NASA SBIR 2008 Phase I Solicitation

X3 Lunar In Situ Resource Utilization

The purpose of In Situ Resource Utilization (ISRU) is to harness and utilize resources at the site of exploration to create products and services which can enable and significantly reduce the mass, cost, and risk of near-term and long-term space exploration. In particular, the ability to make propellants, life support consumables, fuel cell reagents, and radiation shielding can significantly reduce the cost, mass, and risk of sustained human activities beyond Earth. The ability to modify the lunar landscape for safer landing, transfer of payloads from the lander to an outpost, dust generation mitigation, and infrastructure emplacement and buildup are also extremely important for long-term lunar operations. To perform these tasks on the lunar surface, detailed knowledge of the terrain, local minerals and potential resources, and subsurface futures is important for planning and operations at the start of establishing long-term human presence on the lunar surface. Lastly, since ISRU systems and operations have never been demonstrated before in missions, it is important that ISRU concepts and technologies be evaluated under relevant conditions (1/6 g and vacuum) as well as anchored through modeling to lunar soil and environmental conditions. With this in mind, the ISRU Project within the Exploration Technology Development Program (ETDP) has initiated development and testing of hardware and systems in three main focus areas: (1) Regolith Excavation, Handling and Material Transportation; (2) Oxygen Extraction from Regolith; and (3) ISRU Development & Precursor Activities. The purpose of the following subtopics is to develop and demonstrate hardware and software technologies that can be added to on-going analysis and ISRU capability development and demonstration activities in ETDP to meet Outpost architecture and surface manipulation objectives for near and long term human exploration of the Moon.Â

Subtopics

X3.01 Lunar Regolith Excavation and Material Handling

Lead Center: JSC

Participating Center(s): GRC, KSC

The lunar regolith excavation, handling, and material transportation subtopic includes all aspects of lunar regolith handling for oxygen and other resource collection and site preparation and Outpost infrastructure emplacement, including tasks such as clearing/leveling landing areas and pathways, buildup of berms and burying of reactors or habitats for radiation protection. Excavation capabilities may involve excavation and collection of both unconsolidated and consolidated surface regolith. Hardware must be able to operable over broad temperature ranges (generally 110K to 400K) and in the presence of abrasive lunar regolith and partial-gravity environments. Expectations for maintenance by crew must be minimal and affordable. Therefore, general attributes desired for all proposed hardware include the following: lightweight, abrasion resistant, vacuum and large temperature variation compatible materials, low power, robust/low maintenance, and minimize dust generation/saltation during operation.

Specific software and hardware for insertion into on-going ISRU Project development and demonstration activities include:

- Excavation hardware for oxygen production: Unconsolidated material, 17 kg/hr based on hydrogen reduction, <10 cm deep; avoid or mitigate rocks >5 cm diameter (See note on mobility platform below).
- Excavation hardware for deep digging: Consolidated material, 3 m deep and 1 meter in diameter at a minimum; (See mobility platform note below).
- Granular materials mixing and separation for reactor feedstock conditioning: remove material > 0.5 cm diameter before dumping into storage bin during excavation operation for oxygen extraction from regolith.
- Dust tolerant, lightweight mechanisms and actuators for excavation and material transport operations.
- Site preparation hardware, automation, and control for surface contouring and area clearing and leveling.
- Site preparation hardware, automation, and control for berm building; 3 meters tall; 45 degree slope minimum based on landing plume mitigation.

Phase 1 proposals should demonstrate technical feasibility of the technology and/or subsystem through laboratory validation of critical aspects of the innovation proposed, as well as the design and path toward delivering hardware/subsystems in Phase 2 for incorporation into existing development activities.

Proposers are encouraged to use the Lunar Sourcebook at a minimum for understanding lunar regolith material parameters in the design and testing of hardware proposed. To determine implement size and time required to complete tasks, proposers have three options for surface mobility: 1) part time use of NASAâ€™s large crew rover currently under development (2000 kg mass, 1.33 m wide, 4.5 m long, and 0.2 m high chasse frame, 0 to 0.67 m frame height variation capability from surface), 2) operation on a smaller dedicated ISRU rover yet to be developed, 3) optimize vehicle size to minimize total system mass and power. For option 2, interface requirements for on-going development efforts will be provided after selection. For option 3, proposers may evaluate surface mobility aspects in their proposal but cannot exceed 35% of the budget for the proposed effort.Â

X3.02 Oxygen Production from Lunar Regolith

Lead Center: JSC

Participating Center(s): GRC, KSC, MSFC

Oxygen (O_2) production from lunar regolith processing consists of receiving regolith from the excavation subsystem into a hopper, transferring that regolith into a chemical or an electrochemical reactor, intermediate reactions to produce O_2 and regenerate reactants if required, purification and transfer of the O_2 produced, and removal of processed regolith from the reactor to an outlet hopper. Three O_2 production from lunar regolith reaction concepts are currently under development: Hydrogen reduction, Carbothermal reduction, and Molten Oxide Electrolysis at initial lunar Outpost production scale of 1 to 2 MT per year. The production plant will utilize solar power, and two operation options are: 1) operate at polar location with solar energy available for processing to occur 70% of the year with highlands soil feedstock, and 2) operation at an equatorial location with solar energy available for processing to occur 45% of the year with mare soil feedstock. To maximize the benefits of ISRU for lunar missions, O_2 production systems must be able to produce many times their own mass in O_2 and other products, must be able to autonomously operate in a harsh environment that can have wide temperature swings, and must operate with little or no maintenance and little or no loss of reactants and O_2 while handling and processing highly abrasive lunar regolith. Systems must also be able to sustain numerous startup and shutdown sequences when solar power is not available. Shutdown periods can vary from twenty hours to 14 days.

This subtopic is seeking hardware, subsystem, and system components and technologies for insertion and integration into on-going oxygen extraction from regolith development and demonstration efforts. Component and technology areas of particular interest are:

- Move feedstock material from hopper on ground to 2 m height for reactor inlet hopper; 40 kg/hr; material size
- Inlet/outlet regolith hopper design and valve/seal concepts with no gas leakage, 1000's of operating cycles with abrasive lunar material, and minimum heat loss.

- Methods and hardware for recovering heat energy from spent regolith to pre-heat inlet regolith; 1050Â°C spent regolith temp, 750Â°C inlet regolith starting temp; 20 kg/batch.

- Molten material removal from molten electrolysis; 5 to 10 kg per batch size.

- Non-eroding cathode/anode concepts for molten oxide electrolysis; 5 to 10 kg batch size.

- Water condensers that use the space environment for water condensation/separation with minimal energy usage.

- Gas Separators that provide low pressure drop separation of the system and product gas streams from impurities (e.g. HCl, HF, H_2S, SO_2); impurities in ppm quantities.

- Microchannel methanation reactors that convert a mixture of carbon monoxide, carbon dioxide, and hydrogen to methane and water vapor with carbon monoxide and carbon dioxide consumed to the maximum extent possible.

- Advanced reactor concepts for carbothermal reduction or molten oxide electrolysis.

Phase 1 proposals should demonstrate technical feasibility of the technology or hardware concept through laboratory validation of critical aspects of the innovation proposed, as well as the design and path toward delivering hardware/subsystems in Phase 2 for incorporation into existing development activities. Interface requirements for on-going development efforts will be provided after selection. Proposers are encouraged to use the Lunar Sourcebook at a minimum for understanding lunar regolith material parameters in the design and testing of hardware proposed. It is also recommended that JSC-1a simulants be used during testing unless a more appropriate simulant can be obtained or manufactured.

X3.03 Lunar ISRU Development and Precursor Activities

Lead Center: JSC

Participating Center(s): GRC, JPL, KSC, MSFC

The ISRU Project has initiated development and testing of hardware and systems that can achieve early lunar Outpost needs with respect to oxygen (O_2) production from regolith and site preparation and outpost infrastructure emplacement. However, before ISRU hardware will be built and deployed on the lunar surface for Outpost operations, ISRU concepts and operations will need to be anchored through computer modeling, evaluated under simulated lunar environmental conditions (1/6 g and vacuum), and possibly on precursor flight missions. Secondly, before outpost emplacement occurs and O_2 production from lunar regolith begins, detailed knowledge of the terrain, local minerals, and potential resources is important for planning and operations at the start of establishing long-term Outpost capabilities. Lastly, while the other two ISRU subtopics are specifically aimed at increasing the fidelity and performance of on-going development activities at a scale appropriate for early lunar Outpost needs, it is recognized that evaluating the feasibility and benefits of other technologies and concepts not ready for insertion into these efforts should be pursued. With these objectives in mind, this subtopic is aimed at providing development support capabilities, sub-scale or precursor hardware that can be evaluated under simulated lunar environmental conditions (1/6 g and/or vacuum), and advanced ISRU concepts not ready for incorporation into current ISRU system laboratory and field test activities. Proposals aimed at the following are of particular interest:

- Computer models to predict excavation-tool soil interaction and flow behavior of lunar regolith under vacuum conditions and 1/6 g for hardware design and performance prediction.
- Vacuum compatible geotechnical instruments to verify soil bin characteristics; instruments that can be mounted and operated from rovers for field testing are also of interest.
- Mineral beneficiation concepts to separate iron oxide-bearing material from bulk regolith; up to 20 kg/hr based on hydrogen reduction. Hardware/concepts need to be designed for compatibility with both 1/6 g flight experiments and ground vacuum experiments.
- Lunar regolith storage and granular flow devices and instruments to evaluate and characterize regolith behavior under 1/6 g flight and ground vacuum experimental conditions.
- Advanced excavation implement concepts and hardware that can utilized to evaluate implement/soil interaction characteristics under 1/6 g flight and ground vacuum conditions.
- Development of specialty lunar simulants for beneficiation and microwave processing of lunar regolith; proposals must estimate production costs per kilogram by end of Phase 1.
- Lunar surface stabilization and regolith binding methods (including but not limited to sintering and melting) for level areas and trench/berm walls; bearing strength and smoothness requirements are not currently established but should be considered in the proposal.
- Processing concepts for production of carbon monoxide, carbon dioxide, and/or water from plastic trash and dried crew solid waste using solar thermal energy; in situ produced oxygen or other reagents/consumables must be identified and quantified; recycling schemes for reagents to minimize consumables should be evaluated.

Phase 1 proposals should demonstrate technical feasibility of the technology and/or subsystem through laboratory validation of critical aspects of the innovation proposed, as well as the design and path toward delivering hardware/subsystems in Phase 2. Hardware/concepts need to be designed for compatibility with both 1/6 g flight experiments and ground vacuum experiments.