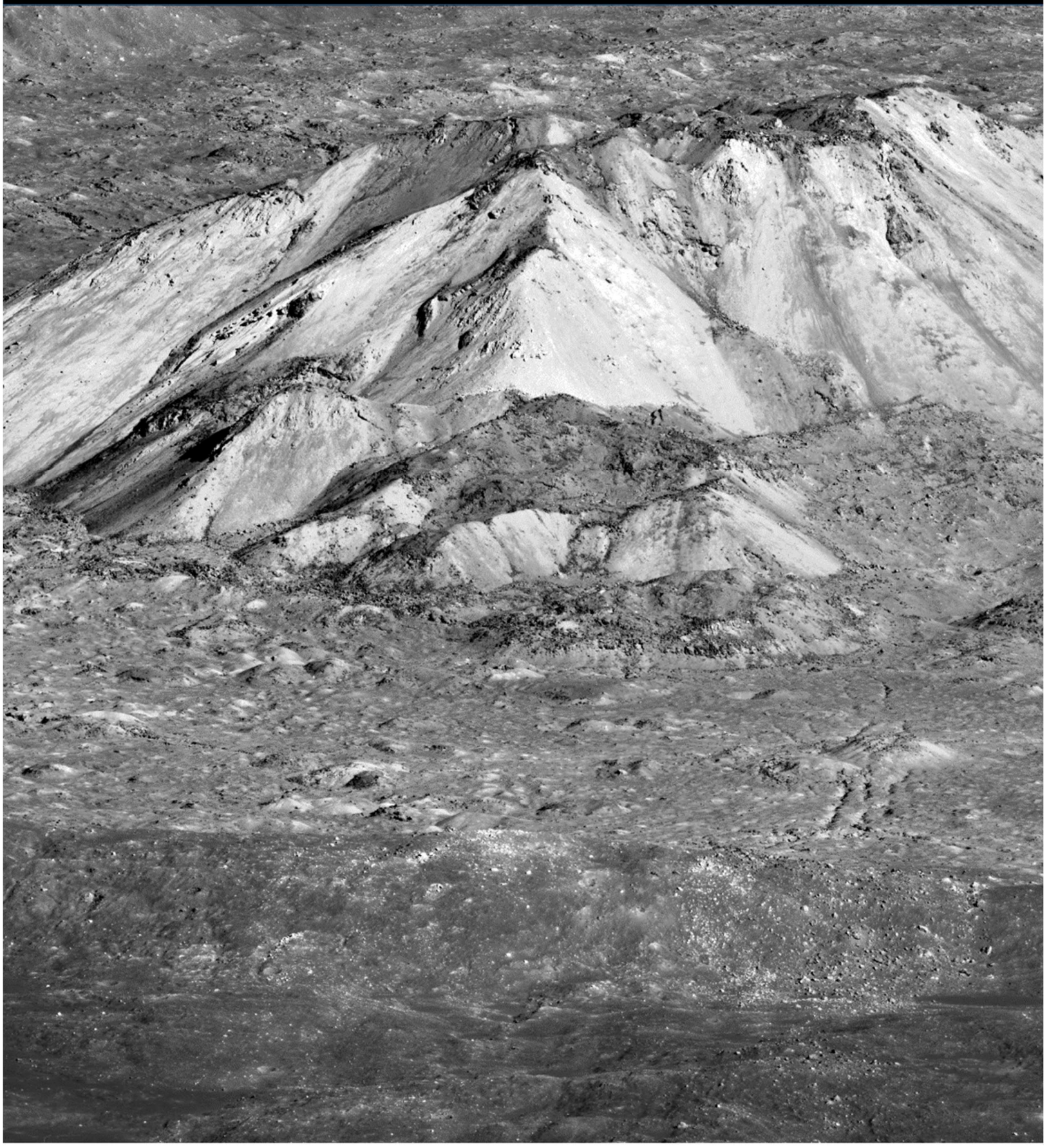
BACK TO THE MOON

REPORT OF THE 2017 WORKSHOP



ON THE FRONT COVER: A Mountain on the Moon! The Moon is a stunning world, with many spectacular vistas that no human being has seen with their own eyes. Tycho crater is about 85 kilometers (53 miles) in diameter, and its central peak rises more than 2000 meters (6562 feet) above the crater floor. Visible from Earth with binoculars, this amazing feature is an important destination for future explorers. LROC NAC Frame M1167178525LR [NASA/Goddard Space Flight Center/Arizona State University]

Version 2 of the 2017 Back to the Moon Report, Released December 2017.

This document may be cited as Lunar Exploration Analysis Group (2017) "Back to the Moon: Report of the 2017 Workshop", Report of the Consensus Findings of the Community Workshop held 12-13 October 2017, Columbia, Maryland, United States of America.

EXECUTIVE SUMMARY

It is the overwhelming consensus of the workshop participants that returning astronauts to the surface of the Moon is of paramount importance to the American space program. The Moon is close, it is scientifically interesting, and it is useful. The Moon is a strategic destination with resources that will enable economic expansion and create new capabilities that will expand the human presence in the Solar System. In view of widespread international interest in a human presence on the Moon, it is essential to establish a strong and enduring United States presence on the surface of the Moon as soon as possible.

Finding 1

Owing to the immense scientific, economic, commercial, and geopolitical value of the Moon, as well as its exploration and utilization potential, NASA's human spaceflight efforts should focus on returning astronauts to the surface of the Moon. These efforts should begin immediately with robotic and human precursor missions designed to build up capabilities and demonstrate resource utilization on the surface. This activity should be followed by ongoing development of subsystems and resources over the next 5-10 years to create an enduring presence on the lunar surface within the decade. The program should be undertaken with a clear understanding of the object of lunar return and be structured to feature continuing, recurring milestones and achievements.

Finding 2

Over the past decade, the private space sector has significantly expanded on its capabilities and is poised to facilitate lunar exploration in the next 2-3 years. NASA therefore should expand its engagement with the private sector through public-private partnerships. These partnerships can take many forms, from co-investments in critical technology or infrastructure to purchasing payload space, services, or commodities (such as propellant) sourced on the Moon.

Finding 3

The lunar surface is an essential component of future space activity. Any credible exploration architecture needs to provide the capability to efficiently access the lunar surface and utilize its resources. We strongly encourage the National Space Council to guarantee a robust and thriving United States presence on the lunar surface by ensuring that an exploration architecture is devised and implemented through an open and transparent process. To achieve an efficient and

lasting presence in space by fully incorporating the Moon into our economic sphere of influence, the exploration architecture should include a regular flight cadence, incorporate ready lunar surface access, optimize the use of lunar resources, promote reusability and hardware/subsystem interoperability, and establish public-private partnerships and international collaborations which are all designed to achieve human lunar return within the next 5-10 years and provide the firm foundation for an enduring presence on the lunar surface.

Finding 4

Emerging commercial capabilities in space launch, landing, surface operation, and other services will facilitate and enhance near-term lunar surface access for a variety of applications. NASA should consider acting as an "anchor customer" of services such as unused launch payload or lunar-sourced propellants that would increase the efficiency of both precursor exploration and human lunar surface activities. Encouraging growth in the U.S. commercial sector would foster a market for multiple providers, which will drive down costs, promote efficiency, increase innovation, and grow the American aerospace industry.

Finding 5

Owing to the significant potential for lunar resources to reduce the cost and increase the capabilities of space activities, NASA should establish a dedicated Lunar Exploration Program Office with sufficient programmatic and budgetary authority to carry out directed missions to study the scientific value of lunar resources, begin resource prospecting, and demonstrate the immense scientific and technological value of lunar in-situ resource utilization.

NASA and its mission directorates (SMD, STMD, and HEOMD) should collaborate with academia and industry to ensure that both science and technology gaps for in-situ resource utilization are met.

IMPORTANCE OF SURFACE ACCESS

EXPLORING AND USING THE LUNAR SUFACE IS ESSENTIAL FOR MAKING NEW SCIENCE DISCOVERIES, ADVANCING HUMAN SPACEFLIGHT, AND CREATING ENDURING OPPORTUNITIES FOR ECONOMIC GROWTH.

The grass-roots "Back to the Moon" initiative arose from community discussions at the 2017 Lunar and Planetary Science Conference, where it became clear that there were three converging trends in lunar exploration and science, outlined below.

First, decades of exciting, post-Apollo era discoveries about the Moon's formation, composition, and evolution underscore the critical importance of renewing lunar surface exploration with robots and humans. Renewed surface exploration will finally enable us to address fundamental questions about the Moon, the Earth, and our Solar System. NASA's ongoing Lunar Reconnaissance Orbiter (LRO) mission provides data critical for exploring targeted sites on the Moon's surface, making now the time to re-initiate surface activities.

Second, results from missions in the past decade have demonstrated that the Moon has significantly more resources than previously understood. Polar volatile deposits are much richer in oxygen and hydrogen than previously suspected. Vast deposits of pyroclastic materials rich in usable resources have been charted. New detailed measurements of the Moon's physical characteristics reveal locations near the poles with relatively stable thermal and energy (sunlight) fluxes for significant fractions of the 28-day lunar diurnal cycle. These properties greatly increase the Moon's importance as a target for human exploration and utilization.

GIVEN WHAT WE HAVE LEARNED FROM RECENT MISSIONS, THE MOON IS AN EVEN MORE VALUABLE DESTINATION FOR EXPLORATION AND USE THAN WE THOUGHT AT THE BEGINNING OF THE 21ST CENTURY.

Finally, emerging capabilities in the U.S. commercial sector arising from the lunar CATALYST (Cargo Transportation and Landing by Soft Touchdown) initiative, a no-funds-exchanged Space Act Agreement commercial partnerships program, promise to increase the capabilities and cadence of lunar missions.

Considering these trends, the Lunar Exploration Analysis Group (LEAG) was urged to lead the way towards leveraging these new capabilities to restore the United States' ability to access the lunar surface for scientific, commercial, geopolitical, and industrial purposes. At the 2017 Lunar and Planetary Science Conference, following an enthusiastic community response to the idea at the LEAG Town Hall Forum, the Lunar and Planetary Institute and the Universities Space Research Association generously offered to facilitate a community-organized, volunteer-driven LEAG workshop designed to explore the impact of emerging new capabilities for lunar surface access with both robots and humans.

ABOUT THE BACK TO THE MOON WORKSHOP

The goal of the Back to the Moon workshop, held on 12-13 October 2017 at the Headquarters of the Universities Space Research Association in Columbia, Maryland, was to use the LEAG Lunar Exploration Roadmap[1] as a springboard for a United States return to the Moon by bringing together stakeholders from industry, commerce, government, and academia to explore making a lunar return with humans and robots an affordable reality in the near future.

The Back to the Moon focused workshop was well-attended by 97 participants, including a cross-section of the lunar exploration community of scientists, engineers, commercial providers, journalists, lawyers, and space advocates.

The workshop consisted of a series of five panels with invited panelists and volunteer moderators specifically sought for topical expertise, in a format designed to encourage open community discussion, interaction, and consensus-building.

Day 1

Panel 1: What is needed to transition NASA to a return to the Moon mode?
Panelists: Doug Cooke, Tom Culligan, Harrison Schmitt
Moderator: Paul Spudis

Panel 2: Successful public-private partnerships to maximize science and exploration return from the Moon
Panelists: A. C. Charania, Dan Hendrickson, Bob Richards, Nantel Suzuki
Moderator: Kris Zacny

[1] https://www.lpi.usra.edu/leag/roadmap/

Day 2

Panel 3: Architectures for sustainable lunar surface access
Panelists: James Carpenter, Tony Lavoie, John Reed, Dennis Wingo
Moderator: Clive Neal

Panel 4: As part of a sustainable lunar return architecture, what are the challenges for launch and service providers in achieving safe and reliable transportation?
Panelists: Dallas Bienhoff, Sean Mahoney, Kurt Klaus, George Sowers
Moderator: Melissa Sampson

Panel 5: What is the role of in-situ resource utilization in sustainable human lunar exploration?
Panelists: William Larson, Gerald Sanders, Barbara Cohen
Moderator: John Gruener

ORGANIZING COMMITTEE

Clive Neal, University of Notre Dame, *Co-Convener*
Julie Stopar, Lunar and Planetary Institute/USRA, *Co-Convener*
Samuel Lawrence, NASA Johnson Space Center, *Program Chair*
Paul Spudis, Lunar and Planetary Institute
George Sowers, Colorado School of Mines
Ryan Watkins, Planetary Science Institute
Kris Zacny, Honeybee Robotics

PANEL 1:
What is needed to transition NASA to a return to the Moon mode?

Outcome

The long-delayed effort to return U.S. astronauts to their rightful place on the surface of the Moon would meet NASA's stated objectives of expanding the human presence, building a thriving presence in space, as well as maximizing science return.

Discussion

- Returning humans to surface of the Moon would develop the needed workforce to meet NASA's stated objectives of expanding the human presence throughout the Solar System.
- A strong U.S. presence on the surface of the Moon, led by NASA, is essential for maintaining America's leadership in space.
- Progress in the form of continuing, recurring achieved milestones serves an important political role in maintaining programmatic continuity and vitality, and demonstrates clear value to taxpayers.
- A clear timeline and well-defined achievements and milestones also serve to avoid unnecessary development efforts.
- The LEAG Lunar Exploration Roadmap[1] provides a basis for defining critical milestones.
- The Apollo program, with its responsive and agile management structure and budgetary reserves, serves as an example of how a program can be successfully implemented. However, in the current geopolitical and budgetary landscape non-traditional approaches will play an important role. While it is important to be inspired by the Apollo example, new thinking and innovative approaches will be needed to create a foundational space transportation system which provides new capabilities for the U. S. on an ongoing basis.
- Efficient, cost-effective, and sustainable transportation to and from the Moon requires the use of lunar resources.

[1] https://www.lpi.usra.edu/leag/roadmap/

Finding 1

Owing to the immense scientific, economic, commercial, and geopolitical value of the Moon, as well as its exploration and utilization potential, NASA's human spaceflight efforts should focus on returning astronauts to the surface of the Moon. These efforts should begin immediately with robotic and human precursor missions designed to build up capabilities and demonstrate resource utilization on the surface. This activity should be followed by ongoing development of subsystems and resources over the next 5-10 years to create an enduring presence on the lunar surface within the decade. The program should be undertaken with a clear understanding of the object of lunar return and be structured to feature continuing, recurring milestones and achievements.

PANEL 2:
Successful public-private partnerships to maximize science and exploration return from the Moon

Outcome

The commercial sector has emerging, near-term capabilities that can be leveraged to support and enhance lunar surface activities. Public-private partnerships have enormous potential to advance U.S. lunar exploration objectives.

The Lunar CATALYST program, initiated by NASA HEOMD, has been successful, and new public-private partnerships to achieve additional lunar exploration objectives should be developed quickly and on a similar basis.

Discussion

- In the past decade, numerous private companies have been created to develop critical technologies for going back to the Moon. These technologies include launch vehicles,

landers, rovers, and critical spacecraft subsystems (e.g., power, propulsion, communication, etc.).

- There are two aspects of public-private partnerships. First, a legal contract between NASA and a private company is established to provide a legal framework for all aspects of the relationship, its goals and deliverables, as well as structure for funds exchange or an in-kind contribution. The second aspect that is absolutely critical to the success of the partnership is the relationship between the teams from NASA and Industry. If the technical exchanges and teamwork between these teams is successful, the partnership will also be successful. The success of the Lunar CATALYST program is attributed to both of these aspects.
- As indicated by the results of NASA's recent Request for Information (RFI) for future lunar surface payloads, there exists significant diversity in the payload types within the main segments such as science, technology, and marketing.
- There is believed to be a significant interest by non-traditional space companies that see value in going to the Moon. This interest represents a new market and an area for potential growth.
- Commercial providers are working with NASA to ensure that their missions meet NASA's planetary protection requirements. The Moon is not considered a restricted environment for planetary protection.

Finding 2

Over the past decade, the U.S. private space sector has significantly expanded on its capabilities and is poised to facilitate lunar exploration in the next 2-3 years. NASA therefore should expand its engagement with the private sector through public-private partnerships. These partnerships can take many forms, from co-investments in critical technology or infrastructure to purchasing payload space, services, or commodities (such as propellant) sourced on the Moon.

PANEL 3:
Architectures for sustainable lunar surface access

Outcome

Since the last Apollo missions, there have been numerous proposed architectures for expansive programs of lunar surface exploration and utilization. Many of the architectures for lunar surface exploration proposed during the past decade have common elements that should be implemented as part of future lunar and space activities, including reusability, robust lunar surface access, use of lunar resources, and an enduring presence on the lunar surface. Both existing commercial launch vehicles and projected new launch vehicles, such as the Space Launch System, can play a role in establishing near-term access to the lunar surface.

Discussion

- The access and use of lunar resources are a key component of <u>any</u> future space exploration efforts.
- Desirable features of a human lunar return architecture include reusability, extended surface presence, and the use of lunar resources from the beginning.
- The competitive aspect of the free market will shape commercial architectures and subsystems and encourage efficiency, ultimately driving down costs.
- NASA can serve as an initial customer of commercial companies, but long-term regular mission cadence is important to commercial aspects of any architecture.
- Core elements of any architecture are transportation, communication, power, and navigation. These services could be commercially provided to NASA, other agencies, and private companies.
- Standard interfaces are needed to facilitate international and commercial partnerships.
- International participation in American efforts to return to the surface of the Moon should be encouraged, but not in NASA's critical path for establishing a strong U.S. surface presence.
- The objectives and plans of different participants should be regularly reviewed for consistency and capability. Doing so will help prevent unnecessary duplication of effort and maintain overall efficiency and capability of the architecture, ensuring that the implemented

architecture will achieve the goal of establishing a thriving U.S. presence on the lunar surface.

Finding 3

The lunar surface is an essential component of future space activity. Any credible exploration architecture needs to provide the capability to efficiently access the lunar surface and utilize its resources. We strongly encourage the National Space Council to guarantee a robust and thriving United States presence on the lunar surface by ensuring that an exploration architecture is devised and implemented through an open and transparent process. To achieve an efficient and lasting presence in space by fully incorporating the Moon into our economic sphere of influence, the exploration architecture should include a regular flight cadence, incorporate ready lunar surface access, optimize the use of lunar resources, promote reusability and hardware/subsystem interoperability, and establish public-private partnerships and international collaborations which are all designed to achieve human lunar return within the next 5-10 years and provide the firm foundation for an enduring presence on the lunar surface.

PANEL 4:

As part of a sustainable lunar return architecture, what are the challenges for launch and service providers in achieving safe and reliable transportation, landings, and infrastructure?

Outcome

Establishing routine landings on the Moon is critical to future space activities, is feasible and affordable, and has a wide array of applications pivotal for scientific, exploration, and industrial purposes as well as economic growth. Lunar landings are well within our engineering knowledge base; there are no insurmountable challenges preventing human lunar landings in the near future. Emerging commercial lunar landing capabilities have the potential to increase the scale and frequency of human and robotic access to the lunar surface.

Discussion

- Challenges for launch and service providers can be minimized through sustained progress over the coming years, continuing potential for profit, and a steady supply of customers.
- Service providers need adequate resources to build credibility and demonstrate the capabilities of commercial/private entities, which reduce risks to NASA investment.
- Building up capability depends on increasing the number of launches per year and developing new markets. For example, in 2016, the United Launch Alliance has proposed to buy propellant (including that produced from lunar materials) at a fixed cost.
- Precursor missions may include returned lunar data and surface samples from a variety of assets in space and on the Moon, services of which NASA, or other entities, might consider being a customer.
- Unused secondary launch payload capability could be utilized for science or demonstrating technology readiness of specific exploration technologies.
- The classic NASA model is to be its own supplier and customer, but the agency has recently been more open to experimentation. However, more than one customer is ultimately required to build a thriving market.

Finding 4

Emerging commercial capabilities in space launch, landing, surface operation, and other services will facilitate and enhance near-term lunar surface access for a variety of applications. NASA should consider acting as an "anchor customer" of services such as unused launch payload or lunar-sourced propellants that would increase the efficiency of both precursor exploration and human lunar surface activities. Encouraging growth in the U.S. commercial sector would foster a market for multiple providers, which will drive down costs, promote efficiency, increase innovation, and grow the American aerospace industry.

PANEL 5: What is the role of in-situ resource utilization in sustainable human lunar exploration?

Outcome

An enduring and thriving presence on the Moon and throughout the Solar System is heavily dependent on lunar resources to reduce the cost and increase the capability of space activities, as well as stimulating the lunar economy for the private sector. Prospecting and in-situ resource utilization (ISRU) prototype missions to assess the nature and use of the resource deposits should be demonstrated on the Moon within the 2020-2023 timeframe. Public-private partnerships should be employed to help carry out these missions.

Discussion

- The next steps for lunar resource utilization include performing surface prospecting at multiple locations, demonstrating techniques with simulants, and in-situ demonstrations on the lunar surface.
- While the concepts of lunar resource utilization are fairly well-developed, more detailed information on the resource feedstock (composition, state, physical properties and locations and concentrations) is needed to finalize the design of the processing chain.
- Additional studies and flight demonstrations of ISRU techniques are needed to fully implement lunar ISRU and mature ISRU technologies. Such activities could be accomplished by establishing an integrated Lunar Exploration Program Office, combining NASA efforts from STMD, HEOMD, and SMD, as well as academic and industrial efforts in space resource utilization.
- Space Act agreements and public-private partnerships could facilitate ISRU demonstration, prospecting, and extraction/refinement.

  The discussion used the Lunar Exploration Roadmap Implementation Plan devised by LEAG in 2011[1] as a foundation.

Finding 5

NASA should establish a dedicated Lunar Exploration Program Office with sufficient programmatic and budgetary authority to carry out directed missions to study the scientific value of lunar resources, begin resource prospecting, and to demonstrate the immense scientific and

[1] https://www.lpi.usra.edu/leag/reports/RoboticAnalysisLetter.pdf

technological value of lunar in-situ resource utilization and the creation of lunar surface infrastructure.

CONCLUSIONS

Fortuitously, the week before the Back to the Moon workshop, in a speech at the National Air and Space Museum Stephen F. Udvar-Hazy Center, during the first meeting of the reconstituted National Space Council, Vice-President Pence committed the United States to "*return America to the Moon, not only to leave behind footprints and flags, but to develop the firm foundation needed to send Americans to Mars and beyond*."

The attendees of the Back to the Moon workshop experienced a profound sense of excitement about the fact that a U.S. return to the surface of the Moon had re-emerged as a strategic goal of United States space activities. Despite the hardships suffered after the cancellation of the lunar focus in 2010, the community has persevered, and the value of lunar exploration and utilization, including human lunar return, is higher than it has ever been.

Given the profound importance of establishing a strong United States presence on the surface of the Moon, the Back to the Moon workshop is the key first step towards determining how to expeditiously achieve that goal. We have waited almost five long decades since the last United States landing on the surface of the Moon – a stunning world of wonder and opportunity that is only a few days away. The Moon awaits the return of those Americans who will purchase the first foothold on our journey ever deeper into the Solar System.

ABOUT THE LUNAR EXPLORATION ANALYSIS GROUP

The Lunar Exploration Analysis Group (LEAG) was established in 2004 to support NASA in providing analysis of scientific, commercial, technical, and operational issues to further lunar exploration objectives, as well as their implications for lunar architecture planning and activity prioritization. LEAG was jointly established by the Science Mission Directorate (SMD) and the Human Exploration and Operations Mission Directorate (HEOMD) and blends members of both communities, building bridges between science, exploration, and commerce whenever and however possible. LEAG is led by a Chair and a Vice-Chair who serve as the principal representatives of the United States lunar exploration community to stakeholders, including NASA and the international community. LEAG has a standing Commercial Advisory Board (CAB) to offer programmatic insights into the capabilities provided by industry. LEAG is a community-based, volunteer-driven, interdisciplinary forum. Membership is open to all members of the lunar exploration community and consists of lunar and planetary scientists, life scientists, engineers, technologists, human system specialists, mission designers, managers, policymakers, and other aerospace professionals from government, academia, and the commercial sector.

ABOUT THE LEAG LUNAR EXPLORATION ROADMAP

The LEAG Lunar Exploration Roadmap (LER) is the cohesive strategic plan for using the Moon and its resources to enable the exploration of all other destinations within the Solar System by leveraging affordable investments in lunar infrastructure. The LER is a living document developed over four years through a comprehensive community-based process and was released in 2012. The roadmap lays out a sustainable plan for Solar System exploration that allows NASA to use its lunar surface infrastructure to explore small bodies, Mars, and beyond. Following the LER will enable commercial development, through early identification of commercial opportunities that will create wealth and jobs to offset the initial investment of the taxpayer. The roadmap will also, with careful planning, enable international cooperation to expand our scientific and economic spheres of influence while enabling an expansion of human and robotic space exploration.

The Roadmap is located at: https://www.lpi.usra.edu/leag/roadmap/
The Implementation Plan is located at: https://www.lpi.usra.edu/leag/reports/RoboticAnalysisLetter.pdf

ON THE BACK COVER: A vast amount of molten rock splashed over the Tycho crater rim and flowed tens of kilometers before creating this "frozen falls" of rock on the Moon - a prime target for future astronaut exploration! [NASA/GSFC/Arizona State University].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