

Moon 2020-2030 and the LEAG Lunar Exploration Roadmap

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Jasper Halekas – ARTEMIS rep (University of Iowa)

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Jerry Sanders – ISRU (NASA-JSC)

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Ben Bussey, NASA-HEOMD

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* Charter currently being drafted



Progressive Exploration

2007: LEAG tasked to develop a comprehensive Lunar Exploration Roadmap (LER).

3 Themes: Science, **Feed Forward**, and Sustainability.

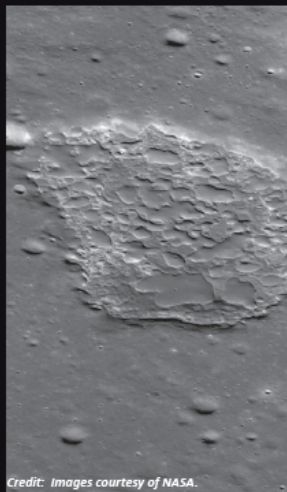
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The Lunar Exploration Roadmap, jointly developed by engineers, planetary scientists, and policymakers, is the cohesive strategic plan for using the Moon and its resources to enable the exploration of all other destinations within the solar system on a sustained basis by leveraging incremental and affordable investments in lunar infrastructure.

Implementing the Roadmap will preserve American leadership, engage and inspire the public, open the space frontier to the energy and vitality of commercial enterprise, and enhance international partnerships as well as world security.

FOLLOW THE ROADMAP

<http://www.lpi.usra.edu/leag/roadmap>



Credit: Images courtesy of NASA.

THE MOON GATEWAY TO THE SOLAR SYSTEM

**PROGRESS IS NOT A SHOT IN THE DARK,
BUT A SERIES OF LOGICAL STEPS.**

— Robert H. Goddard



OPEN THE GATEWAY TO THE SOLAR SYSTEM

SUSTAIN A FOOTHOLD ON THE NEXT FRONTIER



Use the Moon to learn how to live and work productively off-planet for increasing periods, enabling human settlement.

The Moon has abundant material and energy resources that can be used to make ambitious solar system exploration more cost-effective. Lunar resources offer an enduring opportunity for commercial investment and economic growth. Innovative public-private partnerships growing from initial government investment sustain infrastructure and create new spacefaring opportunity.

DISCOVER KNOWLEDGE ON A NEW WORLD



Use the Moon for scientific research that addresses fundamental questions about the Moon, the solar system, and the universe.

A sustained program of lunar exploration will yield significant scientific and technological advances. The Moon retains a record of the formation, evolution, and impact history of Earth and the other terrestrial planets, as well as an otherwise inaccessible record of the Sun's evolution and history. The Moon provides a unique and stable platform for observations of Earth, the Sun, and

PIONEER THE TRAIL TO MARS AND BEYOND



Use the Moon to prepare for future missions to Mars and other destinations beyond

The Moon is a convenient deep space test bed that can be used to reduce cost and risk by testing technologies, systems, and operations. This lunar training ground enables sustained human space exploration beyond low Earth orbit. The Moon's combination of radiation, hard vacuum, and low gravity provides a unique laboratory in which to study the physiological, biological, and biomedical aspects of long-duration space travel.



Lunar and Planetary Institute

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LUNAR EXPLORATION ANALYSIS GROUP (LEAG)

Chartered by NASA HQ to assist in planning the scientific exploration of the Moon

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Lunar Exploration Analysis Group (LEAG)

The Lunar Exploration Analysis Group (LEAG) was established in 2004 to support NASA in providing analysis of scientific, technical, commercial, and operational issues in support of lunar exploration objectives and of their implications for lunar architecture planning and activity prioritization. The LEAG is a community-based, interdisciplinary forum. Membership and participation in the LEAG consists of lunar and planetary scientists, life scientists, engineers, technologists, human systems specialists, mission designers, managers, and other professionals drawn from the broad community of academia, industry, government, and the commercial sector. Details of the purpose of LEAG and its constitution and activities can be found under [LEAG Terms of Reference](#). If you have interest in becoming a member of LEAG, please fill out the [LEAG Indication of Interest](#) form.

Recent Meeting

[Annual Meeting of the Lunar Exploration Analysis Group \(LEAG\)](#)

October 20–22, 2015

Columbia, Maryland

- [Agenda and Presentations](#)
- [Meeting Findings](#)

[Destination Moon](#)



[Lunar Exploration Roadmap](#)

Destination Moon

Use the Moon to create a sustained human space-faring capability, advancing exploration of the Solar System.

The Value of Exploring the Moon

- Open the gateway to the Solar System
- Pioneer development of new technologies
- Advance economic expansion
- Enable new scientific discoveries
- Promote international partnerships

www.lpi.usra.edu/leag



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Lunar Exploration Roadmap v.1-1

The Lunar Exploration Roadmap Version 1.1 is the first second version of a living document that will be updated and further developed over time as more data becomes available from current missions, as further analyses by LEAG Specific Action Teams impact the roadmap, and as other relevant analyses are reported. Suggestions for revisions to the roadmap can be given to the LEAG Chair, the LEAG Executive Secretary or via the e-mail address at the [LEAG website](#).

The three themes described below are at various degrees of fidelity. The Science Theme has a long heritage of study, including NRC studies, and represents community consensus. The Feed Forward Theme has been presented to the Mars Exploration Program Analysis Group and their comments have been incorporated. It has also been presented to the Small Bodies Assessment Group (SBAG). The Sustainability Theme is at the lowest fidelity, representing a small (but growing) body of opinion and knowledge, and will require further refinements.

Overall the roadmap is intended to layout an integrated and sustainable plan for lunar exploration that will allow NASA to transition from the Moon to small bodies to Mars (and beyond) without abandoning the lunar assets built up using tax payer dollars. As such, the roadmap will enable commercial development, through early identification of **"commercial on ramps"**, that will create wealth and jobs to offset the initial investment of the taxpayer. In addition, the roadmap will, 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 draft of the Lunar Exploration Roadmap can be downloaded as a [PDF document](#).

The Lunar Exploration Roadmap is also available as an [Excel file](#).

This Excel file contains a number of different worksheets:

- The *TGOI* worksheet contains everything that is in the PDF document.
- The *OBJECTIVES* worksheet contains just Objectives where all the investigations have the same priority and time phasing, but the investigations are listed under the Objectives when they have different priorities and time phasings;
- The *Timing & Priorities* worksheet puts the list in the previous worksheet into Low, Medium and High priority blocks against Early, Middle and Late stage exploration phases.

The 2011 roadmapping effort had two objectives:



[Lunar Exploration Roadmap](#)

Lunar Exploration Roadmap

Developed by the Lunar Exploration Analysis Group (LEAG)



Why should we go back to the Moon?



Science (Sci) Theme: Pursue scientific activities to address fundamental questions about the solar system, the universe, and our place in them

Feed Forward (FF) Theme: Use the Moon to Prepare for Future Missions to Mars and Other Destinations

Sustainability (Sust) Theme:
Extend Sustained Human Presence to the Moon to Enable Eventual Settlement

Lunar Exploration Roadmap

Developed by the Lunar Exploration Analysis Group (LEAG)

<http://www.lpi.usra.edu/leag/roadmap>



Three Themes:

- Science (Sci)
- Feed Forward (FF)
- Sustainability (Sust)

- Community effort.
- Living document.

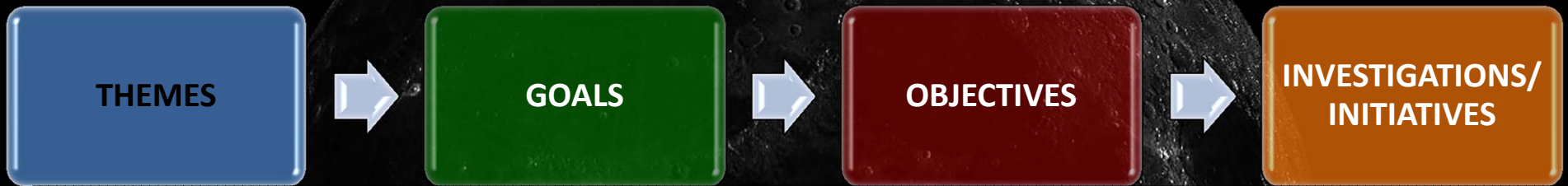
Sustainability is the key:

- Don't abandon assets – leverage them;
- Commercial “on ramps” are defined;
- International cooperation is critical.

Lunar Exploration Roadmap

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Science Theme: Four Goals;

- Understand the formation, evolution, and 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;
- Use the unique lunar environment as research tool.

The Lunar Exploration Roadmap

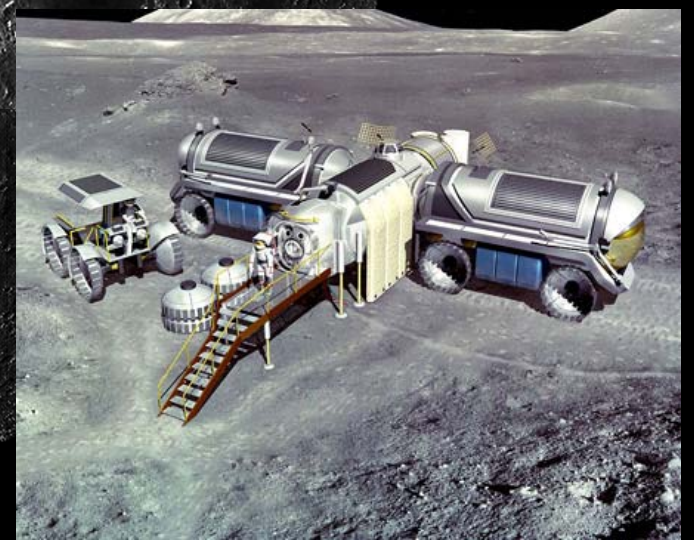
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Feed Forward Theme: Mars and Asteroids;

Mars/Small Body Risk Reduction Value: How well do the candidates address the key risk reduction areas identified through NASA's robotic and human Mars/Small Body mission planning studies;

Lunar Platform Value: Do candidates leverage the unique attributes of a lunar program to achieve success – or – would other platforms be more effective from a technical/cost perspective.



The Lunar Exploration Roadmap

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Sustainability Theme:

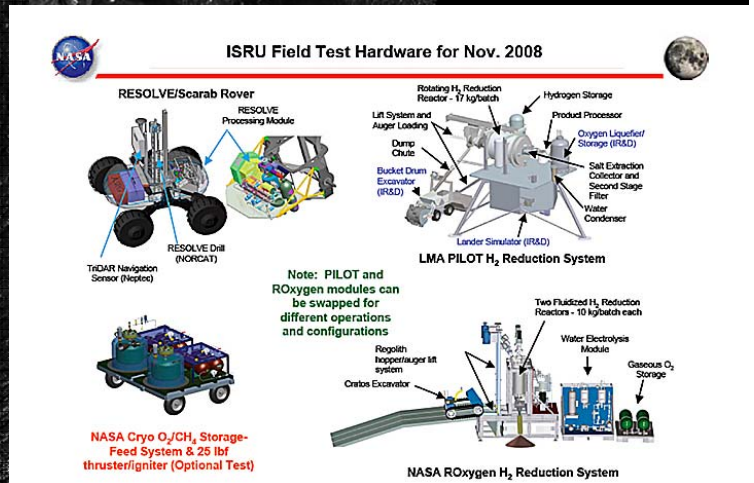
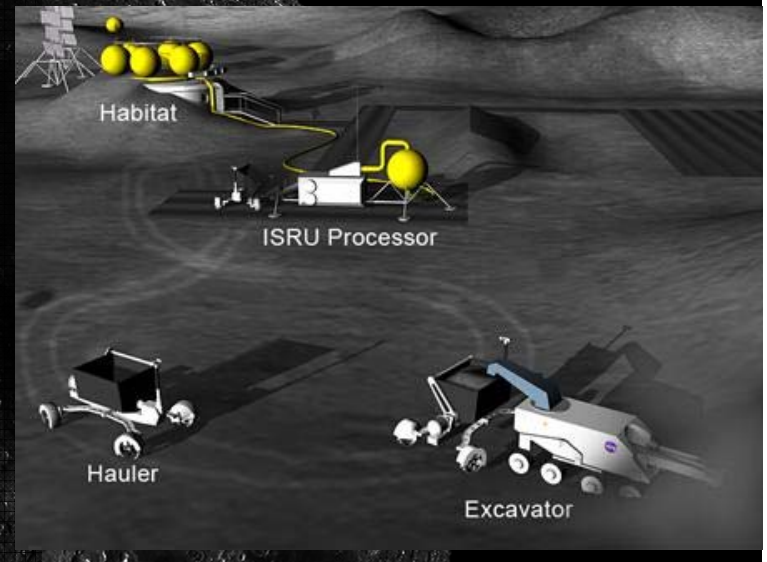
Sustained lunar activities are only possible when they are *sustainable* through ongoing return of value.

Self-sustained settlement is most defensible when strongly linked to **science** and **feeding forward** to other destinations in the solar system.

The role of **commercial activity** as an indispensable aspect of **sustainability**.

Making Exploration Sustainable

- In Situ Resource Utilization (ISRU) is the *game changer* – produce fuel and consumables on the lunar surface to enable human exploration of other airless bodies and Mars.
- Use the Moon to explore the Solar System due to the much reduced “gravity well” and presence of resources.
- Enables international cooperation and commercial participation (i.e., jobs!) in space exploration by starting at the Moon with the goal to go much further.



Enabling Solar System Exploration

Formulation of LER implementation strategy via a phased precursor program.

Phase 1: Lunar Resource Prospecting

- Define composition, form, extent, environment, and accessibility/extractability of the resource;
- Quantify regolith geotechnical properties where the resource is found;
- Ability to traverse several kilometers and target resource-rich deposits for future missions.

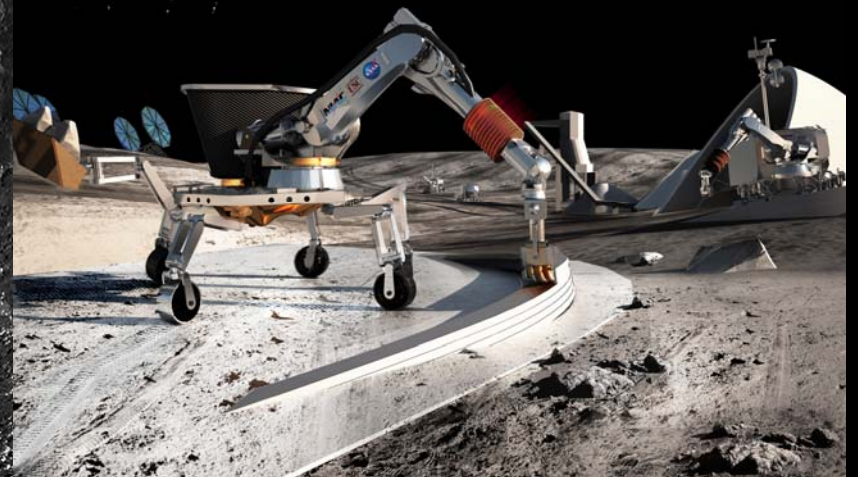
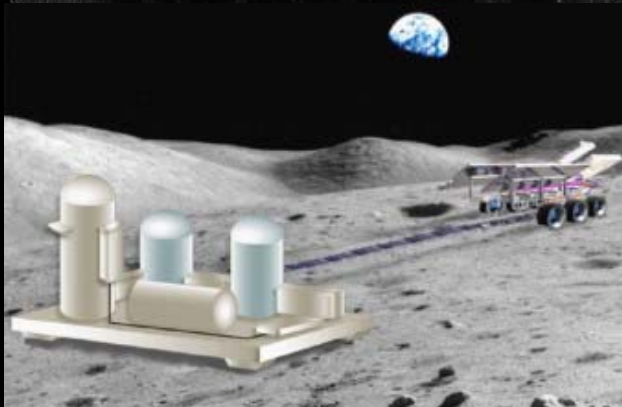


LEAG Lunar Exploration Roadmap (LER): www.lpi.usra.edu/leag

Enabling Solar System Exploration

Phase 2: Lunar Resource Mining

- Feedstock acquisition and handling;
- Resource extraction, refinement, transport, and storage;
- Dust mitigation strategies.



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Enabling Solar System Exploration

Phase 3: Lunar Resource Production

- Large scale production established prior to human return;

The campaign requires build-up of infrastructure at a site defined/characterized by initial prospecting and mining phases.

Production plant will provide consumables to lunar crews and enable future refuelable landers and cis-lunar refueling depots.



LEAG Lunar Exploration Roadmap (LER): www.lpi.usra.edu/leag

The Moon (and cis-lunar space) as an Enabling Asset



Full utilization and servicing of ISS in concert with International partners and commercial providers prepare for exploration beyond Low Earth Orbit



Propellant depots increase payload capability of current and future Launch Vehicles and refueling of reusable In-space Transportation



Hybrid reusable transportation Infrastructure support for EM/L1/2, crew and cargo for Lunar exploration, and Satellite deployment & servicing



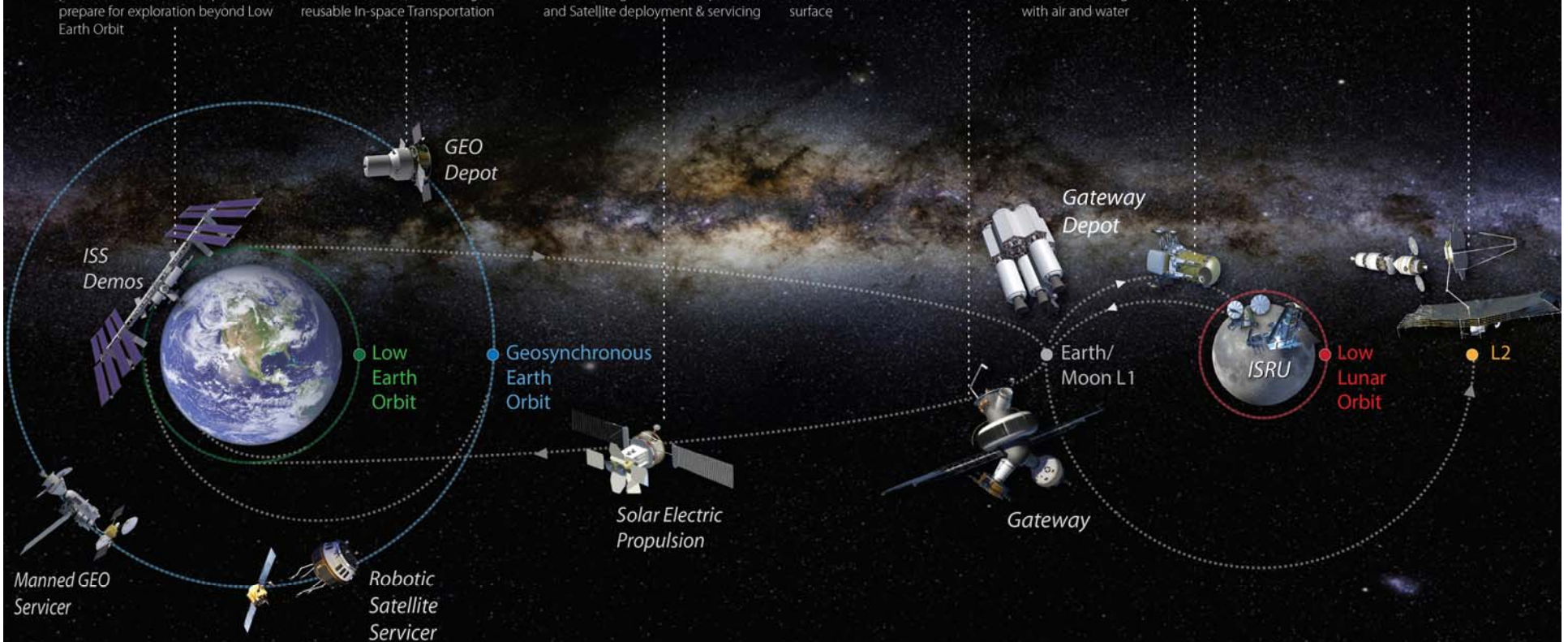
L1/L2 Gateway transportation node location for propellant depot and access to and from the Lunar surface



Lunar In-situ Resources Utilization produces water for rocket propellants and for sustaining surface operations with air and water



Construction and servicing of advanced telescopes and other In-space assets



<http://www.spudislunarresources.com/blog/after-the-vision-what-next/>

Using the Moon to Enable Solar System Exploration and Science



The “*been there, done that*” negativity becomes a positive advantage making the Moon an enabling asset for Solar System exploration and science.



The Moon is an enabling asset