FACTORS AFFECTING ROBOTIC MAPPING OF ICE RESOURCES IN PERMANENTLY SHADOWED REGIONS. S. Withee[1], Lunar Surface Innovation Consortium (LSIC) Extreme Access PNT subgroup participants, [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, Maryland 20723, sarah.withee@jhuapl.edu.

Introduction: Where should an ISRU pilot plant on the Moon be located? Remote sensing data [1] can help narrow the pool of potential candidates, but remote sensing alone lacks sufficient resolution to determine precise location, quantity, and quality of resources. Eventually a robotic resource prospecting mission will be required. In early 2022, the Position, Navigation, and Timing (PNT) subgroup of LSIC brought together lunar scientists and engineers for two meetings devoted to exploration of permanently shadowed regions (PSR) and robotic mapping of ice resources in PSRs. The goal was to identify PNT technologies needed to enable such a mission. Here, we summarize initial recommendations and findings.

Description of the scenarios: The group discussed resource prospecting to support two different scales of ISRU: a pilot plant scenario provided by [2], and a full-scale ISRU setup as described in [3]. For the pilot plant scenario, the parameters were:

- A market for lunar propellant of 10s of tons per year, requiring mining of 1.67 cubic meters of regolith per hour, and
- A production facility the size of an office desk, with a mass budget of 800-900 kg for equipment including a nuclear power source, processing plant, two rovers, and a tool shed.

For the full-scale ISRU setup, the parameters were:

- ISRU base must produce 160,000 kg propellant per year to support four roundtrips flights per year from the Gateway to the ISRU base,
- Excavation of hundreds of thousands of kilograms of regolith per day, and
- The base will be sited in either a PSR or a partially lit region on the border of a PSR.

Group Findings:

*Influence of resource location on mobility type***:** Ice resources may be located in crater walls, in which case it is likely to be "slumped" with ice sandwiched between methanol and ethylene. [2] Resources may also be located on the floor of the PSR. To access ice resources located in steep crater walls, hopping or tethered robotic systems may make more sense than a traditional wheeled robot. For a tethered system, the ideal would be to have both tethered and untethered operation modes to enable ice prospecting along slopes and floors of PSRs. Localization, and, therefore mapping, with such a system is likely to present significant challenges due to slippage. Technologies to support these functions will need to be developed. Due to communications issues (some areas may not have direct-to-earth communications for up to 14 earth days at a time) [4], ideally these calculations would be performed by the robot, rather than offloading processing to mission operations on Earth.

*Navigation sensors***:** Most terrestrial robotic systems rely on visual sensors such as LIDAR or cameras, while Martian rovers are heavily dependent on cameras. To operate in a PSR, visual sensing systems would need significant modification to size, weight, and power, as well as dust mitigation systems. Automotive-type radar, which has been used successfully in research applications in terrestrial robotics [5], would require radiation and thermal testing to determine if it could survive lunar conditions.

Extent of territory to survey: For drill spacing, [2] recommended a 100 m by 100 m grid. Asteroid impacts may create a "swiss cheese effect" in water ice placement, leading to areas with a lot of water ice adjacent to areas with no ice. Scientists and mission operations teams will need to conduct statistical and geological analysis to guide robot decision making on when to abandon an area and begin prospecting elsewhere.

*Multi-robot teams***:** Multi-robot teams will enable efficient prospecting of multiple sites since multiple robots can cover more territory more quickly than a single robot. This will require development not only of greater robotic autonomy, but algorithms for communication and cooperative mapmaking between teams of robots. [6]

Conclusion: robotic lunar resource prospecting will require multiple mobility types, significant modifications to navigation sensors, increased robotic autonomy, and new approaches to mission conops.

References: [1] Bickel, V.T, Moseley, B., Lopez-Francos, Shirley, M. (2021) *Nature* [2] Plate, J., personal conversation, [3] Austin, A., Sherwood, B. et al IAC (2019), [4] Bryant, S., SpaceOps (2010), [5] Hong, Z., Petillot, Y., Wallace, A., Wang, S. IROS (2020), [6] Boroson, E. ICRA (2019)