

LOST ON THE WAY TO THE MOON? TRY THE LUNAR EXPLORATION ROADMAP. A.L. Fagan¹, B.A. Cohen², B.W. Denevi³, S.J. Lawrence⁴, and C.R. Neal⁵. ¹Geosciences and Natural Resources Dept., Western Carolina University, Sylva, NC 28723, USA (alfagan@wcu.edu). ²NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA. ³Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA. ⁴ARES, NASA Johnson Space Center, Houston, TX 77058, USA. ⁵Dept. CEEES, University of Notre Dame, Notre Dame, IN 46556, USA.

Introduction: The Lunar Exploration Analysis Group (LEAG) was founded in 2004 to support NASA by analyzing issues relevant to lunar exploration (e.g., scientific, technical, commercial, operational) across all Agency directives (Science, Human Exploration, and Technology). As a community-based organization, LEAG is comprised of people with a wide range of backgrounds including, but not limited to, life and planetary scientists, astronomers, engineers, academics, government employees, and commercial company representatives [1].

One of the most important analyses conducted by LEAG to date has been the creation of the *Lunar Exploration Roadmap* (LER). This document was first generated as a response to a request in 2006 by the NASA Advisory Council to create a “Lunar Goals Document” that would: (1) Map science goals to objectives, observations, measurements; (2) Identify technological developments; (3) Facilitate coordination with commercial and international partners; and (4) Determine integral “Feed-forward activities” to enable exploration to Mars and beyond [2,3]. The Apollo model, although highly successful and a beacon of American ingenuity, did not enable a sustained human presence on or near the Moon; therefore, LEAG was tasked with evaluating, “How do we get there to stay?”

The LER is a living document, with the first version released in 2009 based on many previous reports (e.g., [4-20]), and updates to make corrections and minor changes. As a reflection of its ability to adapt, the LER has had two significant updates to the body of the text. First, changes in 2010 included language specific to exploration of airless bodies in response to the so-called “Flexible Path” proposed by the Augustine Commission that included visiting a near-Earth asteroid [21]. Second, the 2013 updates reflected feedback from the Mars Exploration Program Analysis Group to better prepare for future missions to Mars and beyond [e.g., 22], with the Moon as an integral and strategic piece.

New updates to the LER are needed to reflect the continually evolving realm of lunar science and exploration and the Moon’s role in expanding our knowledge of the Solar System. In recent years, several Special Action Teams and Workshops have identified knowledge gaps, the importance and presence of volatiles, required technological advances and investments, and potential landing sites on the Moon [23-28]. These reports demonstrate that the active lunar community is invested in exploration of the Moon and

recognize the vital role that our nearest neighbor must play in further exploration of the Solar System. The Moon is the foundation of Solar System exploration; the most important architectural element in any building, a weak foundation will make a house crumble. Similarly, Solar System exploration will not reach its full potential without the continued investment in the Moon.

LER Synergies with International Collaboration:

The essential nature of the Moon for exploration to other bodies in the Solar System, such as Mars, is noted in the *Global Exploration Roadmap* (GER [29]), first created in 2011 by the International Space Exploration Coordination Group (ISECG, [30]) and now in its third edition. The first version of the GER was built upon its preceding document, the 2007 report [18], which provided a shared set of exploration paths by 14 space agencies, including NASA, that highlighted the importance of international collaboration and specified the need for a sustained human exploration of the Moon, near-Earth asteroids, and Mars. There are several unified themes across the LER and GER, most prominently the emphasis of the Moon’s presence on **the** pathway to Mars, the need for sustained human presence on and around the Moon, coordination with the private sector, and in-situ resource utilization (ISRU).

Major Themes of the LER [3]: The LER is divided into a hierarchy with three main themes, each with goals and then objectives or investigations within those goals, pertaining to the exploration of the Moon and beyond: Science, Feed-Forward, and Sustainability. Within these themes, the importance of sustained human presence on the Moon in answering key science questions, enabling future exploration beyond the Earth-Moon system, and establishing a new sector of our economy is highlighted.

Science: The Science theme addresses fundamental questions about the Solar System, universe, and our place in them - a question humanity has asked since before Ptolemy. Science goals include: understand formation, evolution, current state of the Moon; use the Moon as a witness plate for Solar System evolution; use the Moon as a platform for astrophysical, heliophysical, and Earth-observing studies; recognize the Moon’s unique environment as research tool.

Feed Forward: This theme aims to utilize the Moon as a cornerstone to prepare for missions to other targets in our Solar System. Feed-Forward goals include: identification and testing of technologies on the Moon

to enable robotic and human exploration; using the Moon as a test-bed for mission operations and exploration techniques; and preparing for future missions to other airless bodies.

Sustainability: Sustainability aims to ensure extended human presence to support and guarantee the success of the other two themes by enabling eventual settlement following an example such as the sustained presence of humans at McMurdo Station in Antarctica. Goals within this theme include: maximize commercial activity through development of commercial “on-ramps” early in any architecture; collaborative expansion of science and exploration; and enhance security, peace, and safety.

Time-Phasing [3]: Within the LER, the objectives and investigations have recommendations of the appropriate timing to maximize the success of the three themes; these can be found in greater detail on the LEAG website [1], but are summarized here with at least one example of each. There are 3 main stages for time-phasing: Early, Mid, and Late. The Early stage includes robotic precursors (i.e., “pre-early” stage) and 1-2 human landings that last up to one lunar day; one example includes the development and implementation of sample return technologies. The Mid stage comprises continued robotic missions as well as human stays of one lunar day, including part of a lunar night, and an initial outpost; one example includes the development of sustainable transportation between Earth and the lunar surface. The Late stage references continued robotic missions, as well as an established outpost enabling human presence for >30 days at a time; examples include the development and use of power systems and autonomous crew operations.

Prioritization of Goals [3]: In addition to the time-phasing recommendations, the LER provides guidance for prioritization of the objectives and investigations. The LER established prioritization for the Feed-Forward and Sustainability themes, but defers to previous prioritization for the Science theme [20]. High priority indicates essential information and technological developments needed to facilitate habitation on the lunar surface and further exploration as well as facilitate large advancements in scientific knowledge. Low priority indicates topics that are not essential for habitation and exploration, and make incremental advances in scientific knowledge, but are still good to do. An example of a high priority is landing site selection, whereas an example of a low priority is studying the psychological effect of human isolation for long periods (e.g., >500 days); clearly an understanding of isolation effects on astronauts is an important and ethical issue, which demonstrates that the low-priority objectives should not be viewed as unimportant but need not be conducted on the Moon.

What it means for the Moon and Beyond: The LER is a reference for how to get to the Moon to stay and to utilize it to expand humanity throughout the Solar System, as well as commercial participation in space exploration. These intents reflect a desire to know and understand our place in the Solar System and Universe. This is a question that has been addressed by humanity for millennia, and yet we still have more questions. A sustained human presence on the Moon is not a distraction that prevents us from getting to other destinations. Instead, it is the cornerstone of Solar System exploration— an enabling asset that unites our exploration goals across different destinations and the foundation to humanity’s understanding of our place in space and time.

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