OVERVIEW

This document contains the finalized findings based on community discussion at the 2021 annual meeting of the Lunar Exploration Analysis Group (LEAG), which was held virtually August 31-September 2, 2021 due to the continued global health crisis caused by the COVID-19 pandemic. The LEAG Executive Committee, on behalf of the attendees of the meeting, endorse the findings contained within. These findings are grouped into themes and are expanded upon with specific findings and rationale in the following pages.

THEME INDEX:

THEME 1: ARTEMIS

Finding 1.1: ***LEAG strongly advocates for the establishment of an Artemis Program Office with clearly defined roles and responsibilities that are designed to enable the accomplishment of the highest priority science objectives by ensuring an enduring and sustained human presence on the lunar surface in conjunction with the economic development of cis-lunar space. In addition, we urge the identification of an Artemis Director to begin a leadership position while the Artemis Program Office is under development.*** Artemis, by necessity, is made up of components by three separate mission directorates (Science, Space Technology, and Exploration Systems Development), which means that there is no clear management hierarchy for optimizing lunar activities therein. For science management in particular, we find that the current organization of the effort to return humans to the Moon under Artemis as communicated to the lunar science and exploration community at the 2021 annual LEAG meeting conflicts with the best organizational practices identified for science management in human exploration of space identified by the National Academies Committee on Human Exploration Systems[1]. We reiterate the importance of Finding 1R and Recommendation 1R from the 2007 NRC SCEM report[2], which identified that NASA should establish a science office "to plan and implement science… Following the Apollo model, such an office should report jointly to the Science Mission Directorate and the [Exploration Systems Development Mission Directorate], with the science office controlling the proven end-to-end science process." In addition, without a formal Director (or equivalent leader), it is unclear who makes final decisions regarding priorities and ensuring effective balance that can drive integrated system-level requirements. Currently, there is a strong appearance of uncertainty in the boundaries between, and goals of, Artemis as an entity and other entities within NASA, potentially to the detriment of our national space policy. We urge NASA to rectify these issues, as the success of the Artemis program is of critical importance to the entire LEAG community, the future exploration initiatives of the nation, and our international partners.

Finding 1.2: ***We commend the message presented by the Science Mission Directorate and Exploration Science Strategy and Integration Office at the annual LEAG meeting that an Artemis Science Team will be solicited in the near-term.*** LEAG stands ready to facilitate developing a strategy for science community participation in all Artemis activities (e.g., through Town Hall discussions and/or Specific Action Teams. With the imminent solicitation of the Artemis Science Team and because the science requirements for Artemis missions are being written now (HEO-006 Utilization Plan, which is expected to be released in fall 2021), LEAG encourages NASA to rely less on *ad hoc* internal groups and more on the Science Team to define near- and long-term Artemis science goals.

Finding 1.3: ***The LEAG community looks forward to the upcoming flights of Artemis I and II and their valuable science payloads as well as a plethora of international missions, and we encourage early and regular communication with the broad lunar science and exploration community as updates are available for upcoming missions.*** As part of this, we request updates be announced at regular cadences at the annual LEAG meeting and LEAG town-halls, as well as general announcements to the community and regarding Artemis II's and Artemis III's progress to launch including, but not limited to, updated launch date, crew announcements, science and exploration objectives, selection of secondary payloads, and testing and delivery of final components. In addition, we look forward to seeing how data from upcoming international missions can integrate with and complement new NASA missions within the umbrella of Artemis and its periphery.

[1] 1997 The Human Exploration of Space; http://www.nap.edu/catalog/6058

[2] 2007 National Research Council Scientific Context for Exploration of the Moon; https://www.nap.edu/11954

THEME 1: ARTEMIS CONTINUED

Finding 1.4: ***Field science and science operations training is critical for not only Artemis lunar surface crews but also the future Artemis Science Team and Artemis flight controllers, in order to promote an exploration workforce who understands driving principles of conducting field science.*** The success of the Apollo J-missions can in part be traced directly to the program of intense, field-based geologic training that each primary and backup crew on Apollo's 15, 16, and 17 received, starting with their initial selection, and continuing monthly until launch. It should be emphasized that this training is unlike International Space Station Laboratory training, and training for lunar surface missions cannot be reduced to computer-based training refreshers that the crew reviews during trans-lunar coast. LEAG applauds the detailed geologic training that has been given to the 2009, 2013, and 2017 Astronaut Classes, and strongly supports the current plan for this training, which will continue geologic field training beyond the Astronaut Candidate years and into advanced research- and analog-focused geologic training opportunities for flight-assignment eligible astronauts and into intensive, mission specific geologic training for Artemis crews. Once the Artemis Science Team is selected, this Science Team and key Artemis flight controllers should also prioritize the early integration of field testing, field training, and integrated mission simulations into their mission preparation to adequately prepare for lunar surface exploration.

Finding 1.5: ***NASA, in preparation for receiving the Artemis samples, should invest in maintaining and upgrading current, or procuring new, state-of-the-art equipment, instrumentation, and facilities.*** The importance of procuring and curating lunar samples has never waned, and these precious samples are often regarded as "the gift that keeps on giving." As a community, we continue to find new ways to analyze these samples, garnering new information from the Apollo samples as well as more recently obtained meteorite and other extraterrestrial samples – a capability largely due to the excellent curation of the Apollo and meteorite collections. The admirable curation efforts of NASA allow continued advancement of our scientific knowledge of the Moon decades after sample collection. In order to facilitate the same success in maximizing the science return from the Artemis samples, both in the near-term and in the future, we must ensure that the curation and analytical facilities are properly prepared for the return of Artemis samples, which includes volatile and cold-sample storage. We strongly advocate for the implementation of the findings from the 2019 National Academies report, "Strategic Investments in Instrumentation and Facilities for Extraterrestrial Sample Curation and Analysis[3]" regarding investment in sample curation and curatorial facilities.

[3] 2019 Strategic Investments in Instrumentation and Facilities for Extraterrestrial Sample Curation and Analysis http://nap.edu/25312

THEME 1: ARTEMIS CONTINUED

Finding 1.6: ***We encourage NASA to take several steps regarding sample collection for Artemis III and further Artemis missions, including following the Artemis III science program, investing in surface technology and infrastructure, and re-examining upmass requirements***. The lunar south polar region is geologically diverse and will require strategic sample collection to ensure the samples returned to Earth are representative and will help to achieve high-level science objectives. The candidate Artemis III science program recommended by the Artemis III SDT report[4] should guide the path for sample collection, specifically its recommended sample strategies and associated mass and volume estimates to thoroughly characterize the diversity of materials at the landing site. It is critical to invest in technologies for *in situ* analysis on the lunar and to include further triage support in surface plans for astronauts to allow the down-select of samples from initial collection efforts to stay within limited up-mass requirements. The Moon is lithologically diverse, and to address the prioritized science goals outlined in the 2007 NRC SCEM report[5] and the US LER[6], extensive sample collection is needed; thus, it is preferable to remove the 100 kg limit for sample upmass and to prioritize radically increasing the upmass capability for future lander solicitations. The returned sample mass should be large enough to be representative of the full lithological variation at any landing site. LEAG stands ready to facilitate updated discussions regarding sample up-mass requirements for Artemis III as well as future missions within Artemis.

[4] Artemis III Science Definition Team Report; https://www.nasa.gov/sites/default/files/atoms/files/artemis-iii-science-definition-report-12042020c.pdf

[5] 2007 National Research Council Scientific Context for Exploration of the Moon; https://www.nap.edu/11954

[6] The United States Lunar Exploration Roadmap; https://www.lpi.usra.edu/leag/roadmap/

THEME 2: A STRATEGIC LUNAR EXPLORATION PLAN: INVESTMENTS, STRATEGIES, AND THE FUTURE (ARTEMIS & BEYOND)

Finding 2.1: ***LEAG encourages the Lunar Discovery and Exploration Program (LDEP) to be developed as a Program with a director within the Planetary Science Division rather than simply remain a budget line.*** As presented at the annual LEAG meeting, there are many moving parts for the scientific exploration of the Moon, with robotic, commercial, and human exploration efforts. A coordinated Program is required to effectively ensure the accomplishment of high-priority lunar science goals and objectives using this complex set of implementation options and to maximize international collaboration; it could also work to ensure that areas where multiple interests intersect (e.g., science of volatiles and resource prospecting) could also be best coordinated by this program. Such a Program will require a dedicated director who is responsible for and has authority to implement a strategic plan for lunar science guided by science objectives as outlined in community documents.

Finding 2.2: ***NASA should work with the community towards identifying and addressing all necessary remote sensing capabilities employed around the Moon (currently and in the future) to accomplish high-priority science and exploration objectives.*** For example, the Lunar Reconnaissance Orbiter (LRO) has been and continues to be a tremendous asset to the lunar community as evidenced in the LRO highlights session. As such, the community supports its continuance into its proposed 5th extended mission. However, LRO will not last forever, and its successor must be developed soon. Plans must be made for formulating a next generation lunar orbiter (NGLO) capable of addressing key goals identified in the US LER[7], 2007 NRC SCEM Report[8], and the Decadal Survey (Visions and Voyages[9] and the forthcoming report for 2023-2032[10]). Continuity (if not overlap) between the remaining lifespan of LRO and its potential successor will be important for both science as well as for supporting Artemis and other exploration efforts. LEAG encourages a release of a Request for Information (RFI), in consultation with the Science (SMD), Exploration Systems Development (ESDMD), and Space Technology Mission Directorates (STMD), to the lunar community to assess the need, and capabilities available, for an NGLO to enable surface mission support and scientific investigation of the Moon in the post-LRO era; all three mission directorates should contribute to the NGLO, as it will be a lunar mission rather than solely a science, exploration, or technology mission. In conjunction with the RFI, LEAG supports further broad community input on the needs and required capabilities for NGLO via a virtual forum in the style of the successful Lunar Surface Science Workshops. Finally, LEAG can initiate a Specific Action Team to further refine an NGLO concept. Given the anticipated remaining lifetime of LRO (6-7 years), this process should begin now to ensure that the lunar science and exploration community has a long term, stable orbital asset to support Artemis and CLPS[11] missions and to enable new investigations of the lunar surface and subsurface that would identify new, exciting landing sites.

[7] The United States Lunar Exploration Roadmap; https://www.lpi.usra.edu/leag/roadmap/
[8] 2007 National Research Council Scientific Context for Exploration of the Moon; https://www.nap.edu/11954
[9] Vision and Voyages for Planetary Science in the Decade 2013-2022; https://www.nap.edu/catalog/13117
[10] https://www.nationalacademies.org/our-work/planetary-science-and-astrobiology-decadal-survey-2023-2032
[11] Commercial Lunar Payload Services; https://www.nasa.gov/content/commercial-lunar-payload-services

THEME 2: A STRATEGIC LUNAR EXPLORATION PLAN CONTINUED

Finding 2.3: ***LEAG encourages NASA to develop an integrated resource prospecting campaign as an ideal mechanism to properly assess the presence, viability, form, and composition of the variety of resources at and near the lunar surface as well as for developing the most efficient mechanisms for resource extraction to benefit human exploration; furthermore, we applaud the development of and encourage the enactment of the water resource plan as outlined in the 2021 LWIMS[12] report.*** Fully leveraging lunar resources to drive the cislunar economy is the most viable way to make missions to Mars and other destinations in the 2030s affordable and capable, and prove out ISRU capability to allow humans to survive and thrive on the Moon and Mars. As outlined in the US LER[13], lunar resource extraction is a key element of sustainable surface presence in developing commercial activity on the lunar surface. As such, the Volatiles Investigating Polar Exploration Rover (VIPER) could benefit from data from the Trailblazer and Polar Resources Ice Mining Experiment-1 (PRIME-1) missions to ensure that VIPER travels along a traverse with sites that will have ice, and these three missions could represent the first step in building a resource campaign. To better ensure that these missions can benefit from one another, the LEAG community supports examining pathways to fly Trailblazer earlier than its scheduled launch date in conjunction with Interstellar Mapping and Acceleration Probe (IMAP). In addition, a coordinated and synergistic resource campaign could help to guide future calls and selections of Commercial Lunar Payload Services (CLPS[14]) payloads (including[15] NPLP, LSITP, PRISM, and technology demonstrations) that also have direct relevance to resource identification and utilization.

Finding 2.4: ***The LEAG Commercial Advisory Board (CAB)[16], in conjunction with the broader LEAG community, strongly encourages NASA to develop and communicate a roadmap of future task orders and pathways for accomplishing prioritized science through Commercial Lunar Payload Services (CLPS).*** This should include what might be involved within the task orders as well as when they might be solicited, particularly when they involve a new capability such as mobility, surviving the lunar night, sample return, or pre-deployment of surface assets for Artemis III. A CLPS roadmap will allow the vendor pool to have enough time to make the internal investments and decisions required to submit a competitive bid. A roadmap for accomplishing prioritized science through CLPS should include how will missions will build on each other as capabilities evolve. Science priorities should be set up front prior to landing site decisions, and the science priorities can guide the required innovations in CLPS capabilities as well as to guide instrument development (e.g., through Development and Advancement of Lunar Instrumentation- DALI). The CLPS program remains an exciting paradigm shift in the delivery of lunar scientific and technology payloads, and we look forward to its continued evolution.

[12] Lunar Water ISRU Measurement Study (LWIMS): Establishing a Measurement Plan for Identification and Characterization of a Water Reserve; https://ntrs.nasa.gov/citations/20205008626

[13] The United States Lunar Exploration Roadmap; https://www.lpi.usra.edu/leag/roadmap/

[14] Commercial Lunar Payload Services; https://www.nasa.gov/content/commercial-lunar-payload-services

[15] NPLP: NASA Provided Lunar Payloads; LSITP: Lunar Surface Instrument and Technology Payload; PRISM: Payloads and Research Investigations on the Moon

[16] LEAG Commercial Advisory Board; https://www.lpi.usra.edu/leag/cab/

THEME 2: A STRATEGIC LUNAR EXPLORATION PLAN CONTINUED

Finding 2.5: ***LEAG supports prioritizing the development of technologies that will enable sample return, surviving the lunar night, and techniques and instrumentation that will enable the science goals as outlined in the Artemis III Science Definition Team Report as well as various community documents such as the 2007 NRC SCEM report[17], ASM-SAT[18], and the US LER[19].*** The quickening pace of lunar exploration (including the upcoming start of CLPS[20] deliveries to the Moon, the upcoming first test flights of Artemis program spacecraft, etc.) highlights the need to address important remaining science and exploration technology gaps soon. At the same time, the number of opportunities to develop and test those technologies is increasing. LEAG applauds the regular cadence of PRISM[21], LuSTR[22], and other lunar-centric technology-development and implementation opportunities, as well as the urging by NASA officials for the community to respond to requests for information on topics at the intersection of science and exploration. LEAG will continue to work with NASA, LSIC[23] and the rest of the lunar community and stands ready to contribute to science and exploration technology-related efforts, for example revisiting/redrafting the NASA Strategic Knowledge Gaps (SKGs).

Finding 2.6: ***LEAG urges NASA to consider a commercial services solicitation to provide global lunar communication, data, mobility and position services; such services should reflect a coherent, well-planned out activity rather than developed for one small mission at a time.*** LEAG recognizes and supports the critical need for robust lunar infrastructure early, especially for far-side activities. Infrastructure includes many items such as power generation, landing pads, precision location assets, local ISRU capabilities, tankage, oxygen production, sustainability, human biological and life support needs, communication, and uplink/downlink capabilities. In particular, communication is crucial for supporting humans on and around the surface as well as for robotics in any location on the lunar surface; this also includes robotic rover missions coordinated with crewed surface missions with rovers that function in parallel with human activity or preceding the human presence as reconnaissance assets to amplify science to be achieved. In addition, the initial operating capability of 2027 for the Lunar Terrain Vehicle (LTV), as indicated in the recent LTV Request for Information (RFI[24]), implies that there is no current plan to include a rover on the first human landed mission within Artemis, which goes against Artemis III SDT [25]Recommendation 7.3-1 that "NASA should include a rover or other mobility solution for crew use on the lunar surface starting as early in the Artemis program as possible, ideally for Artemis III;" mobility capabilities for Artemis III was also a finding from the 2020 annual LEAG meeting[26], as it would "uniquely [provide] enhanced benefits and capabilities to surface missions [and] is critical for a variety of scientific, commercial, and exploration purposes."

[17] 2007 National Research Council Scientific Context for Exploration of the Moon; https://www.nap.edu/11954
[18] 2017 Lunar Exploration Analysis Group (LEAG) *Advancing Science of the Moon: Report of the Specific Action Team*; https://www.lpi.usra.edu/leag/reports/ASM-SAT-Report-final.pdf
[19] The United States Lunar Exploration Roadmap; https://www.lpi.usra.edu/leag/roadmap/
[20] Commercial Lunar Payload Services; https://www.nasa.gov/content/commercial-lunar-payload-services
[21] PRISM: Payloads and Research Investigations on the Moon
[22] Lunar Surface Technology Research Program
[23] Lunar Surface Innovation Consortium; https://lsic.jhuapl.edu/
[24] Lunar Terrain Vehicle (LTV) Notice; https://sam.gov/opp/9e777623a1f3478296f21f2f0d787113/view
[25] Artemis III Science Definition Team Report; https://www.nasa.gov/sites/default/files/atoms/files/artemis-iii-science-definition-report-12042020c.pdf
[26] 2020 Annual Meeting of the Lunar Exploration Analysis Group Findings; https://www.hou.usra.edu/meetings/leag2020/LEAG2020AnnualMeetingFindings_FINAL.pdf

THEME 2: A STRATEGIC LUNAR EXPLORATION PLAN CONTINUED

Finding 2.7: ***LEAG urges NASA to establish requirements and recommendations for future lunar operations to protect the ability to achieve high-level science and exploration objectives (e.g., ISRU[27]) for the benefit of all without undue regulation of commercial and international activities.*** NASA has an opportunity to set a standard for the utilization and necessary preservation of the lunar environment such that the integrity of science to be achieved on the Moon can be maintained without unnecessarily restricting commercial and international activities. However, overly restrictive standards run the risk of diminishing utilization of resources that would be needed to ensure a sustained and sustainable human presence on the lunar surface and to other destinations, such as Mars. To ensure that we understand the complexities of materials left on the lunar surface by humans, requirements for documenting and recording all materials that interact with the lunar surface are essential. We also encourage NASA to identify regions of particular scientific, engineering, and cultural merit (including past landing and impact sites) and establish and clearly communicate recommendations for the preservation and scientific examination of such regions (e.g., micrometeorite impacts on Surveyor or Apollo apparatuses), while considering both planetary protection and commercial activity viewpoints.

Finding2.8: ***The LEAG community is eager to have new samples returned from the lunar surface and encourages NASA to pursue the potential for sample return missions using Commercial Lunar Payload Services (CLPS) providers.*** A campaign, driven by science objectives outlined in the 2007 NRC SCEM report[28], ASM-SAT[29], and the US LER[30], using the CLPS[31] providers could ensure that science and exploration objectives outside the polar region can be assessed. As part of this, we seek more information regarding the 2020 NASA notice regarding "Purchase of Lunar Regolith and/or Rock Materials from Contractor," and how this fits into the larger lunar strategic plan.

[27] *In Situ* Resource Utilization

[28] 2007 National Research Council Scientific Context for Exploration of the Moon; https://www.nap.edu/11954

[29] 2017 Lunar Exploration Analysis Group (LEAG) *Advancing Science of the Moon: Report of the Specific Action Team*; https://www.lpi.usra.edu/leag/reports/ASM-SAT-Report-final.pdf

[30] The United States Lunar Exploration Roadmap; https://www.lpi.usra.edu/leag/roadmap/

[31] Commercial Lunar Payload Services; https://www.nasa.gov/content/commercial-lunar-payload-services

THEME 3: SUPPORTING AND UTILIZING THE LUNAR SCIENCE AND EXPLORATION COMMUNITY

Finding 3.1: ***LEAG encourages NASA to investigate the feasibility of creating a Tribal Liaison office to help connect the broader lunar community (as well as the planetary science community in general) and indigenous populations and facilitate fruitful partnerships.*** LEAG recognizes the importance of respectfully including Indigenous communities in lunar exploration and especially in any nomenclature decisions that use language related to indigenous cultures. LEAG recognizes that equity, diversity, and inclusion efforts are critical for the lunar community at this time. Moving forward, more input from the community is needed to identify the most important equity-, diversity-, and inclusion-related issues that the lunar community should address first.

Finding 3.2: ***LEAG encourages NASA to consider open calls for involvement in various decision-making committees and rapid-response teams to better capture the breadth of the expertise of the entire lunar community to help ensure the success of Artemis as well as other lunar exploration endeavors (e.g., PRISM[32]).*** We encourage open calls for involvement in committees to better capture the diverse and inclusive workforce that we often discuss; e.g., the current model, as expressed to the broader community, seems to be that committees/teams will seek out advice from individuals in the broader community as needed, but this mechanism may not capture all the needed expertise and tends to be less transparent and potentially exclusionary. A clear path for integrating with NASA to propose selection of landing sites as well as to work directly with small internal committees (e.g., Contamination and Research Integrity team [CaRI] or CLPS Manifest Selection Board [CMSB][33]) should be developed and communicated. For example, will the Fall 2021 Lunar Surface Science Workshop (LSSW) be the only direct path for providing input for PRISM[34] and CLPS[35] landing sites in the near term? The current selection process of CLPS through the consult of community documents is somewhat opaque and could benefit from more direct input from the entire community, such as a review panel examining community proposals. It may also be beneficial to hold a workshop to examine lessons learned from site selection during the Apollo program and how best to apply those lessons to the current time.

Finding 3.3*:* ***We encourage NASA to continue to seek active collaboration with US-based and international individuals and entities (e.g., domestic commercial companies and international space agencies) and to explore mechanisms for facilitating direct engagement between the non-NASA community and multiple divisions and directorates at NASA.*** Collaboration will be critical as we continue to explore the Moon, as demonstrated by several components presented at the meeting from the Science Mission Directorate panel, international partners, the entire (very complicated) lunar program, Commercial Lunar Payload Services (CLPS) providers, Exploration Science Strategy and Integration Office (ESSIO), multiple polar missions, development of a communication relay, etc. We thank our colleagues for engaging in panels to demonstrate the manners in which these important collaborations are taking place. While NASA is communicating between the divisions and directorates regularly, it was less-clear to the community how the non-NASA community can directly engage in multiple divisions or directorates for research and missions. For example, we encourage NASA to explore opportunities for participating scientist programs for US scientists on international missions and vice versa. In addition, we encourage active communication between NASA and non-NASA scientists with commercial companies to move forward with achieving high-level lunar priorities.

[32] PRISM: Payloads and Research Investigations on the Moon

[33] NASA Astrophysics Advisory Committee; October 19-21, 2021; https://science.nasa.gov/files/science-pink/s3fs-public/atoms/files/Burns-APAC%20-%20CLPS%20&%20AP%20Payload%20Update%20-%20Oct%202020_TAGGED.pdf

[34] PRISM: Payloads and Research Investigations on the Moon

[35] Commercial Lunar Payload Services; https://www.nasa.gov/content/commercial-lunar-payload-services