International Strategy for Using Lunar Volatiles

A proposed approach under consideration by the International Space Exploration Coordination Group (ISECG)

Nantel Suzuki
NASA HQ/Human Exploration and Operations Mission Directorate

John Gruener
NASA JSC/Astromaterials Research and Exploration Science Directorate

Global Exploration Roadmap Stakeholder Meeting: Focus on Science
NASA Research Park, Moffett Field, CA
24 July 2014

Introduction

Proposal: Develop a coordinated international lunar volatiles strategy

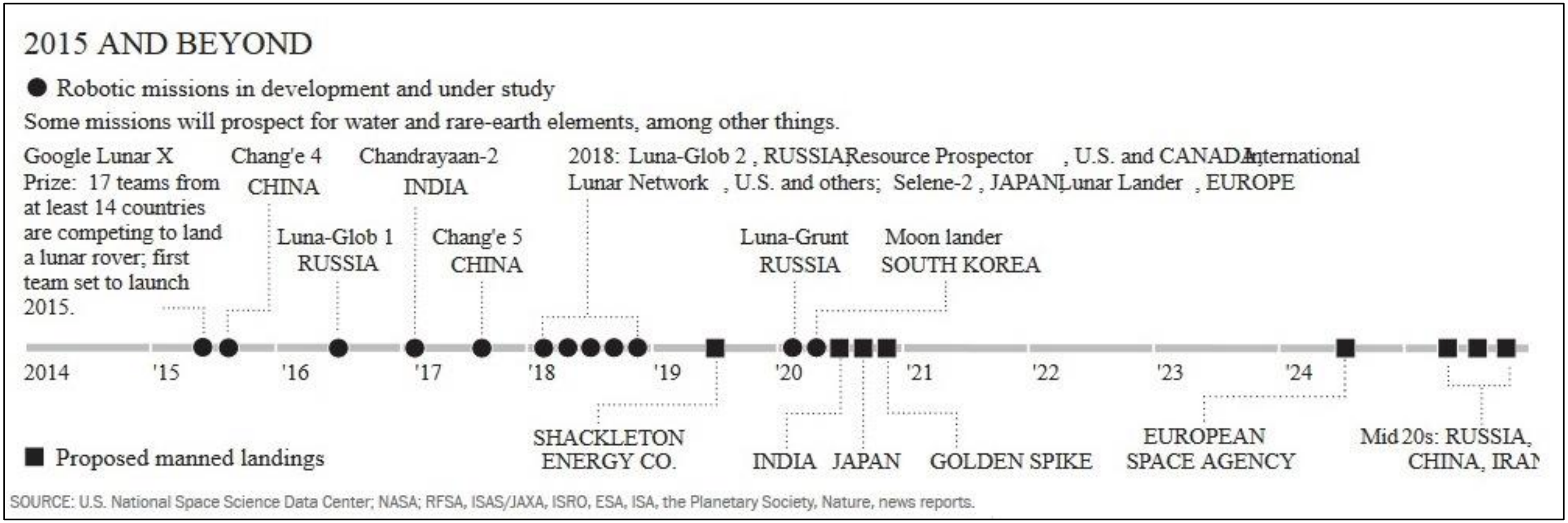
- *Lunar volatiles are a meaningful first focus area for an international strategy because*
  - *(a) They are of great interest to the science community and provide clues to help understand the solar wind, comets, and the history of the inner solar system*
  - *(b) Use of local space resources, including lunar volatiles, for propellant, life support, etc will improve the sustainability of human space exploration*
  - *(c) Technologies and methods for accessing lunar volatiles are relevant to potential future Mars resource utilization*
- *Coordination of international opportunities to access and study lunar volatiles and assess their usability as resources will accelerate resolution of key questions/issues*

Strategy Key Features:

- Phased Approach
  - Prospecting: Understand the nature & distribution of the volatiles through measurements from the lunar surface
  - ISRU Demo: Understand whether potential resources could be extracted and processed economically and safely
- Technically feasible and programmatically implementable

International and Commercial Interest in Lunar Exploration

- **Interest in exploring the lunar surface is increasingly diverse**
- **A variety of government and private entities have lunar mission plans, at varying stages of maturity, and many are targeting polar regions (sampling shown below)**



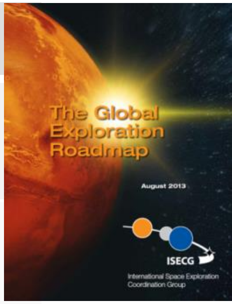
(From Washington Post, 1/27/2014)

Lunar Polar Volatiles ISRU Approach (from GER)

- LRO, Kaguya, Chandrayaan, and LCROSS measured the distribution of lunar polar volatiles. Data indicate higher levels of hydrogen in the polar region, and the LCROSS spacecraft identified water and other volatiles at a single location in a permanently shadowed crater.
- However, higher resolution measurements of the **concentration and distribution of the volatiles** (widely available near the surface or largely in permanently shadowed regions) is needed to understand whether they could be extracted and used cost-effectively.
- The first step is **robotic prospecting** to take measurements on the lunar surface. Additional information may be needed prior to committing to a **processing demonstration mission**.
- If these initial steps look promising, **human missions** to the Moon would provide valuable insight, assessment and troubleshooting for the **robotic installation of a larger resource recovery and return facility**.
- While there are differences in the physical, mineral, and chemical forms of the soil on the Moon, asteroids, and on Mars, as well as different types and concentrations of ice and other volatiles, commonalities in technologies and processes can be found to reduce the cost and risk of using local resources. Planned robotic **missions to the Moon can provide information relevant to potential future Mars resource utilization** by contributing information related to prospecting and processing techniques and equipment.

Key Lunar Volatiles Challenges and Questions are traceable to Common Exploration Goals/Objectives and SKGs

Common Goals	Objectives
Perform Science to Enable Human Exploration	Characterize available resources at exploration destinations (e.g. Moon, asteroids, Mars)
Develop Exploration Technologies &Capabilities	Develop and validate tools, technologies, and systems that extract, process, and utilize resources to enable exploration missions.



Strategic Knowledge Gaps (SKGs):

ISECG

July 22, 2013

Strategic Knowledge Gaps

In order to prepare for future human missions, system and mission planners desire data that characterize the environments, identify hazards, and assess resources. Recent, currently operating, and future science missions are invaluable resources for providing this data. The knowledge developed from this data will inform the selection of future landing sites, inform the design of new systems, and reduce the risk associated with human exploration. While some data can be obtained through ground-based activities, other data can only be gained in space by remote sensing, in-situ measurements or sample return.

MOON					
1) Knowledge Domain	2) Strategic Knowledge Gap: Description and Priority	3) Target measurement	4) Mission or ground based activity addressing the SKG		Measurements: R = Robotic mission SR = Sample Return G = Ground based activities
Resource Potential	**Solar Illumination Mapping:** Combined elevation-illumination models to map solar energy incidence over time.	Data is in hand but R & A resources are required to reduce and leverage the data. LRO extended mission enables detailed multi-temporal mapping of lunar poles.	NASA LRO JAXA Kaguya Roscosmos Luna-26	NASA–R&A ESA-R&A	No additional measurements needed.
Resource Potential	**Regolith Volatiles from Apollo Samples:** Quality/ quantity/ distribution/ form of H species and other volatiles in mare and highlands regolith.	Measure volatiles and organics returned in "pristine" Apollo samples (core vacuum sample containers 69001, 73001). Measure the extent of disruption of volatiles during handling and processing.		NASA-R&A UK OU-R&A	G
Resource Potential	**Regolith Volatiles from Robotic Missions:** Quality/ quantity/ distribution/ form of H species and other volatiles in mare and highlands regolith.	Robotic in situ measurements of volatiles and organics on the lunar surface and eventual sample return of "pristine" samples.	Roscosmos Luna-25 Roscosmos Luna-27 Roscosmos Luna-28/ Luna 29		R, SR
Resource Potential	**Lunar Cold Trap Volatiles:** Composition/ quantity/ distribution/ form of water/ H species and other volatiles associated with lunar cold traps.	In-situ measurement of volatile characteristics and distribution within permanently shadowed lunar craters or other sites identified using remote sensing data (e.g. from LRO).	Roscosmos Luna-25/ Luna-27 NASA-CSA RESOLVE Roscosmos Luna-28/ Luna-29		R, SR

Lunar Cold Trap Volatiles: Composition/ quantity/ distribution/ form of water/ H species and other volatiles associated with lunar cold traps.

Currently Planned Missions and Strategic Knowledge Gaps

- Missions by diverse entities may complement each other to collectively fill SKGs

Lunar Exploration Strategic Knowledge Gaps	Luna 25 Lander	Luna 26 Orbiter	Resource Prespector Mission	Luna 27 Lander	
I. Understand the Lunar Resource Potential					
A. Solar Resources					
A-1. Solar illumination mapping					
B. Regolith Resources 1 (Earth based study of Apollo samples)					
C. Regolith Resources 2					
C-1. Quality/quantity/distribution/form of H species and other volatiles in mare & highlands					
D. Polar Resources					
D-1. Extent, magnitude and age of cold traps (Earth analysis)					
D-2. Correlation of cold traps and permanent darkness (Earth Aanalysis)					
D-3. Geotechnical characteristics of cold traps			H	L-M	
D-4. Physiography and accessibility of cold traps			VH	L-M	
D-5. Charging and plasma environment within and near PSR	H			H	
D-6. Earth visibility timing and extent (Earth analysis)					
D-7. Concentration of water and other volatiles species within depth of 1-2 m			VH	VH	
D-8. Variability of water concentration on scales of 10's of meters			VH		
D-9a. Mineralogical, elemental, molecular, isotopic, make up of volatiles	M		H	H	
D-9b. Mineralogical, elemental, molecular, isotopic, make up of polar regolith	M		L-M	VH	
D-10. Physical nature of volatile species (e.g. pure concentrations, intergranular, globular)			H	H	
D-11. Spatial and temporal distribution of OH and H2O at high latitudes			M-H		
D-12. Detect and measure exospheric water in association with surface-correlated deposits					
D-13. Monitor and model movement towards and retenion in PSR			M		
E. Pyroclastic Deposit Resources					
E-1. Composition/volume/distribution/form of pyroclastic/dark mantle deposits					
F. Lunar ISRU production efficiency (Earth testing)					
G.Lunar ISRU production efficiency 2					
G-1. Measure actual efficiency of ISRU processes in the lunar environment			M		

VH= Very High; H = High; M-H = Medium to High; M = Medium; L-M = Low to Medium; L = Low

Courtesy NASA/J. Sanders

Lunar Polar Volatiles Strategy - Initial Core Elements

- Strategy must be driven by economic considerations
- Coordinated/aligned activity by international and commercial entities is essential for success
- Mission scaling trade-offs
  - Low frequency of larger-scale missions vs high frequency of smaller missions

- **3 initial core elements to the strategy:**

1. Common Lunar Region

Build consensus among broad community for a common "Region" on the lunar surface to be collectively explored by a variety of sequential, coordinated missions. "Region" is larger than a lunar site for a single mission, perhaps 10-100 km diameter zone. (e.g. near South Pole/ Shackleton crater)

2. Low Entrance Barriers

Facilitate participation by space agencies, commercial entities, and universities by:

a. Deployment of surface or orbital infrastructure assets that allow for simpler, lower cost rovers or other surface systems and provide productivity-enhancing utility services within the specified region (i.e., power generation, thermal protection, communication)

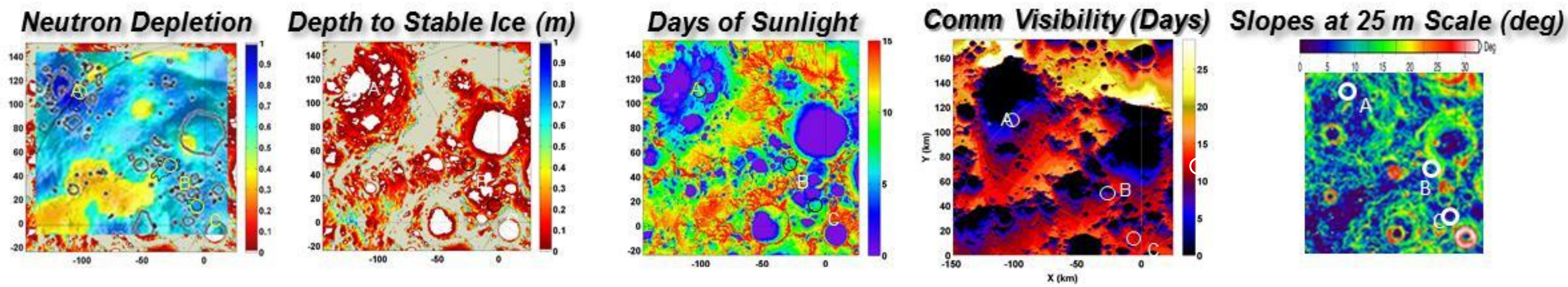
b. Collaborative development of instrument or surface system capabilities between participants

3. Standards

Standard interfaces (mechanical, electrical, communication) and standard propellants to optimize use of surface utility services, permit interchangeability of vehicle payload complements, and maximize interoperability

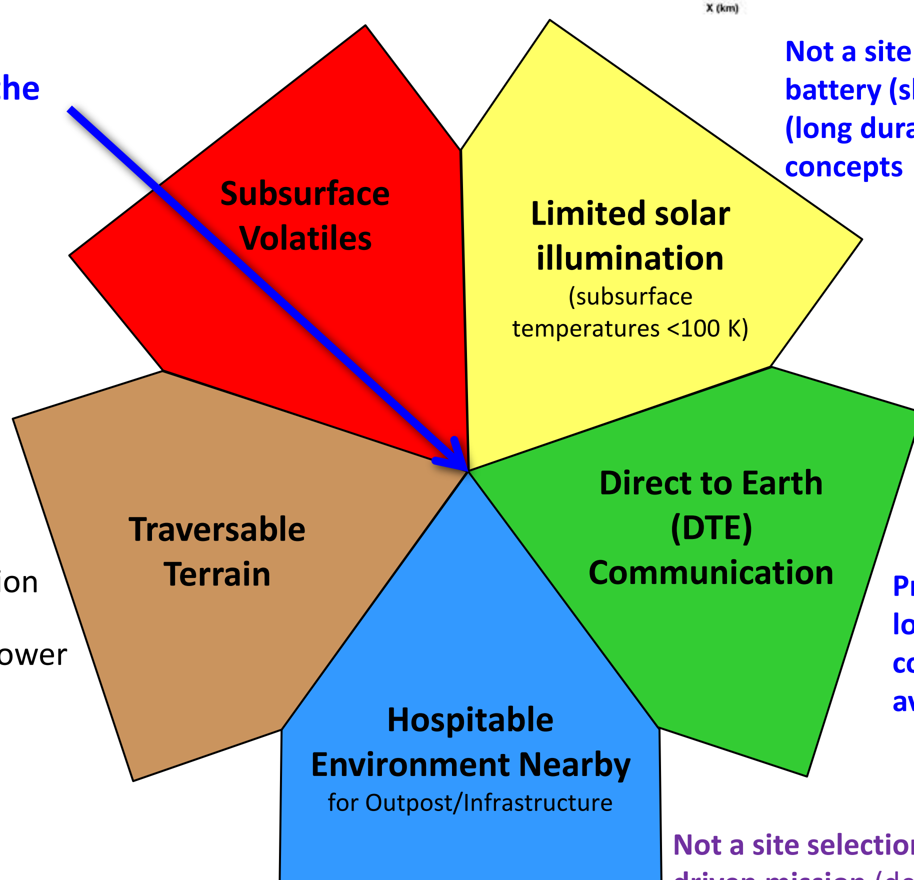
Site Selection Criteria for Polar Volatiles Prospecting

Global Data Provided by Orbital Instruments



Polar landing site based on meeting the following Five main criteria

1. Surface/Subsurface Volatiles
   - High hydrogen content (LRO LEND instrument)
   - Constant <100 K temperatures 10 cm below surface (LRO Diviner instrument)
   - Surface OH/H_2O (M^3, LRO LAMP)
2. Reasonable terrain for traverse
3. Direct view to Earth for communication
4. Sunlight for duration of mission for power generation (non-nuclear)
5. Hospitable environment nearby for mining and logistics infrastructure



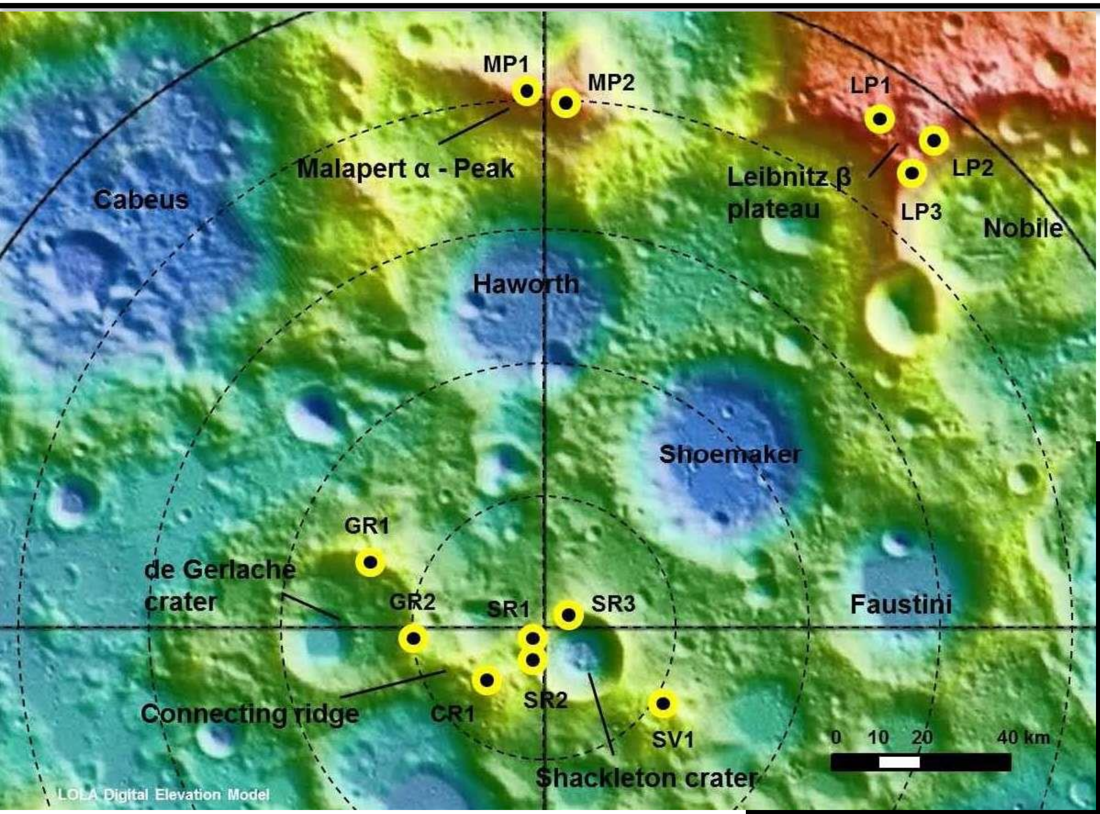
Not a site selection criteria for battery (short duration) or nuclear (long duration) science mission concepts

Prevents lunar farside locations unless a communication orbiter is available

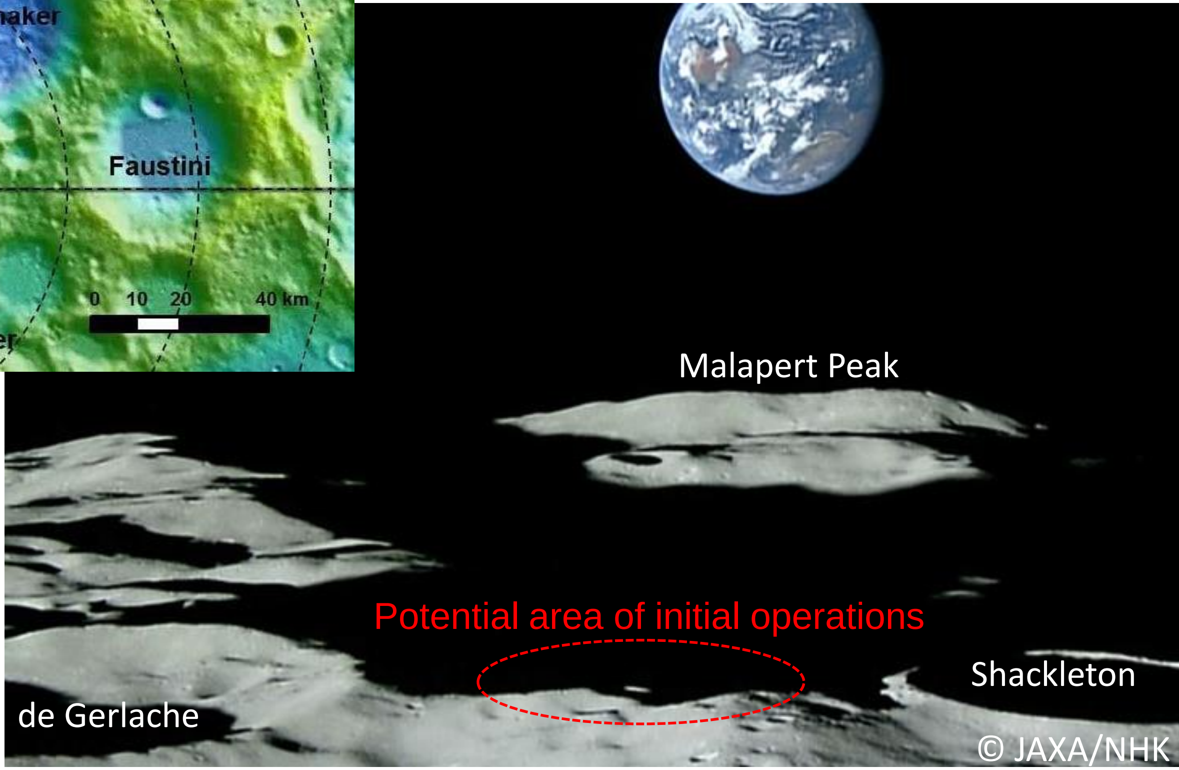
Not a site selection criteria for Science driven mission (deep PSR crater is viable location)

Courtesy NASA/J. Sanders

Regions of Interest for Volatiles Prospecting



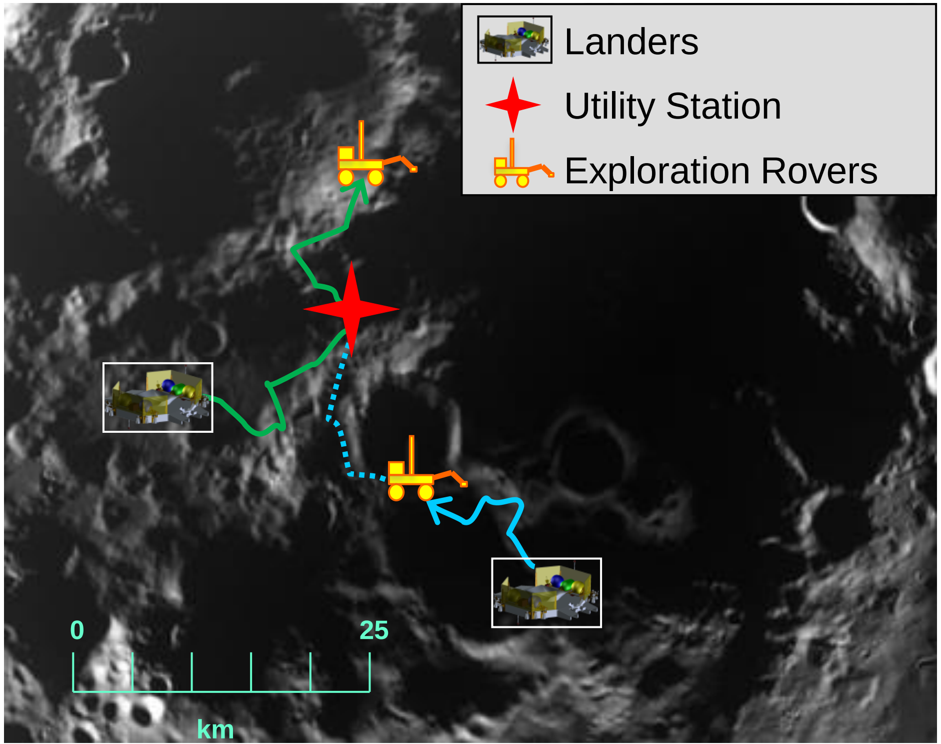
Regions of Interest may be found near the Moon's South Pole.



Low Entrance Barriers

Deploying infrastructure can lower entrance barriers to space exploration

- Example: Small utility stations on the lunar surface can offload functional requirements from mobile elements, enabling high mission productivity with relatively small, simple rovers
  - Positive return on investment in such stations may require concentration of rovers in a common region
- This approach may lower lunar exploration entrance barriers, allowing a greater diversity of international and commercial participants, while improving productivity (e.g. enabling robotic missions to achieve long duration (months) and regional-scale mobility (10s of km))
- A variety of small, coordinated missions leveraging such utilities may collectively achieve resource prospecting objectives



A lunar polar utility station providing thermal protection services to multiple rovers. Power and communications utility services could also be provided.

Standards

Standards can promote interoperability of exploration elements and plug-and-play of equipment

- **Interoperability among rovers, surface utility stations, ISRU demonstration elements, and other surface assets is essential for sustainable exploration of lunar volatiles, and standard interfaces are essential for interoperability**
- **Notional examples of useful interface standards:**
  - Lander-to-Payload Interfaces
  - Rover-to-Payload/instrument Interfaces
  - Communications among all surface assets (lander, rovers, utility stations, etc)
  - Rover-to-Utility Station Interfaces
    - Power interfaces (possibly wireless inductive power transfer)
    - Conductive thermal charging interfaces
  - Others…

Next Steps

- **Share initial feedback/input from agencies on proposed strategy at July ISECG workshop (e.g. degree of interest; comments on content and process)**
- **Establish an ISECG special action team to develop lunar volatiles strategy; Topics for discussion may include:**
  - Assessment of opportunities to close lunar volatile-related SKGs
  - Approaches to identifying candidate common regions
  - Share status of planned and conceptual lunar missions, including site selection options
  - Assessment of interest in common infrastructure
  - Assessment of interest in standards development