



NASA SBIR 2017 Phase I Solicitation

H2.01 Lunar Resources

Lead Center: KSC

Participating Center(s): ARC, GRC, GSFC, JPL, JSC, LaRC, MSFC

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 of this 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.

An ancillary benefit is that the 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.

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.

Small payloads up to 2 kg in mass are needed to characterize and map the lunar volatiles resources so that they can be included in a future lunar ISRU strategy. This payload may be delivered to 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. Impactors and other devices that are used or released in lunar orbit are not within the scope of this solicitation.

The entire surface of the Moon is covered with fragmental and unconsolidated crushed rock material known as regolith, which was formed over billions of years of high-energy impacts by meteorites, comets and other solar system debris. Estimates are that this regolith covers the top 8-10 meters of the Moon's surface. Regolith represents a significant resource due to the bound oxygen that is present in some minerals; metals such as aluminum, iron and magnesium that can be extracted to make parts; and its use as a bulk construction aggregate material for civil engineering structures or radiation shielding. In addition other engineering parameters such as

trafficability must be known before effective exploration can take place.

Silicate minerals, composed dominantly of silicon and oxygen, are the most abundant constituents, making up over 90% by volume of most lunar rocks. The most common silicate minerals are pyroxene, $(Ca,Fe,Mg)_2Si_2O_6$; plagioclase feldspar, $(Ca,Na)(Al,Si)_4O_8$; and olivine, $(Mg,Fe)_2SiO_4$. Oxide minerals, composed chiefly of metals and oxygen, are next in abundance after silicate minerals. They are particularly concentrated in the mare basalts, and they may make up as much as 20% by volume of these rocks. The most abundant oxide mineral is ilmenite, $(Fe,Mg)TiO_3$, a black, opaque mineral that reflects the high TiO_2 contents of many mare basalts. The second most abundant oxide mineral, spinel, has a widely varying composition and actually consists of a complex series of solid solutions. Members of this series include: chromite, $FeCr_2O_4$; ulvöspinel, Fe_2TiO_4 ; hercynite, $FeAl_2O_4$; and spinel (sensu stricto), $MgAl_2O_4$. Another oxide phase, which is only abundant in titanium-rich lunar basalts, is armalcolite, $(Fe,Mg)Ti_2O_5$.

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

I-C. Regolith 2: Quality/ quantity/distribution/form of H species and other volatiles in mare and highlands regolith (requires robotic precursor missions).

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 NEA-Mars. Relevant to Planetary Science Decadal survey.

I-D-1. Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps.

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

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.

Required robotic exploration of deposits and sample return. Enables prospecting for lunar resources and ISRU. Relevant to Planetary Science Decadal survey.

I-G. Lunar ISRU production efficiency

Measure the actual efficiency of ISRU processes in the lunar environment. Highly dependent on location & and nature of the input material. Process at high temperature to test techniques for extracting metals (e.g., Fe, Al) from regolith. This is enhancing long duration activity on the Moon and potentially beyond LEO.

III-C-2 Lunar surface trafficability – in-situ measurements

Characterization of geotechnical properties and hardware performance during regolith interactions on lunar surface.

III-D-1 Lunar dust remediation

Test conceptual mitigation strategies for hardware interactions with lunar fines, such as hardware encapsulation and microwave sintering of lunar regolith to reduce dust prevalence.

III-D-2 Regolith adhesion to human systems and associated mechanical degradation

In-situ grain charging and attractive forces, and cohesive forces under appropriate plasma conditions to account for electrical dissipation. Analysis of wear on joints and bearings, especially on space suits.

III-D-4 Descent / ascent engine blast ejecta velocity, departure angle and entrainment mechanism

Measurement of actual landing conditions on the lunar surface and in-situ measurements of witness plates and other instrumentation.

III-G Test radiation shielding technologies

Protecting human crews beyond the magnetic fields of the Earth from space radiation is a critical. In addition to Earth-based testing, could be further accomplished during lunar robotic missions.

All proposals need to identify the state-of-the-art of applicable technologies and processes. Hardware to be delivered at the conclusion of Phase II will be required to operate under lunar equivalent vacuum and temperature conditions, so thermal management during operation of the proposed technology will need to be specified in the Phase I proposal. Phase I 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 the Phase II delivered payload hardware. Proposals will be evaluated on mass, power, volume, and complexity. At the end of Phase II, the payload hardware should be capable of being ready to be flown in space within one year, with additional testing taking place during that year.