



NASA SBIR 2018 Phase I Solicitation

H2.01 Lunar Resources

Lead Center: KSC

Participating Center(s): GRC, JPL, JSC

Technology Area: TA7 Human Exploration Destination Systems

Whereas the Moon was once thought to be dry, more recent discoveries indicate that there are a variety of resources that exist on the Moon in an embedded or frozen state in the regolith. When acquired and exposed to higher temperatures and vacuum, these resources will change state into the vapor phase and are known as volatiles. Examples are polar water ice or Hydrogen and Helium 3 embedded in the regolith grains by the sun.

Lunar volatiles are a meaningful first focus area for a space exploration strategy because:

- Use of local space resources, including lunar volatiles, for propellant, life support, etc. will improve the sustainability of human space exploration.
- Technologies and methods for accessing lunar volatiles are relevant to potential future Mars resource utilization.
- Volatiles 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.

NASA is interested in this proposal solicitation for small payloads up to 5 kg in mass which are needed to characterize and map the lunar volatiles resources, so that they can be included in a future lunar ISRU strategy, as listed in selective NASA Strategic Knowledge Gaps (SKG) below. This payload may be delivered to the surface of the Moon on a small commercial lunar lander and could be stationary on the lander, mobile on a mobility device, or it may itself be mobile and/or deployable. The Phase I proposal shall indicate the type of lunar surface assets, interfaces and commodities that are required to carry and support the payload. Impactors and other devices that are used or released in lunar orbit are not within the scope of this solicitation.

The goal of this subtopic is to develop the technologies necessary for small payloads delivered to the Moon on a commercial lander to characterize and map the lunar volatiles resources. All proposals need to identify the state-of-the-art of applicable technologies and processes and Technology Readiness Level (TRL) expected at the end of Phase I, with a credible development plan. By the end of Phase I, feasibility of the proposed payload technology should be established with a notional payload packaging concept and evidence that the payload is feasible. If a Phase II is awarded, then further development of the payload technologies and payload packaging shall be required, including a payload prototype delivered to NASA at the end of the two-year project with a goal of achieving TRL 6. Due to the fact that lunar volatiles primarily exist in permanently shadowed craters, the prototype hardware proposed will need to operate under lunar vacuum conditions and either need to be designed to operate and be tested at extremely low temperatures (down to 40 K) or include estimates on thermal management and power to operate under these temperatures. Methods to collect the volatiles without significant loss to sublimation

are of high interest. Proposals for innovative technologies and processes must include the design and test of critical attributes or high-risk areas associated with the proposed payload technology or process to achieve the objectives of potential SBIR Phase II proposed Lunar payload hardware. At the end of Phase II, successful payload designs will be considered for funding applied to a commercial lunar lander flight in a potential Phase III award.

Proposals will be evaluated on the basis of feasibility, mass, power, volume, and complexity. All proposals shall identify the SKG(s) from the list below that will be met. Payloads with a proposed mass of greater than 5 kg shall not be considered in this subtopic.

The following information is provided so proposers understand the context and purpose of the small payloads being solicited for a robotic lunar landing mission.

Recent data from NASA's Lunar CRater Observation and Sensing Satellite (LCROSS), and Lunar Reconnaissance Orbiter (LRO) missions indicate that as much as 20% of the material kicked up by the LCROSS impact was volatiles, including water, methane, ammonia, hydrogen gas, carbon dioxide and carbon monoxide. The instruments also discovered relatively large amounts of light metals such as sodium, mercury and possibly even silver.

The following criteria are relevant to this SBIR solicitation, as reported by the Lunar Exploration Analysis Group (LEAG):

Significant uncertainties remain regarding to the distribution of volatiles at the 10 to 100 m resolution scales accessible to near term orbital missions. Data and models are clear that volatiles are distributed unevenly at this scale and mission success scenarios should accommodate this likelihood. We also found that a range of new orbital missions and science support activities could reduce this risk by improving both the empirical data upon which site selections are based upon, and the scientific understanding of polar volatile evolution. Regarding landed experiments, there are several key measurements-- such as compositional variation and soil geotechnical and thermal properties--within the capabilities of small near-term missions that would greatly improve the understanding of polar volatiles; obtaining any of the needed quantities would benefit subsequent missions.

There are sufficient data to support near-term landing site selections; Enhanced hydrogen is widespread across the polar regions and is sometimes concentrated in permanently shadowed regions (PSRs). Data show that average annual surface temperatures below 110K are also widespread, including both PSRs and areas sometimes illuminated. This characteristic allows preservation of shallow buried ice for geologic time. LCROSS demonstrated hydrogen and water do occur at shallow depths at the LCROSS target site PSR. However, arguments derived from lunar surface processes suggest volatiles will be distributed irregularly and high water abundance observed by LCROSS was not consistent with the regional H abundance indicating sampling of a local concentration.

The expected patchy nature of hydrogen distributions constitutes significant risk to missions requiring detection and sampling of hydrogen. Higher resolution definitive hydrogen data would reduce this risk.

LEAG Volatiles Specific Action Team (SAT) Landed Measurements Finding #1

Small near-term missions can provide critical data to resolve important unknowns regarding polar volatile science and resource utilization:

- Lateral and vertical distribution of volatiles.
- Chemical phases that contain volatile elements.
- Geotechnical and thermal properties of polar soils.
- Mobility of volatiles and associated timescale(s).
 - Landed experiments obtaining any of the important quantities are of great science and exploration value.

LEAG Volatiles Specific Action Team (SAT) Landed Measurements Finding #2

Early characterization of the variation in volatile abundance at ISRU and scientifically relevant spatial scales would greatly benefit all future missions:

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- Current understanding of the spatial variation of volatile abundance at the scale of landers and small rovers is a major uncertainty. This ignorance is a strong inhibitor for the use of static landers.
 - Several studies suggest that near surface volatiles will be very unevenly distributed due to the impact process and other mechanisms.
 - A small rover traversing several hundred meters could characterize the variation in volatiles at this scale with simple instrumentation. A rover traverse of several hundred meters to several kilometers is required. The minimum distance for ground truthing is 20 km. Minimum distance to confirm if there are volatiles present is likely to be ~1 km.
 - This would provide ground-truth for orbital volatile measurements by beginning to close the gap in scales.

LEAG Volatiles Specific Action Team (SAT) Landed Measurements Finding #3

The physical and chemical forms of abundant volatile elements are critical to understanding the resource and its origins:

- Early measurements should include unambiguous determination of the chemical phase of volatiles present to a depth of one or more meters.
- Measurements should not be restricted to the detection of water, but include other volatile species.
- Profiling is desirable, but a bulk analysis would be of very high value.
- It is necessary to measure the isotopic composition of volatile elements. Both with respect to fundamental volatile science and with respect to assessing quantitatively potential landing-induced contamination of the surface materials.

LEAG Volatiles Specific Action Team (SAT) Landed Measurements Finding #4

Successful exploitation of in-situ resources requires knowledge of the physical (geotechnical) and thermal properties of polar regolith in addition to the volatile abundance:

- The utility of a resource is highly dependent on the cost of extraction that is in turn dependent on the physical and chemical state of the volatile and its refractory matrix.
- The ISRU community should develop specific measurement objectives for geotechnical and temperature dependent properties.
- Thermal analysis of polar soils such as differential scanning calorimetry would greatly enhance the ability to develop ISRU regolith processing strategies, even in a volatile poor polar target:
 - Thermal analysis can also be made sensitive to volatiles found in the LCROSS plume that could cause significant concerns for contamination and degradation of ISRU hardware including H₂S, Hg, and Na.
- Physical and thermal properties of polar regolith should be measured. The potential effect of some volatile compounds such as Hg and Na on instrument degradation should be quantified.

LEAG Volatiles Specific Action Team (SAT) Landed Measurements Finding #8

In addition to ISRU goals, landed experiments should include measurements of current volatile flux to aid understanding volatile transport mechanism:

- Apollo surface experiments revealed a dynamic exosphere and produced a lengthy list of potential volatile atmospheric species.
- Measurements might include:
 - Pressure.
 - Atmospheric species.
 - Flux directions.
 - Measurements at PSR contacts to measure the volatile flux into cold traps.

The relevant lunar Strategic Knowledge Gaps (SKG€™s) for this subtopic are listed below:

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- I-C. Regolith 2: Quality/ quantity/distribution/form of H species and other volatiles in mare and highlands regolith (requires robotic precursor missions).Â Robotic in-situ measurements of volatiles and organics on the lunar surface and eventual sample return of pristine samples. Enables prospecting for lunar resources and ISRU. Feeds forward to Near Earth Asteroids (NEA)-Mars. Relevant to the Planetary Science Decadal survey.
 - I-D-1. Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps.Â Required ground truth; in-situ measurement within permanently shadowed lunar craters or other sites identified using LRO data. Technology development required for operating in extreme environments. Enables prospecting of lunar resources and ISRU. Relevant to Planetary Science Decadal survey.
 - I-D-3 Subsection c: Geotechnical characteristics of cold traps Landed missions to understand regolith densities with depth, cohesiveness, grain sizes, slopes, blockiness, association and effects of entrained volatiles.
 - I-D-7 Subsection g: Concentration of water and other volatiles species with depth 1-2 m scales
Polar cold traps are likely less than ~2 Ga, so only the upper 2-3 m of regolith are likely to be volatile-rich.
 - I-D-9 Subsection I: mineralogical, elemental, molecular, isotopic make up of volatiles.Â Water and other exotic volatile species are present; must know species and concentrations.
 - I-D-10 Subsection j: Physical nature of volatile species (e.g., pure concentrations, inter-granular, globular)
Range of occurrences of volatiles; pure deposits (radar), mixtures of ice/dirt (LCROSS), H₂-rich soils (neutron).
 - I-E. Composition/volume/distribution/form of pyroclastic/dark mantle deposits and characteristics of associated volatiles.Â Required robotic exploration of deposits and sample return. Enables prospecting for lunar resources and ISRU.Â Relevant to Planetary Science Decadal survey.