

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

(The Lunar Exploration Roadmap)

A Community Effort Coordinated by the
Lunar Exploration Analysis Group

Report to the PSS, October 2, 2008

- Theme 1:** Pursue scientific activities to address fundamental questions about the solar system, the universe, and our place in them.
- Theme 2:** Use the Moon to prepare for future missions to Mars and other destinations.
- Theme 3:** Extend sustained human presence to the Moon to enable eventual settlement.

Lunar Exploration Strategy

Themes

Why are we going to the Moon?

Crosscutting Themes:

- Learn to live and work successfully 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.

Theme 1: Pursue scientific activities to address fundamental questions about the solar system, the universe, and our place in them.

Goal 1A: Understand the formation, evolution and current state of the Moon.

Objective 1A-1: Understand lunar differentiation. 5

Objective 1A-2: Understand formation of the Earth-Moon system. 3

Objective 1A-3: Understand volcanic processes. 4

Objective 1A-5: Understand the impact process. 5

Objective 1A-5: Determine the stratigraphy, structure, and geological history of the Moon. 4

Objective 1A-6: Understand the dynamical evolution and space weathering of the regolith. 4

Objective 1A-7: Characterize the environment and processes in lunar polar regions. 4

Objective 1A-8: Development and implementation of sample return technologies and protocols. 4

Objective 1A-9: Understand the environmental impacts of lunar exploration. 2

Theme 1: Pursue scientific activities to address fundamental questions about the solar system, the universe, and our place in them.

Goal 1B: Use the Moon as a “witness plate” for solar system evolution..

Objective 1B-1: Understand the impact history of the Inner Solar System as recorded on the Moon. **4**

Objective 1B-2: Regolith as a recorder of extra-lunar processes. **5**

Theme 1: Pursue scientific activities to address fundamental questions about the solar system, the universe, and our place in them.

Goal 1C: Use the Moon as a platform for astrophysical, heliophysical, and earth-observing studies.

Objective 1C-1: Astrophysical Investigations using the Moon. 6

Objective 1C-2: Heliophysical Investigations using the Moon. 10

Objective 1C-3: Earth Science Investigations using the Moon. 6

Theme 1: Pursue scientific activities to address fundamental questions about the solar system, the universe, and our place in them.

Goal 1D: Use the unique lunar environment as a research tool.

Objective 1D-1: Investigate and characterize the fundamental interactions of combustion and buoyant convection in lunar gravity. 4

Objective 1D-2: Perform tests to understand and possibly discover new regimes of combustion. 4

Objective 1D-3: Investigate interactions of multiphase combustion processes and convection at lunar gravity. 3

Objective 1D-4: Use the unique environment of the lunar surface to perform experiments in the area of fundamental physics. 4

Objective 1D-5: Obtain experimental data to anchor multiphase flow models in partial gravity environment. 3

Objective 1D-6: Study interfacial flow with and without temperature variation to anchor theoretical/numerical models. 3

Objective 1D-7: Study behavior of granular media in the lunar environment. 3

Objective 1D-8: Investigate precipitation behavior in supercritical water in partial gravity environment. 2

Theme 1: Pursue scientific activities to address fundamental questions about the solar system, the universe, and our place in them.

Goal 1D: Use the unique lunar environment as a research tool (continued).

Objective 1D-9: Investigate the production of oxygen from lunar regolith in lunar gravity. **2**

Objective 1D-10: Investigate the behavior of liquid-phase sintering under lunar gravity. **1**

Objective 1D-11: Study the fundamental biological and physiological effects of the integrated lunar environment on human health and the fundamental biological processes and subsystems upon which health depends. **1**

Objective 1D-12: Study the key physiological effects of the combined lunar environment on living systems and the effect of countermeasures. **2**

Objective 1D-13: Evaluate consequences of long-duration exposure to lunar gravity on the human musculo-skeletal system. **2**

Objective 1D-14: Understand the impact of Lunar environments on multiple generations of terrestrial life forms that impact human health. **2**

Objective 1D-15: Monitor real-time environmental variables affecting safe operations, which includes monitoring for meteors, micrometeors, and other space debris that could potentially impact the lunar surface. **1**

Theme 2: Use the Moon to prepare for future missions to Mars and other destinations.

Goal 2A: Identify and test technologies on the Moon to enable robotic & human solar system science & exploration.

Objective 2A-1: Develop surface life support systems to reduce risks associated with long duration Martian surface stay times. **7**

Objective 2A-2: Develop Crew Health Systems That Enable Safe, Long Duration, Surface Stays. **6**

Objective 2A-3: Develop surface mobility capabilities that allow human crews to efficiently and safely explore the surfaces of the Moon and Mars. **7**

Objective 2A-4: Develop the capability to acquire and use local resources to sustain long-term exploration and habitation of planetary surfaces. **10**

Objective 2A-5: Develop the capability to produce adequate levels of power on planetary surfaces to allow human crews to work and live productively. **14**

Theme 2: Use the Moon to prepare for future missions to Mars and other destinations.

Goal 2A: Identify and test technologies on the Moon to enable robotic & human solar system science & exploration (cont.).

Objective 2A-6: Develop the capability to autonomously land safely and accurately on the Moon and Mars. **2**

Objective 2A-7: Develop the capability to autonomously land safely and accurately on the Moon and Mars. **3**

Objective 2A-8: Develop the capability for crews on the Moon or Mars to communicate with other assets on the surface, and navigate to and from those assets. **6**

Objective 2A-9: Develop the capability for human crews to operate safely on planetary surfaces, protected from the extreme environment and hazards. **5**

Theme 2: Use the Moon to prepare for future missions to Mars and other destinations.

Goal 2B: 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.

Objective 2B-1: Develop the capability for autonomous crew operations on the Moon and Mars. 7

Objective 2B-2: Develop the capability for productive and efficient human-robotic interaction in the exploration of planetary surfaces. 6

Theme 2, Other

Establish a set of export control laws and regulations that will enhance effective global cooperation on lunar activities.

Establish standards and common interface designs to enable interoperability of systems developed by a global community.

Establish a global partnership framework to enable all interested parties to participate in exploration activities.

Develop cost effective surface systems that can be developed in a relatively short period of time (if a lunar outpost takes 30 years to develop and deploy – Mars missions may be a longgggg way away).

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

Goal 3A: Expand Science: Provide support, services, and infrastructure to enhance and enable new science to the Moon, on the Moon, and from the Moon (crossover with Theme 1).

Objective 3A-1: Provide servicing of science instruments and infrastructure (commercial on ramp).

Objective 3A-2: Provide data and communication assets (commercial on ramp).

Objective 3A-3: Promote ‘settlement’ science (e.g. biological life support; crossover with Goal 1D – combustion science, fundamental physics, material science).

Objective 3A-4: Provide mitigation for activities that negatively impact the lunar environment and Science (e.g. lunar atmosphere science).

Objective 3A-5: Develop a high performance planetary mobility / EVA suit system.

2

Investigations still being developed

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

Goal 3B: Expand Human Exploration: Expand in-space and surface transportation capabilities beyond initial NASA transportation architecture to discover and reach new territories (crossover with Themes 1 and 2).

Objective 3B-1: 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 3B-2: Develop, simulate, and demonstrate operational capabilities and protocols in Earth analogue environments (crossover with Themes 1 and 2).

Objective 3B-3: Perform demonstrations on the Moon of Settlement capabilities to benefit Outpost activities early and retire risk of Settlement development. 6

Objective 3B-4: Facilitate sustainable transportation to/from Earth to lunar surface (commercial on ramp). 3

Objective 3B-5: Facilitate global access to lunar surface from Settlement. 3

Objective 3B-6: Facilitate global navigation and communication (commercial on ramp). 3

Objective 3B-7: 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

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

Goal 3C: Enhance Security: Protect and benefit Earth, and guarantee peace and safety both for settlers and for the home planet.

Objective 3C-1: Near-Earth Object detection and possible mitigation strategies.

Objective 3C-2: Power-beam or lunar-derived energy (**commercial on ramp**).

Objective 3C-3: Remote and hazardous research (e.g., bio/nano technology).

Objective 3C-4: Non-lunar extraterrestrial material triage and/or curation [Late]

Objective 3C-5: Strategic uses of Earth reconnaissance (e.g., weather, etc.) (on ramp)
[Early]

Objective 3C-6: Involve international agencies and astronauts in all aspect lunar exploration and settlement

Investigations still being developed

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

Goal 3D: 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 settlement, and to enable NASA to explore beyond the Moon.

Objective 3D-1: 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 3D-2: Enable transition from government-to-commercial when and where appropriate. 5

Objective 3D-3: Facilitate commercial activities on Moon. 4

Investigations still being developed

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

Goal 3E: Sustaining human presence on the Moon.

Objective 3E-1: Identify and characterize (including resources) lunar locations where permanent facilities should be established.

Objective 3E-2: Utilize robotic and the initial human lunar missions to demonstrate infrastructure capabilities and technologies and retire risk early for lunar settlement.

Objective 3E-3: Keep humans safe and healthy. 4

Objective 3E-4: Reduce Dependency on Earth (commercial on ramps). 4

Objective 3E-5: 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. 1

Investigations still being developed

On Going Activities

- Time Phasing;
- Prioritization
- Community input:
 - Web based
 - Meetings

Unveiling at LEAG meeting.