

# Lunar Exploration Roadmap

## Theme 3: Sustainability

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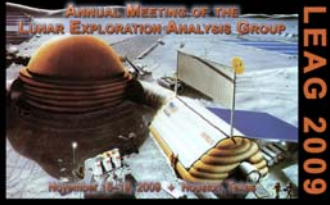
Annual Meeting of the Lunar Exploration Analysis Group

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USRA Lunar and Planetary Institute

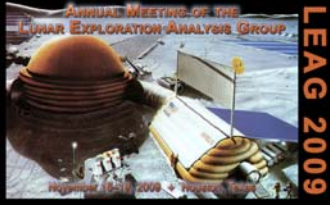
Houston, TX

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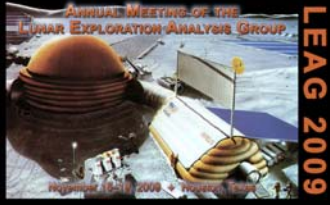
# Sustainability Premises

- Lunar activity should involve sustainable Science, Exploration, Commerce and Security
- Sustainability: real or anticipated return of value to stakeholders, public and private
  - scientific discovery
  - technology developments with terrestrial application
  - expected time to self-sustaining commercial activity
  - opportunity costs of lunar exploration



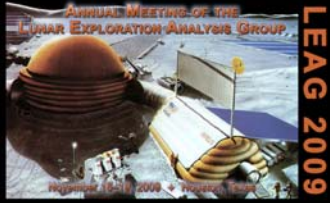
# Roadmap: Sustainability of Lunar Exploration

- Goal A: Maximize Commercial Activity
- Goal B: Enable and Support the Collaborative Expansion of Science and Exploration
- Goal C: Enhance the Security, Peace and Safety of People on Earth



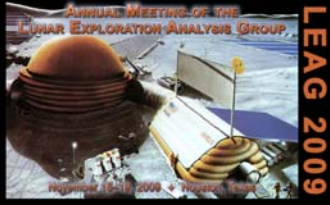
# Goal A: Maximize Commercial Activity

- Summary: Actions necessary to ensure that economically self-sustaining commercial endeavor is employed except where inherently-governmental activity is necessary.
- A Key Enabler: Market Demand
  - Integrating & aggregating needs: exploration, science, international, commercial
  - Encouraging efficient delivery, sustainable market size, early start
  - Defining essential requirements within “missions”
  - Limiting autonomy to maximize opportunity
  - Combining resources to obtain capability



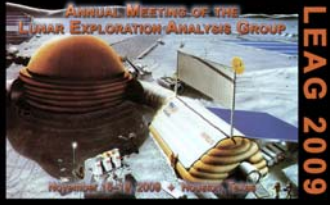
# Maximize Commercial Activity: Objectives

- Sust-A-1 (High, Early): Policies and implementation of comprehensive, coordinated governmental and intergovernmental action
- Sust-A-2 (High, Early): Preparation-I: comprehensive resource and market assessment of potential commercial lunar support services
- Sust-A-3 (High, Early): Preparation-II: small-scale demonstrations of potentially commercial lunar support services



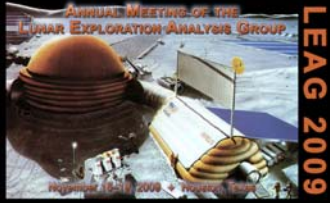
# Maximize Commercial Activity: Objectives

- Sust-A-4 (High, Middle): Transition-I: pilot-plant scale demonstrations of potentially commercial lunar support services
- Sust-A-5 (High, Late): Transition-II: fully operational delivery of commercial lunar support services



## Goal B: Enable and Support the Collaborative Expansion of Science and Exploration

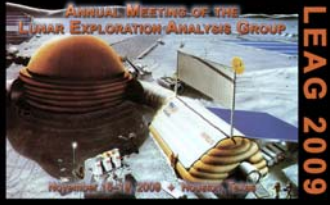
- Summary: Direct, conduct and support a variety of *scientific investigations* in complement to *exploration activities* involving discovering and exploiting resources and otherwise learning to live away from the Earth.



# Collaborative Expansion of Science and Exploration: Objectives

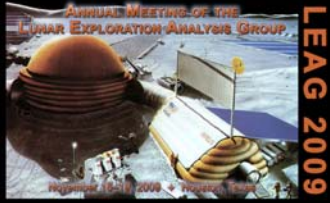
- Sust-B-1 (High, Early): Implementation of *comprehensive, coordinated integration* of diverse scientific and exploration activities to maximize complementary operations and minimize operational and environmental conflicts
- Sust-B-2 (High, Early): Establishment and implementation of comprehensive *site-selection criteria and processes*
- Sust-B-3 (High, Early): Development of *surface power and energy storage systems*





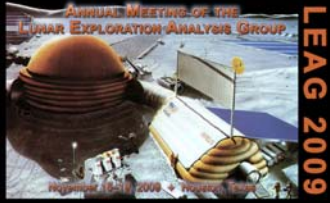
# Collaborative Expansion of Science and Exploration: Objectives

- Sust-B-4 (High, Early): Establishment of sustainable *transportation between Earth and the lunar surface*
- Sust-B-5 (High, Early): Deployment of *robotic facilities for science and exploration operations*
- Sust-B-6 (High, Early): Establishment of *global communications and navigation capability*



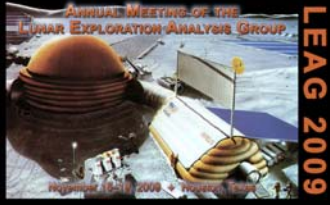
# Collaborative Expansion of Science and Exploration: Objectives

- Sust-B-7 (High, Late): Establishment of sustainable *human transportation between lunar sites*
- Sust-B-8 (High, Early): Deployment of *habitat and laboratory facilities* for human science and exploration operations
- Sust-B-9 (High, Early): Establishment of *in-situ production of life-support, power system reagents, propellants and related resources*



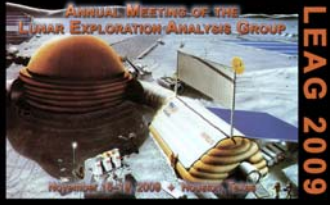
# Collaborative Expansion of Science and Exploration: Objectives

- Sust-B-10 (High, Middle): Establishment of *in-situ* food production capability
- Sust-B-11 (Middle, Late): Establishment of *in-situ* repair, fabrication, manufacturing and assembly capability
- Sust-B-12 (High, Early): Establishment of *integrated design, development and testing* capability



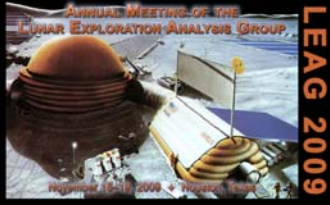
## Goal C: Enhance the Security, Peace and Safety of People on Earth

- Summary: Return value to Earth from missions other than scientific and exploration that cannot be accomplished in other ways



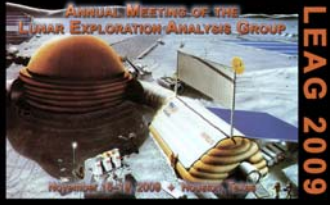
# Security, Peace and Safety of People on Earth: Objectives

- Sust-C-1 (High, Late): Detection and mitigation of threats from Near-Earth objects
- Sust-C-2 (High, Late): Beamed power and other lunar-based energy sources for terrestrial consumption
- Sust-C-3 (Medium, Late): Remote and Hazardous Research and Testing
- Sust-C-4 (Medium, Early): Applied Earth observations
- Sust-C-5: Archiving of Critical Human Records and Biological Samples



# Theme-Goal-Objective-Initiatives

- 3: Sustainability > B: Science/Exploration
  - 6: Robotic Facilities for Science and Exploration
    - Initiative A: Develop *standardized robotic platforms* for lunar operations that reduce the unit cost of such platforms through amortization of development costs and economies of scale in manufacturing and delivery.
    - Initiative B: Utilize *robotic precursor missions* to conduct selected *lunar science investigations* that focus on characterizing the pristine lunar environment and contribute *to identifying lunar resource* concentrations.
    - Initiative C: Utilize *robotic precursors* to evaluate and obtain critical *fundamental, applied, design, and engineering data for lunar infrastructure* (ex. life support, power, ISRU, communications, etc.).
    - ... through “L”



# Sustainability of Lunar Exploration: Summary

- Sustainability depends on efficiencies in planning and execution:
  - Stakeholder Integration: Science/Exploration, Government/Commercial, International, Public Engagement
- Sustainability depends on adopting it's principles early
  - Removal of Barriers to Commerce
  - Robotic Missions for Science, Resource Prospecting, and Technology Risk Reduction
  - Infrastructure development

**Sustainability: Return of Value to Stakeholders**