that proved the existence of water on the Moon, a potential future mission would take the next step in understanding how to harvest those resources. This potential "Resource Prospector" concept is being reviewed by the Agency to determine how and when the critical measurements should be pursued.

- The NASA Frontier Development Lab (FDL) is an Artificial Intelligence (AI) research and development (R&D) accelerator that tackles gaps in knowledge useful to the space program. NASA, in collaboration with SETI, established this public-private partnership with leading IT companies such as Intel, Nvidia, IBM Watson, Google, and others. FDL's industry partners provided hardware, software, subject matter experts, and funding while NASA provided modest stipends for the U.S.-based participants and subject matter experts. The 2017 FDL was an intense eight-week concentrated study on topics not only important to NASA, but also to humanity's future. This year, FDL focused on challenges within the fields of planetary defense, space resources, and space weather. The Space Resources challenge, funded in part by the Luxembourg Space Resources LLC, focused on developing algorithms to speed identification of craters and other hazards on the lunar surface. Working from data sets from NASA's LRO spacecraft, the team of lunar science and AI early-career scientists applied machine learning to removing artifacts from the imagery and altimeter data that yielded faster image resolution.

Conclusion

NASA is making advances to push the boundaries of human exploration farther into the solar system, and continues to spur development in the commercial space sector. Robotic missions to the Moon have revealed the existence of local resources including oxygen and water that may be highly valuable for exploration of the solar system. The potential to use the lunar surface in partnership with our commercial and international partners may allow these resources to be characterized and used to enable future exploration and pioneering. NASA is committed to expanding partnerships with other U.S. Government agencies, as well as the academic, industrial, entrepreneurial, and international

communities, recognizing them as indispensable contributors of skill and creativity to our missions. An important part of NASA's strategy is to partner with the commercial space industry to help the Agency achieve its strategic goals and objectives. NASA's collaborative efforts are fostering innovation and a growing commercial space industry, while transforming capabilities and accelerating technologies needed to achieve national strategic goals.

Mr. Chairman, I would be happy to respond to any questions you or the other Members of the Subcommittee may have.