Potential Science and Exploration Linkages Between the Moon and Mars

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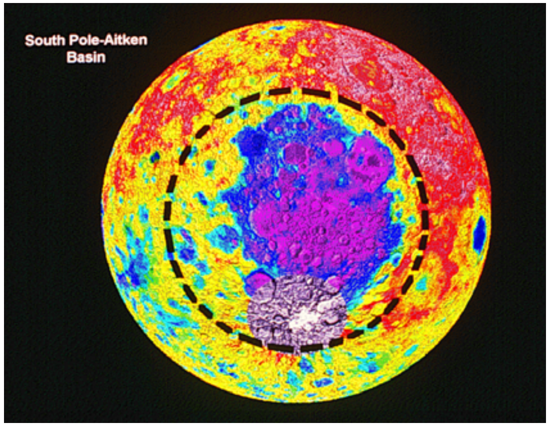
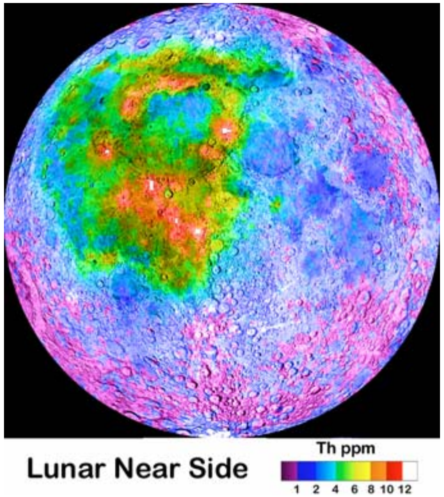
Are there scientific and engineering linkages between Moon and Mars?0

Outline of Presentation

- Introduction to MMSL-SSG.
  - Membership.
  - MMSL-SSG Charter.
  - Assumptions of the Study.
- The Moon as a Unique Vantage Point for the Scientific Exploration of the Solar System.
- Moon⇒Mars Linkages
  - Examples of Potential Linkages.
- Priorities





Moon→Mars SCIENCE LINKAGES SCIENCE STEERING GROUP (MMSL-SSG)

Co-Chairs: Chip Shearer (UNM) and David Beaty (JPL).

Members: Ariel D. Anbar, Arizona State University
Bruce Banerdt, JPL
Don Bogard, JSC
Bruce A. Campbell, Smithsonian CEPS
Michael Duke, Colorado School of Mines
Lisa Gaddis, USGS, Flagstaff
Brad Jolliff, Washington University
Rachel C.F. Lentz, University of Tennessee
David McKay, JSC
Greg Neumann, GSFC/MIT
Dimitri Papanastassiou, JPL
Roger Phillips, Washington University
Jeff Plescia, JHU APL
Mini Wadhwa, Field Museum, Chicago

Finding: Reported in unpublished white paper, 29 p, posted October, 2004 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag/reports/index.html.

MMSL SSG Charter

The Moon→Mars Science Steering Group was chartered on behalf of MEPAG to complete the following:

1. Develop an analysis of the potential ways in which the scientific objectives for the exploration of Mars can be advanced through any of the following activities:
   a) Scientific investigations on the Moon
   b) Engineering demonstrations on the Moon (including demos of technically challenging scientific activities)
      - Demonstrations of instrument, tool, and spacecraft operations.
2. Develop an assessment of the priority of the possibilities outlined above.

Assumptions for this Study

1. Assume scientific priorities for the exploration of Mars are described in the MEPAG Goals document (http://mepag.jpl.nasa.gov/reports/MEPAG_goals-3-15-04-FINAL.doc).
2. This SSG is asked to focus its effort on martian and lunar surface science, rather than orbital science.
3. Lunar science objective

   The most recent consensus-based description of lunar science goals, objectives, and investigations was developed by the Lunar Exploration Science Working Group (LExSWG).

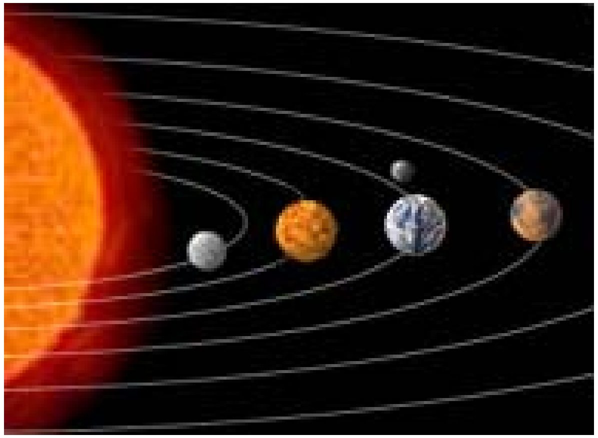
   A Planetary Science Strategy for the Moon, Lunar Exploration Science Working Group, July 1992, JSC document JSC-25920.

   Lunar Surface Exploration Strategy, Lunar Exploration Science Working Group (LExSWG), Final Report, February, 1995.

The Moon as a Unique Vantage Point for Solar System Exploration

<u>FINDING</u>: The Moon offers a unique vantage point for certain aspects of Solar System exploration:

- Cornerstone for Understanding Early Planetary Processes.
- Understanding Volatile Record and Reservoirs.
- Testbed for Scientific Exploration of the Solar System.
- Astrobiology.



The Moon as a Unique Vantage Point for Solar System Exploration

Cornerstone for Early Planetary Processes

- Preserves the remnants of one style of planetary differentiation: Magma Ocean.
- Illustrates a style of early planetary asymmetry that is related to early differentiation processes.
- Illustrates a pathway of planetary evolution that is related to a style of planetary accretion and differentiation.
- Illustrates the full crustal formational and magmatic history of a cooling planetary body.
- Recorded and preserved the early impact environment of the inner solar system.
- Interactions between a planetary surface and space are preserved in the lunar regolith.

The Moon as a Unique Vantage Point for Solar System Exploration

Volatile Record and Reservoirs

- Moon is an planetary end-member for volatile abundance.
- Clearer view of three primary sources of volatiles:
  - Endogenic volatiles
    - Volcanism, volcanic degassing
  - Exogenic volatiles
    - Solar wind and galactic cosmic rays
    - Impacts of comets and asteroids
- Moon:
  - Surface contains all three, although endogenous volatiles are in very low abundance. The lunar surface is unprotected from space exposure.
  - Surface records solar wind, galactic cosmic ray history. Polar cold traps may record the more volatile species from volcanic eruptions and impacts.
- Mars
  - Surface contains abundant endogenous volatiles and is protected by atmosphere and potentially larger ancient magnetic field.
  - Volatiles on Mars, especially water, present at poles, in megaregolith, in atmosphere, bound in minerals, etc.

The Moon as a Unique Vantage Point for Solar System Exploration

Testbed for Scientific Exploration of the Solar System

- The Moon has a number of unique testbed attributes:
  - Close proximity to Earth.
  - Hostile environment.
    - *Atmosphere*
    - *Temperature*
    - *Low volatile content*
    - *Dust*
  - Reduced gravity levels.
  - Low seismicity.
  - Planetary-scale sterile environment.

The Moon as a Unique Vantage Point for Solar System Exploration

Astrobiology

- The Moon preserves unique historical information about events and processes that affected the habitability of the entire inner Solar System, a record obscured on Earth and Mars.
  - *Impact chronology (esp. first billion years)*
  - *Composition of impactors, IDPs flux, etc.*
  - *Delivery of exogenous volatiles and organics*
  - *Nearby supernovae and Gamma Ray Burst (GRB) events*
  - *Solar activity (solar wind; flares)*
- The Moon provides a uniquely accessible planetary-scale sterile environment useful for assessing engineering goals of astrobiological importance, especially for life detection and planetary protection.
  - *Control experiments for life-detection technologies (extinct and extant)*
  - *Quantify "forward contamination" by robotic and human explorers*

Moon→Mars Linkages

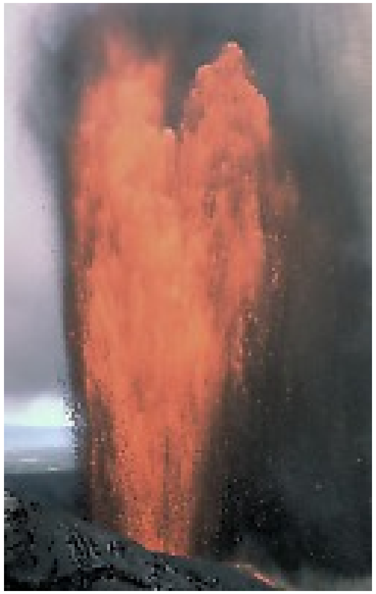
<u>FINDING</u>: We have identified three categories of linkages between possible lunar exploration activities and a future benefit to martian science. These are organized as:

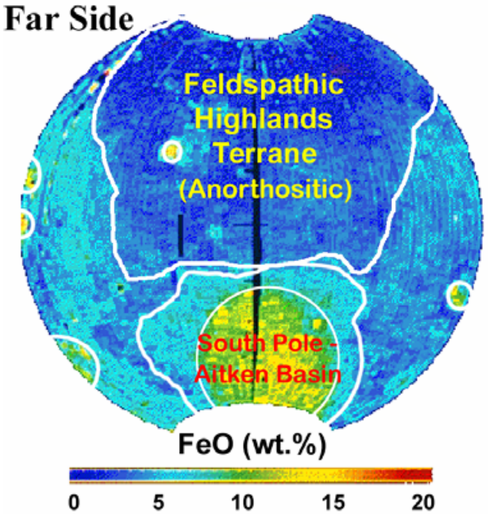
- **<u>Category A</u>. Investigations related to processes of terrestrial planet formation and evolution**
- **<u>Category B</u>. Human-related resource issues**
- **<u>Category C</u>. Demonstrations of scientific methods and capabilities**

Category	# of Linkages Identified
A	10
B	3
C	7
TOTAL	**20**

A. **Investigations** related to the processes of terrestrial planet formation and evolution.

- **Early planetary evolution and planetary structure.**
  - ***A1. Interior Planetary Structure.***
  - ***A2. Early Planetary Differentiation.***
  - ***A3. Thermal and Magmatic Evolution.***
  - ***A4. Planetary Asymmetry.***





A1. Interior Planetary Structure

What is the Linkage?

- Understanding the structure of planetary interiors is fundamental for understanding the origin and differentiation of a planet, dynamical processes, surface evolution, tectonics, magmatism, magnetic field, predictive tool for locating and evaluating resources.

Relevance to Lunar Science

- Provide constraints for the bulk composition of the Moon, its origin, and the manner in which it differentiated.
- Characterize crust, mantle, core structural domains, to anchor our understanding of lunar asymmetry, mantle dynamics, magnetic field and current thermal state.

Relevance to Mars Science

- Place constraints on the mechanism of martian differentiation and early dynamical processes of the martian interior.
- Characterize the current structure and dynamics of the martian interior.
- Determine the origin and history of the magnetic field.

Possible Lunar Measurements

Moon-wide seismic array.

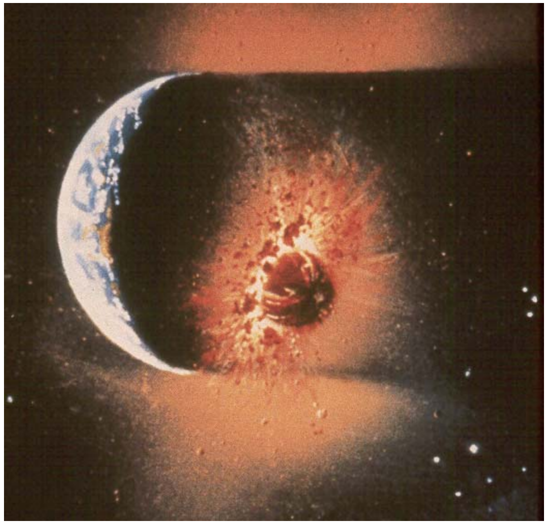
Far side gravity field measurements

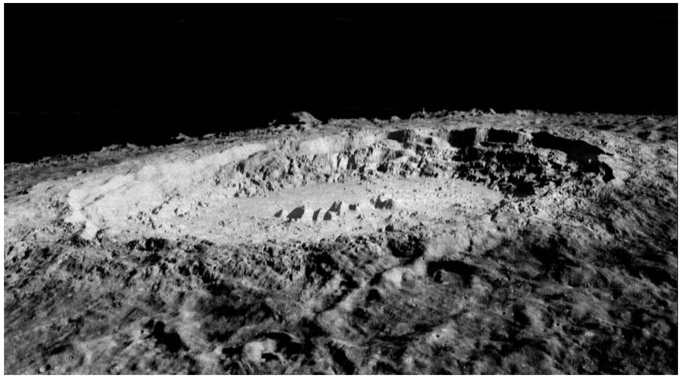
Ranging transponders on Surface

Sample return from other lunar terraines

Detailed topography measurements

A. **Investigations** related to the processes of terrestrial planet formation and evolution.

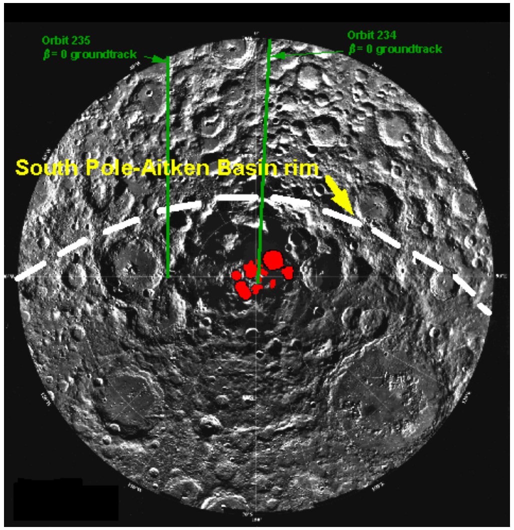


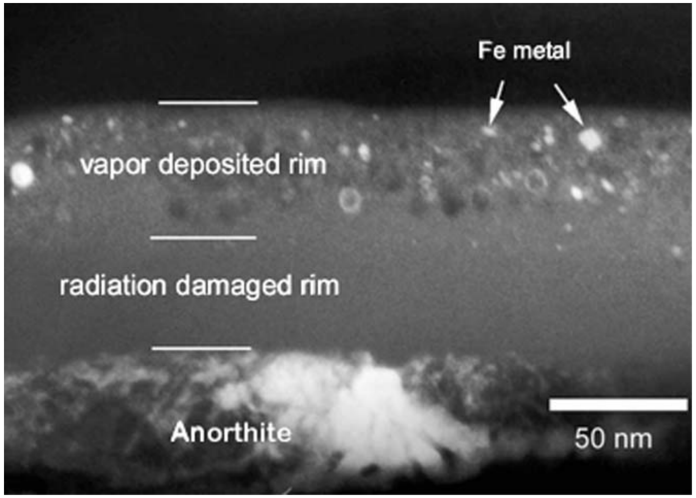


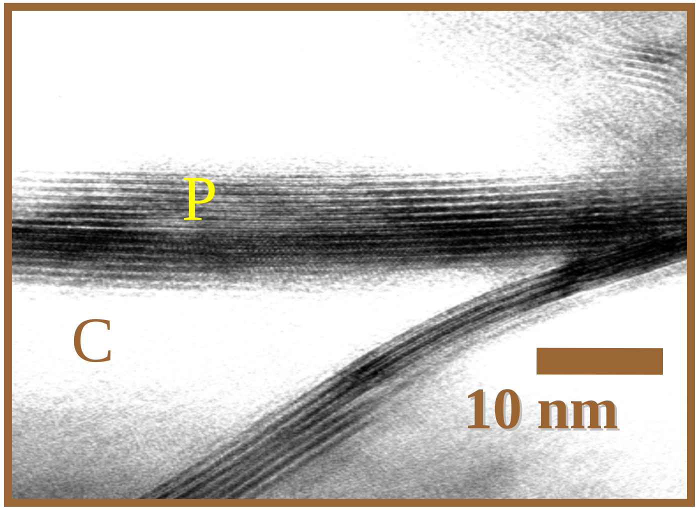
- **Early planetary surfaces.**
  - ***A5. Impactor Flux vs. Time.***
  - ***A6. Regolith History.***
  - ***A10. Interpreting Geologic Environments***

A. **Investigations** related to the processes of terrestrial planet formation and evolution.

- Record of volatile evolution and behavior.
  - A7. Energetic Particle History.
  - A8. Endogenic Volatiles.
  - A9. Exogenic Volatiles.

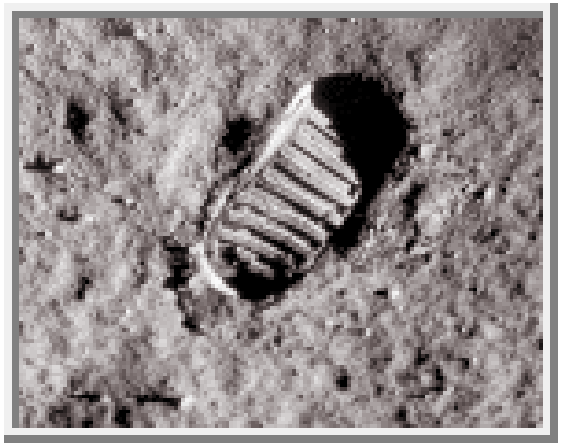


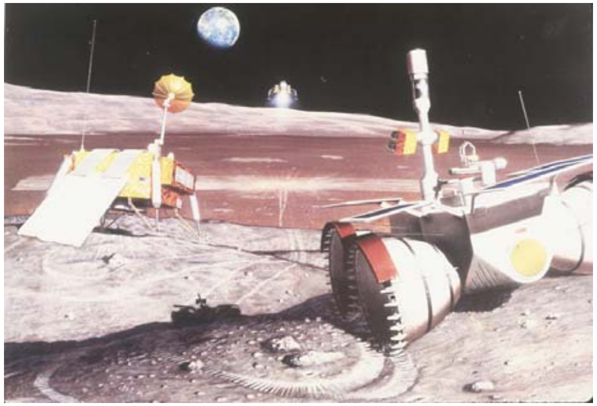




B. Evaluate lunar resources to be used to support exploration activities on the Moon and beyond.

- Investigations
  - *B1. Water as a Resource*
  - *B2. In-situ fuel sources*
  - *B3. Exploration and Processing of Planetary Materials*





B1. Water as a Resource

What is the Linkage?

- Water is critical to life support for human missions to both bodies.
- Moon and Mars may contain accessible water in various forms.
- Exploration questions are similar: What is form, concentration, extraction processes.

Relevance to Lunar Science

- Determine locations and physical/ chemical form of lunar water
- Utilize water-rich layers as tracers for lunar regolith processes.
- Utilize lunar propellant to support Moon-space transportation.

Relevance to Mars Science

- Demonstrate use of in situ derived water for life support activities.
- Develop/demonstrate exploration approaches to determining chemical and physical properties of volatile deposits.

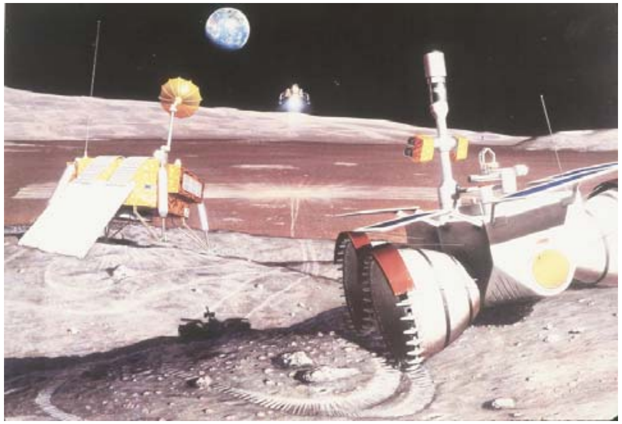
Possible Lunar Measurements

- Characterize of hydrogen in lunar polar regions – form, concentration, extractability.
- Develop efficient technologies for excavating regolith and extracting H_2/H_2O.
- Develop technologies for purification and storage.

C. Demonstrations at the Moon

Investigations to gain experience, mitigate risk, improve performance, confirm capability and cost reduction technologies.

- *C1. In-situ Sample Selection and Analysis*
- *C2. Communication and Ranging Systems*
- *C3. Drilling Technologies*
- *C4. Seismic Technologies/Studies*
- *C5. Life Detection & Planetary Protection*
- *C6. ISRU Technology Demonstrations*
- *C7. Sample Return*



C7. Sample Return

What is the Linkage?

- Sample return is a key approach for exploring both Mars and Moon.
- Sample return missions allow the full range of terrestrial analytical techniques to be used to address important planetary problems. **“The gift that keeps giving”**
- Future lunar missions to sample geologically complex and fragile materials will be directly relevant to sample acquisition and return from Mars.

Relevance to Lunar Science

- Reduce risk of robotic sample return and increase capability of coupled human-robotic sample return .
- Increase sampling capability of complex and fragile materials.
- Sampling of terrains outside the lunar equator on the near-side to address high-priority planetary science, lunar resource, and technology issues.

Relevance to Mars Science

- MSR missions can be conducted with currently known technologies, but technical feasibility of MSR can be advanced based on the lunar experience.
- Search for evidence of life.
- Define environmental hazards and potential resources for human exploration
- Define the nature and history of the martian crust and mantle.

Possible Lunar Measurements

- Test robotic sample return from outside the Apollo terrain to address planetary problems (A1-A10).
- Test complex robotic sample return (i.e. lander-rover) of fragile materials for scientific and resource issues.
- Test more complex coupled human-robotic systems for exploration & sample return.

Moon→Mars Priorities

<u>FINDING</u>: We have found significant differences in the **<u>relative</u>** priority of the identified Moon→Mars linkages.

1. The priority of Moon→Mars linkages was assessed:
   a) From the perspective of Mars alone
   b) From the perspective of the Moon alone

<u>Note</u>: Assessing priority in an absolute sense requires that factors beyond the scope of this study be considered.

Priority of Identified Lunar Investigations
to Mars Science

RELATIVE PRIORITY

HIGHER

PRIORITY GROUP 1:

A5: Impactor Flux vs. Time

A9: Exogenous Volatiles

PRIORITY GROUP 2:

A3: Thermal and Magmatic Evolution

A10: Interpreting Geologic Environments

A6: Regolith History

A8: Endogenous Volatiles

PRIORITY GROUP 3:

A1: Interior Planetary Structure

A4: Planetary Asymmetry

A2: Early Planetary Differentiation

A7: Energetic Particle History

LOWER

Prioritization Criteria:

- The intrinsic scientific value of each theme for advancing our understanding of Mars if the investigation was first carried out on the Moon.
- Degree of criticality of the possible lunar activity to one or more future Mars missions (or surface measurement activities)
- Degree of alignment with MEPAG's priority system for Mars exploration

Note: Differences in priority within priority groups are not judged to be significant.

Priority of Identified Lunar Investigations
to Lunar Science

RELATIVE PRIORITY

HIGHER

PRIORITY GROUP 1:

A1. Interior Planetary Structure

A2. Early Planetary Differentiation

A5. Impactor Flux vs. Time

PRIORITY GROUP 2:

A3. Thermal & Magmatic Evolution

A4. Planetary Asymmetry

A10. Interpreting Geologic Environments

A9. Exogeneous Volatiles

A6. Regolith History

LOWER

PRIORITY GROUP 3:

A7. Energetic Particle History

A8. Endogenic Volatiles

Prioritization Criteria:

- Intrinsic scientific value (for the Moon).
- Degree to which identified investigations are likely to make major contributions to advancing knowledge about the important science questions.
- Feasibility within the emerging strategy for precursor robotic lunar missions in support of human exploration.

Note: Differences in priority within priority groups are not judged to be significant.

Resource and Demo. Priorities

Test crucial instrument or strategy, or establish test bed under the proviso that (*i*) Activity cannot be done satisfactorily on Earth, or (*ii*) Moon provides a unique (or vastly superior) martian analog than does the Earth.

RELATIVE PRIORITY

HIGHER

PRIORITY GROUP #1:

C1: In-situ sample selection and analysis

C7: Sample Return

C3: Drilling technologies

PRIORITY GROUP #2:

C4: Seismic technologies/Studies

B1: Water as a Resource

B2: In-situ fuel resources

C5: Assess Bio-Organic Contamination

PRIORITY GROUP #3:

C6: ISRU Technology Demonstrations

C2: Communication and ranging systems

B3: Other resource issues

LOWER

Prioritization Criteria:

1. If successfully carried out at the Moon, the value to our ability to correctly plan and successfully implement the future Mars exploration program.
2. Timing: Importance that these measurements/demonstrations be carried out by the lunar robotic program prior to 2020.
3. Cost: General affordability of these measurements/ demonstrations.
4. Technology readiness: Our technical ability to carry out these measurements/ demonstrations within the time frame specified in #2 above.

Conclusions

- The Moon offers a unique vantage point for certain aspects of Solar System exploration:
  - Cornerstone for Understanding Early and Fundamental Planetary Processes.
  - Understanding Volatile Record and Reservoirs.
  - Testbed for Scientific Exploration of the Solar System.
  - Astrobiology.

- Numerous linkages exist between possible lunar exploration activities and a future benefit to martian science.
- However, there are significant differences in the **relative** priority of the identified Moon$\rightarrow$Mars linkages.
- Many of the technology demonstration address fundamental scientific problems relevant to the Moon, Mars, and beyond.
- Important to set scientific and applied scientific priorities for the exploration of Moon in a LEAG Goals document. Equally important that there is a conduit to decision makers.

C6. ISRU Technology Demonstrations

What is the Linkage?

- Use of in-situ resources for the support of human and robotic missions.
- Different technological approaches may have commonalities at the sub-system level.
- Many processes are affected by operations at reduced gravity levels.
- Demonstrating reliability/stability/longevity of power systems and sensors.

Relevance to Lunar Science

- Excavation technologies are required for any process that extracts useful materials from the regolith.
- Demonstrate feasibility of extracting minor volatile constituents from regolith (H, C, N)
- Materials handling demonstrations to understand factors that will allow scale-up from robotic to human scale missions.

Relevance to Mars Science

- Excavation technologies are required for any process that extracts useful materials from the regolith.
- Demonstration of ISRU capability on the Moon will increase the likelihood that such approaches will be used on Mars.
- Long-term testing of systems to establish reliability and maintainability is essential because Mars applications will be difficult to repair if they fail.

Possible Lunar Measurements

- Practical small-scale excavators.
- Regolith thermal extraction of volatiles and gas separation and purification technologies.
- Hydrogen or carbon reduction processing of lunar regolith to produce oxygen.
- Demonstrations of practical use for exploration (charging a fuel cell on a rover for long-range exploration).