Priorities for Demonstrating Lunar ISRU Capabilities

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Introduction

The exploration of space will be easier when local (*in situ*) resources are used to produce items and consumables that otherwise would have to be shipped up through the deep gravity well of Earth. But nothing has ever been produced from raw materials collected anywhere other than Earth. Can it be done reliably? How must terrestrial processes be changed to be viable on the Moon, or on Mars? And how much can utilization of *in situ* resources (ISRU) contribute to the Vision for Space Exploration (VSE) and its potential evolution into the colonization of space?

Mission planners need to know such things. Capabilities and their limitations are most effectively confirmed or denied through demonstrations on-site, so precursor missions should include opportunities to demonstrate ISRU processes. The results must be returned in time for follow-up missions. However, the size, number, and duration of precursor missions are constrained by cost and timing, so hard choices must be made: Which capabilities are so important they must be demonstrated first?

Several assumptions about the generic architecture of the VSE make the ranking of potential ISRU-related demonstrations tractable:

- Human missions will rely upon some ISRU process(es) by 2022+.
    - The process is mission-enhancing, but not necessarily critical-path.
- Robotic landers will go to the moon on two- to three-year intervals, beginning in the next decade.
    - Robotic landers may be mobile or stationary.
    - Landed payload mass about 500 kg, including the power system.
    - Payload mass and power <u>not</u> dedicated totally to ISRU on most missions.
    - Power is solar for missions to sunlit regions, and fuel cell for shadowed regions (lifespan about 2 weeks). Nuclear power is assumed not available.

Given these constraints, the Space Resources Roundtable makes the following recommendations for which ISRU-related technologies should be demonstrated during the lead-up to, and the early stages of, the return to the Moon. After that, ISRU is expected to be an integral part of human and robotic presence on the Moon and in the push onward to Mars.

ISRU Demonstration Priorities

To be useful for realizing the VSE, mission-based demonstrations must satisfy certain criteria:

- Demonstrate sooner rather than later.
- Engage mission architects, whether NASA or industrial.
- Engage the public.
- Meet program needs in terms of launch mass and cost.
- Demonstrate appropriate technology, at an appropriate scale.

- Serve dual uses:
  - Show mission planners what to expect from ISRU, and
  - Prove the technology.
- Require *in situ* lunar demonstration; in other words, cannot be performed on Earth.

ISRU will generate the most "bang for the buck" (or the ton) when it is applied to:

Regolith excavation and transport.	For radiation/micro-meteorite shielding and thermal moderation.
Water production.	From regolith for life support and radiation shielding.
Oxygen production.	From regolith for life support and propulsion.
Fuel production.	From regolith for Earth return, lunar surface/orbital science expeditions, etc.
Energy production, transport, storage, and distribution.	For outpost use.
Structural and **building material** fabrication.	For outpost use.
Spare part, machine, and **tool** production.	For outpost use.
Construction and **site preparation**.	Using *in situ* materials and *in situ* energy.

These capabilities are demonstrable as single steps, as subsystems, and ultimately as end-to-end systems. The sub-capabilities can be divided roughly into the categories of *excavation and materials handling*, *materials processing*, and *manufacturing*. Unrelated technologies, or demonstrations of multiple approaches to the same end, can share the same mission, especially in the proof-of-concept stages where their scales are very small.

The logistics, planning, autonomy, and overall operations aspects of the necessary demonstrations (especially the integrated ones) require discussions outside the scope of this white paper. Nevertheless, they are important, and may be addressed in a future white paper.

Excavation and Materials Handling

The first stage in using any local material is gathering it (aside from resource characterization, which ISRU shares with the scientific study of the Moon). Various samples have been collected, holes drilled, and trenches dug, but that is not enough for mission planning. Can these tasks be done repeatedly and autonomously? For how long, before equipment needs repair? How hard will it be to fix? What production rates can be expected? Can they provide feedstocks of the properties desired?

Several classes of excavation and materials handling capabilities should be demonstrated, in increasing order of complexity:

- Robotic precursor mission – **excavate** 10 kg regolith.

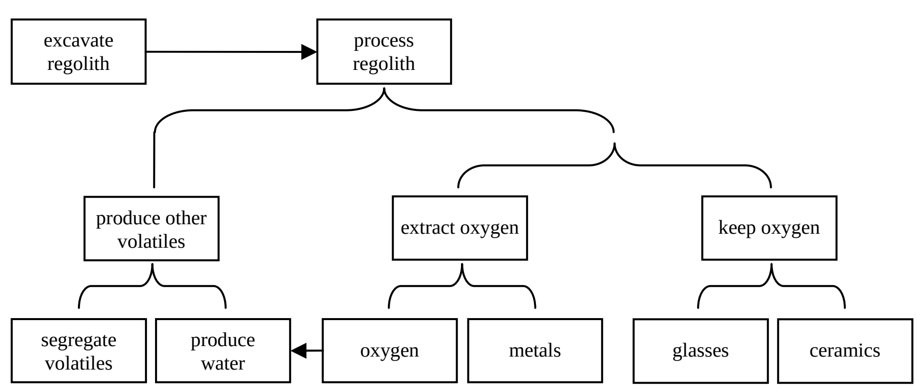
    - Prove concepts for lunar surface excavation and material transport.
    - Validate analytical models.
    - Measure soil mechanics properties pertinent to later needs.
- Excavate regolith for **oxygen production**.
    - Demonstrate equipment performance.
    - Leverage terrestrial deep mining and small-scale mining technologies.
    - Test systems-level design.
- Excavate regolith for lunar **surface preparation**.
    - Large scale manipulation of regolith – berms, habitats, shielding, roads.
    - Test multiple, teamed excavation units for flexible capabilities.
- Excavate polar regolith for **water extraction**.
    - Mobility methodologies into and out of shadowed craters.
    - Different techniques required for regolith-ice mixes than for dry surface regolith than for deeper, compacted regolith.

Materials Processing and Manufacturing

The materials processing and manufacturing categories are grouped at this stage, but as the ISRU concepts are proven, these categories must be broken apart again for appropriate incorporation into mission architectures. In order of performance, early demonstrations should:

- Produce **life support** consumables.
    - Oxygen, water, nitrogen.
    - Increase safety margin.
- Produce **propulsion** consumables.
    - Oxygen, water, nitrogen.
    - Different product specifications than for life support.
    - Increase access to space, and safety margin.
- Generate **power** on-site.
- **Manufacturing**.
    - Metals, ceramics, spare parts.
    - Demonstrate at later stages of planning the return to the Moon.
- Produce **surface construction** materials and capabilities.
    - Demonstrate at later stages of planning the return to the Moon.

One possible integrated lunar ISRU demonstration mission.



Conclusion

"Living off the land" is a compelling strategy for the VSE. But it has never been done anywhere other than Earth. The ISRU demonstration missions outlined below will give mission architects knowledge they need to incorporate ISRU in their planning.

The time lag between missions using each other's results prompts parallel missions, especially in the early stages of the VSE. Later missions take advantage of earlier mission findings.

• ***Mission 1a – equator*** o Scaleable oxygen production o Scaleable digging for feedstock o Characterize waste products o Study *in situ* volatiles	• ***Mission 1b – shadowed polar crater*** o Scaleable oxygen production o Scaleable digging for feedstock o Characterize waste products o Study *in situ* volatiles

- ***Mission 2***
  - Longer-duration digging for feedstock
  - Extract volatiles
  - Produce power

- ***Mission 3***
  - Integrated oxygen production at larger scale, including utilization of byproducts
  - And/or extract water (complexity same as Mission 1)

- ***Mission 4***
  - Expanded power production

- ***Mission 5***
  - Pilot/sub-pilot scale extraction or production, driven by results of Missions 3 and/or 4

These missions are doable within current time and cost constraints – indeed, they may already be planned for other purposes – and they can generate critical data for mission planners.

Background

These ISRU demonstration priorities were developed during Space Resources Roundtable VIII, the eighth annual meeting of the Space Resources Roundtable, Inc. (SRR), 31 Oct-2 Nov 2006. Joining individuals from the space exploration community, the financial sector, and the mining and minerals industries, the SRR discusses issues related to the sustainable utilization of lunar, asteroidal, and martian resources in support of extra-terrestrial human and robotic activities. Our website is www.ISRUinfo.com.