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The Lunar Exploration Analysis Group (LEAG)



Exploring the Moon in the 21st Century: The Lunar Exploration Roadmap



Clive R. Neal
LEAG Chair



Dept. Civil Eng. & Geological Sci.
University of Notre Dame
Notre Dame, IN 46556



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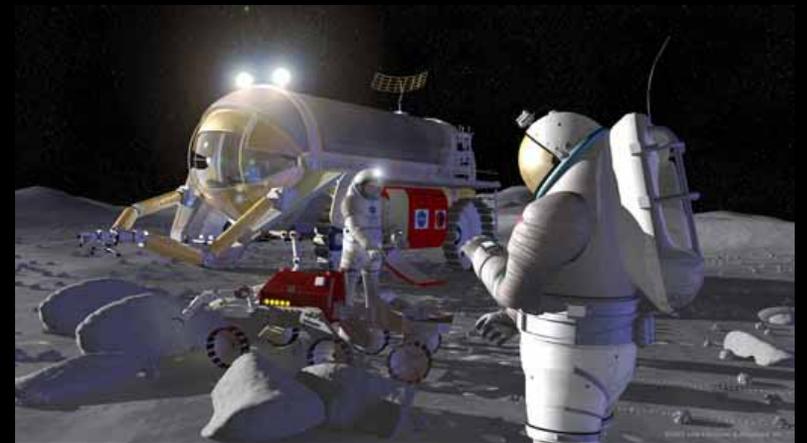


Membership and participation in the LEAG:

Lunar & planetary scientists; Human systems specialists;
Engineers & Technologists; Mission designers, managers;
Other participants in sustained lunar exploration drawn from
the broad community of:

- Academia;
- Industry;
- Government;
- Commercial sector.

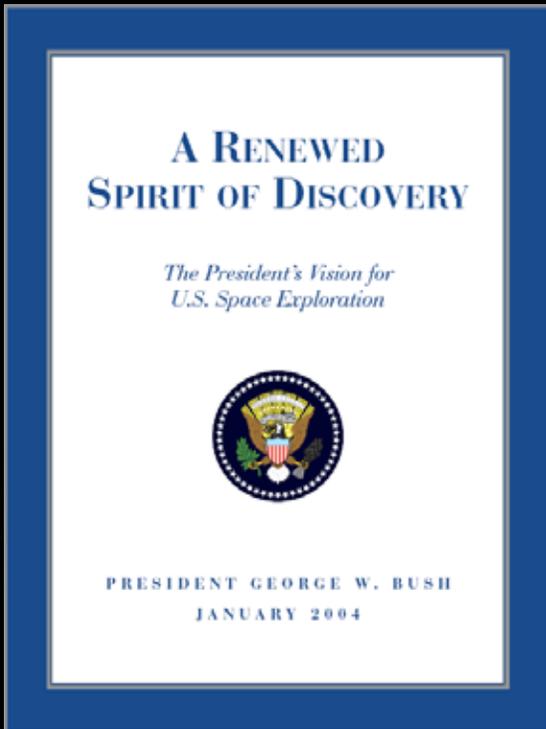
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The fundamental goal of this vision is to advance U.S. scientific, security, and economic interests through a robust space exploration program. In support of this goal, the United States will:



- Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
- Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;



- Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

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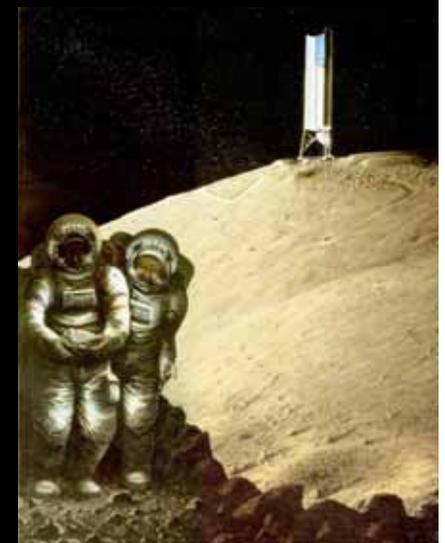
Lunar Exploration Roadmap

The Charge from the NAC

The Science Committee recommends that the Lunar Exploration Analysis Group (LEAG) be tasked to prepare a “Lunar Goals Roadmap” that maps science goals to objectives, and to observations and measurements. This roadmap should include an assessment of needed technology developments, areas of potential coordinated activities for commercial and international participation, and potential feed-forward activities for the exploration of Mars and beyond.



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The Lunar Exploration Roadmap

*Exploring the Moon in the 21st Century:
Themes, Goals, Objectives, Investigations,
and Priorities, 2008*

**A Community Effort Coordinated by the
Lunar Exploration Analysis Group
(LEAG)**

Dave Beaty, Mike Duke, Paul Eckert, Michelle Gates, John Gruener, Dave Kring, Dan Lester, Peter Mouginiis-Mark, Steve Mackwell, Paul Neitzel, Lewis Peach, Jerry Sanders, Chip Shearer, Kelly Snook, Jim Spann, Paul Spudis, Jeff Taylor, Larry Taylor, Jeff Volosin, Mike Wargo.



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Why are we going back to the Moon?



Learn to live and work productively on another world.

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

Feed-Forward Theme: Use the Moon to prepare for future missions to Mars & other destinations.

Sustainability Theme: Extend sustained human presence to the Moon to enable eventual settlement.



Crosscutting Themes:

- Learn to live and work productively on another world.
- Expand Earth's economic sphere to encompass the Moon, and pursue lunar activities with direct benefits to life on Earth.
- Strengthen existing and create new global partnerships.
- Engage, inspire, and educate the public.

Maps back to previous work!



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

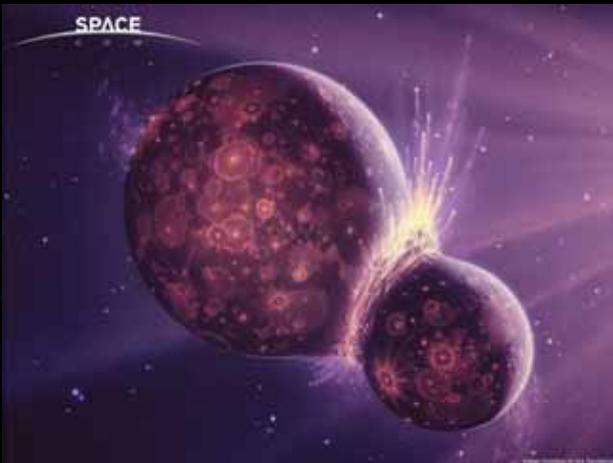


Goal: Understand the formation, evolution and current state of the Moon.

Goal: Use the Moon as a “witness plate” for solar system evolution.

Goal: Use the Moon as a platform for astrophysical, heliophysical, and earth-observing studies.

Goal: Use the unique lunar environment as a research tool.



Science Goal: Understand the formation, evolution & current state of the Moon



Objective: Understand lunar differentiation. **5**

Objective: Understand formation of the Earth-Moon system. **3**

Objective: Understand volcanic processes. **4**

Objective: Understand the impact process. **5**

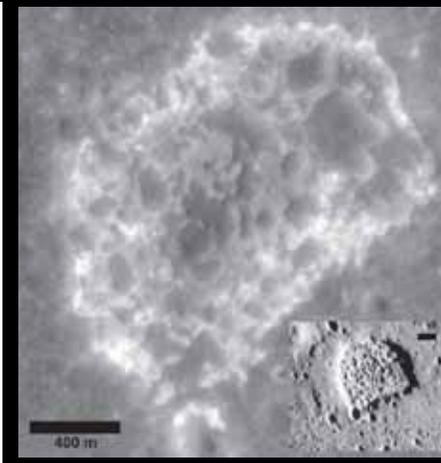
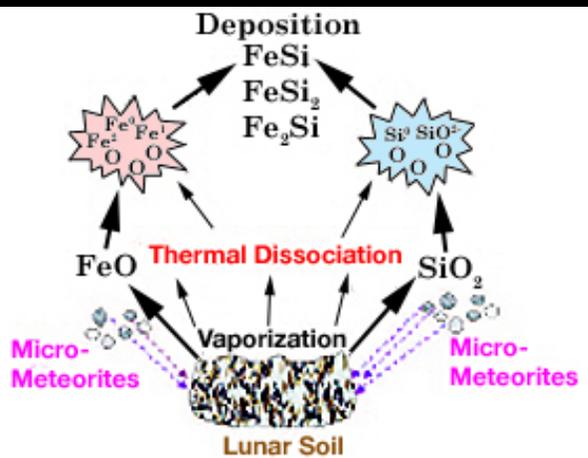
Objective: Determine the **stratigraphy**, structure, and geological history of the Moon. **4**

Objective: Understand the dynamical evolution & space weathering of the regolith. **4**

Objective: Characterize the environment and processes in lunar polar regions. **4**

Objective: Development and implementation of sample return technologies and protocols. **4**

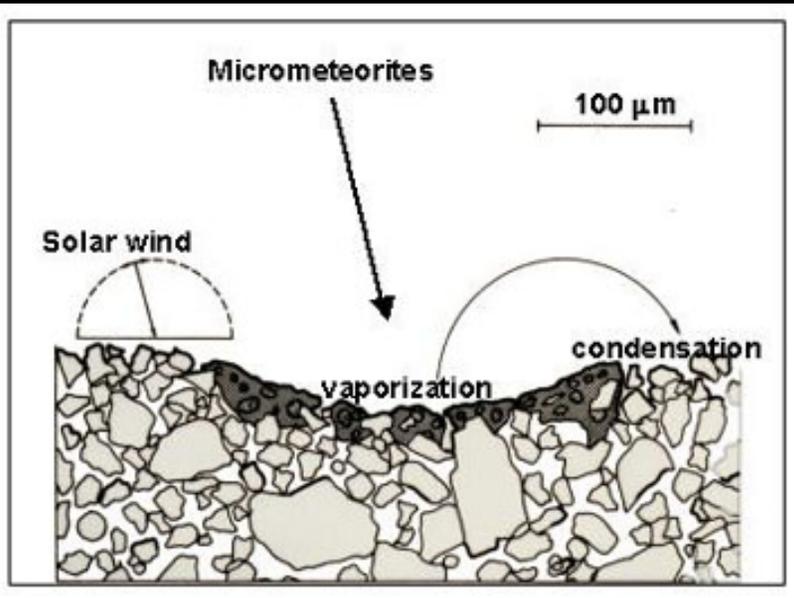
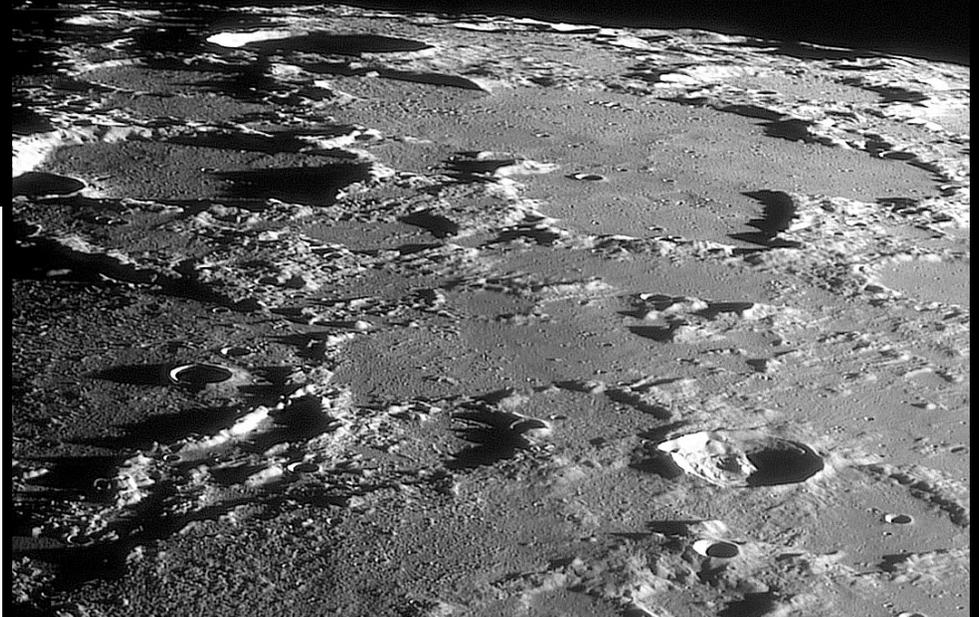
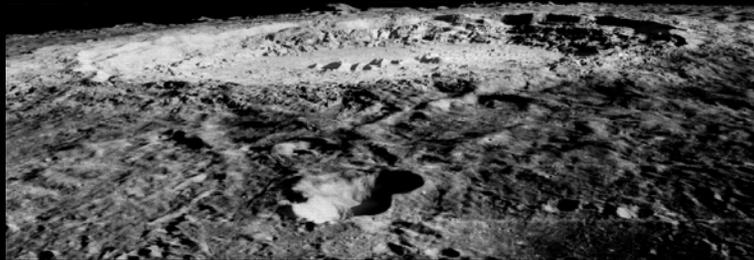
Objective: Understand the environmental impacts of lunar exploration. **2**



Science Goal: Use the Moon as a “witness plate” for solar system evolution

Objective: Understand the impact history of the Inner Solar System as recorded on the Moon. 4

Objective: Regolith as a recorder of extra-lunar processes. 5



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Science Goal: Use the Moon for astrophysical, heliophysical, and Earth-observing studies.



Objective: Astrophysical Investigations using the Moon. 6

Objective: Heliophysical Investigations using the Moon. 10

Objective: Earth-observing Investigations using the Moon. 6



Science Goal: Use the unique lunar environment as a research tool.



Objective: Investigate and characterize the fundamental interactions of combustion and buoyant convection in lunar gravity. **4**

Objective: Perform tests to understand and possibly discover new regimes of combustion. **4**

Objective: Investigate interactions of multiphase combustion processes and convection at lunar gravity. **3**

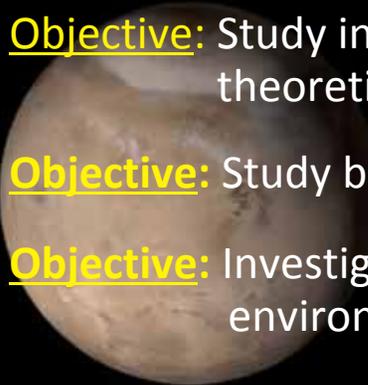
Objective: Use the unique environment of the lunar surface to perform experiments in the area of fundamental physics. **4**

Objective: Obtain experimental data to anchor multiphase flow models in partial gravity environment. **3**

Objective: Study interfacial flow with and without temperature variation to anchor theoretical/numerical models. **3**

Objective: Study behavior of granular media in the lunar environment. **3**

Objective: Investigate precipitation behavior in supercritical water in partial gravity environment. **2**



Feed Forward Theme: Use the Moon to prepare for future missions to Mars and other destinations.



Goal: Identify and test technologies on the Moon to enable robotic and human solar system science and exploration.

Goal: Use the Moon as a test-bed for mission operations and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond.



Theme 3: Extend sustained human presence to the Moon to enable eventual settlement.

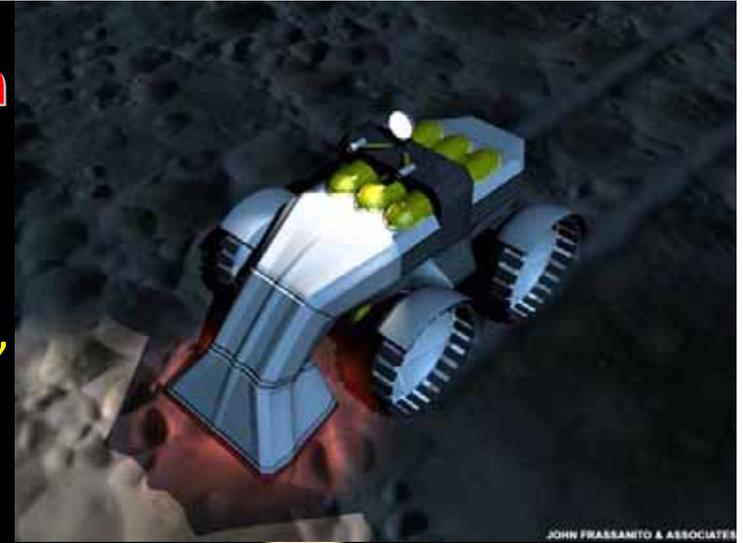
Goal: Expand Science: Provide support, services, and infrastructure to enhance and enable new science to the Moon, on the Moon, and from the Moon.

Goal: Expand Human Exploration: Expand in-space and surface transportation capabilities beyond initial NASA transportation architecture to discover and reach new territories.

Goal: Enhance Security: Protect and benefit Earth, and guarantee peace and safety both for settlers and for the home.

Goal: Promote Space Commerce: Promote and enable the creation of value and wealth from space-related activities that satisfy human needs, enable space economic activity to benefit Earth and lunar settlers and to enable NASA to explore beyond the Moon.

Goal: Sustaining human presence on the Moon.



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Sustainability Goal: Expand Science.

Objective: Provide servicing of science instruments and infrastructure (**commercial on ramp**).

Objective: Provide data and communication assets (**commercial on ramp**).

Objective: Promote 'settlement' science (e.g. biological life support; cross-over with Goal 1D – combustion science, fundamental physics, material science).

Objective: Provide mitigation for activities that negatively impact the lunar environment and Science (e.g. lunar atmosphere science).

Objective: Develop a high performance planetary mobility / EVA suit system.

2

Investigations still being developed



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Sustainability Goal: **Expand Human Exploration.**

Objective: Develop technologies in Earth labs to enable exploration of extreme lunar environments and early demonstrations of Settlement capabilities (crossover with Themes 1 and 2).

Objective: Develop, simulate, and demonstrate operational capabilities and protocols in Earth analogue environments (crossover with Themes 1 and 2).

Objective: Perform demonstrations on the Moon of Settlement capabilities to benefit Outpost activities early and retire risk of Settlement development. **6**

Objective: Facilitate sustainable transportation to/from Earth to lunar surface (**commercial on ramp**) **3**

Objective: Facilitate global access to lunar surface from Settlement. **3**

Objective: Facilitate global navigation and communication (**commercial on ramp**). **3**

Objective: Employ dust mitigation techniques to protect crews, materials and instruments during extended lunar stays. Test and evaluate these strategies and refine them to develop confidence in systems for Mars application. **3**



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Sustainability Goal: Enhance Security.

Objective: Near-Earth Object detection and possible mitigation strategies.

Objective: Power-beam or lunar-derived energy (**commercial on ramp**).

Objective: Remote and hazardous research (e.g., bio/nano technology).

Objective: Non-lunar extraterrestrial material triage and/or curation.

Objective: Facilitate global access to lunar surface from Settlement. 3

Objective: Strategic uses of Earth reconnaissance (e.g., weather, etc.) (**commercial on ramp**).

Objective: Involve international agencies and astronauts in all aspect lunar exploration and settlement.



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Sustainability Goal: Promote Space Commerce (commercial on ramps)

Objective: Cooperate in the development of a legal framework of International agreements, laws, resource ownership, and land rights, including commercial operations on the Moon, with appropriate national and international agencies and organizations.

Objective: Enable transition from government-to-commercial when and where appropriate. 5

Objective: Facilitate commercial activities on Moon. 4



Sustainability Goal: Sustaining Human Presence on the Moon.



Objective: Identify and characterize (including resources) lunar locations where permanent facilities should be established.

Objective: Utilize robotic and the initial human lunar missions to demonstrate infrastructure capabilities and technologies and retire risk early for lunar settlement.

Objective: Keep humans safe and healthy. 4

Objective: Reduce Dependency on Earth (**commercial on ramp**). 4

Objective: Provide and test health care services on the Moon to reduce likelihood of early mission termination or LOC (loss of crew) due to medical contingency.



Exploring the Moon in the 21st Century:



Lunar Exploration Roadmap