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Introduction: In 2019 NASA announced plans to return humans to the Moon by 2024 and reach a sustainable lunar presence by 2028. Utilization of lunar resources to produce mission consumables, or In-Situ Resource Utilization (ISRU), is a key part of sustainable surface operations. Water, which has been identified at the lunar polar regions (Figure 1), would provide both fuel and oxygen for refueling vehicles as well as life support consumables. However, the nature and extent of this resource is not well understood. Identification of the presence of water alone is not adequate for ISRU architecture planning and engineering design.

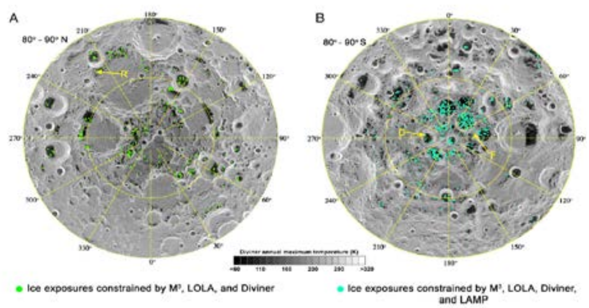

Figure 1. Inferred distribution of lunar polar ice at the north pole (A) and south pole (B) based on data from M^3, LOLA, Diviner, and LAMP (figure from [1]).

Both the ISRU community and the lunar science community require further measurements targeting lunar water. While measurement requirements for the different communities are significantly overlapping, they are not fully inclusive (Figure 2). Therefore, in mid-2019 NASA initiated the Lunar Water ISRU Measurement Study (LWIMS). The goal of this study is to assess and define the type, amount, and fidelity of the information, and measurements needed, to select mining locations for lunar water ISRU and define requirements for ISRU hardware development and architectures (mining operations, hardware emplacement, concept of operations). LWIMS was spear-headed by the NASA ISRU Systems Capability Leadership Team with support from all three mission directorates. It consists of a small group of core members with expertise in ISRU, lunar science, and instrumentation/measurement techniques. While this core team is limited to NASA and JPL personnel, broader input is anticipated going forward.

Study Objectives:

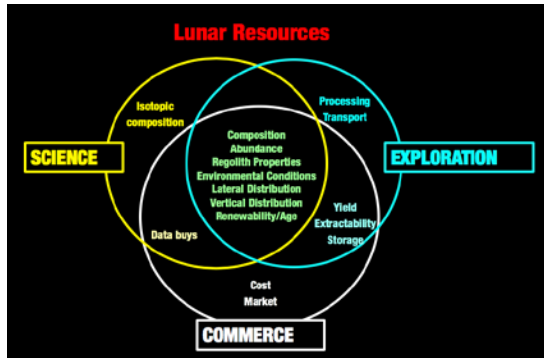

Figure 2. Diagram illustrating the overlaps in information needs of different stakeholders for lunar resources including lunar volatile resources (figure from [2]).

1. <u>Identify the measurement knowledge gaps that need to be addressed to evaluate polar water as a mineable ISRU resource.</u> This includes information that feeds into production estimates for ISRU, such as the concentration and form of the water, as well as the distribution (depth and lateral) and extent of the water which will govern potential excavation/collection techniques. Geotechnical, or mechanical, properties of the regolith also significantly impact ISRU in terms of excavation methods, mobility options and hardware emplacement. While the former has some overlap with science objectives, the latter generally does not. This objective focuses on identifying the information needed, as well as the range and accuracy of the measurements required for ISRU development. The information will be prioritized to drive hardware and architecture decisions, recognizing that more specific information may be needed once these decisions have been made.

2. <u>Identify what measurement needs overlap with the science community objectives.</u> LWIMS is leveraging the work done by the LEAG-ISECG (Lunar Exploration Analysis Group-International Space Exploration Coordination Group) V-SAT 2 (Volatiles Specific Action Team 2) [3], and the more recent LEAG VVMSAT (Volatiles Volatile Viability Measurement Special Action Team), similar studies charted by the Science Mission Directorate science community which developed a list of measurement needs for lunar water and volatiles. Overlapping measurements objectives from this study are being identified and flagged. Likewise the comprehensive list of measurement techniques and instrumentation identified during this study is being leveraged.

3. Identify the number and methodology of measurements needed to define a mineable 'reserve' of water. The difference between a potential resource and a reserve is the confidence level in the resource characterization. Hardware design, architectures, and infrastructure emplacement all require that adequate resource will be accessible to meet the production needs. Uncertainty is reduced by increasing sample size (number of measurements). Measurement methodology refers to how to choose the appropriate sample set: both the types of measurement and frequency/distribution of those measurements. Traditional mining definitions of how to define a reserve, while considered, must be modified to account for the shear difficulty in obtaining information as compared to terrestrial capabilities.

4. Identify what instruments or suite of instruments, and what sequence of missions/instruments could be used to obtain the necessary measurements. This includes identifying the state of the art of currently available instruments that could achieve the measurement objectives. Measurements will be prioritized and compared against which instruments, or set of instruments could accomplish the most. Consideration will be given for current mission plans, both instruments already manifested as well as planned upcoming flight opportunities (e.g. Commercial Lunar Payload Services (CLPS) opportunities). This is expected to be a broad set of recommendations, with a variety of options traded against potential risk to ISRU decisions.

Study approach: Thus far LWIMS has been in the data gathering phase. The team has divided into three subteam areas, corresponding to the objectives. Subteam 1 is focused on ISRU engineering aspects. The goal of this group is defining what specific measurements are needed to select and design ISRU systems and architectures; as per objective #1. ISRU system models are being used to understand the sensitivity of the measurements and bound the range and accuracy needed. Subteam 2 is evaluating the information needed to do predictive modeling of the water formation and distribution. This team focuses on objective #3; using discrete measurement data to define the extent of the resource and increase confidence in the reserve. Finally, subteam 3 is evaluating measurement techniques and instrumentation. This team's primary focus is objective #4. Objective #2 is considered during the work of all three subteams, especially subteams 2 and 3.

As of the end of calendar 2019, the LWIMS subteams have completed their preliminary data gathering. Initial findings include critical parameter definitions. For example, the minimum regolith water concentration needed for ISRU use is currently set at 6wt% ± 5wt%. Below this value, the mass and power of an ISRU system does not trade well, particularly when comparing against ISRU systems that target oxygen from mineral oxides. Likewise water resources below 1m do not trade well, so the water distribution is needed in the top 1m to a 10cm accuracy. A full list of parameters has been developed an is being refined. The team considered four potential water sources; pyroclastic deposits, deep bulk water (>1 m depth), surface "frost", and shallow bulk water (<1 m depth). The LWIMS team has decided to focus on shallow bulk polar water to have the best potential to exceed ISRU engineering thresholds. The team has agreed to approach measurement recommendations in terms of an overall exploration plan, where risk and measurement uncertainty is balanced against instrument suites and number/type of missions. The larger team is now working to integrate the initial subteam findings, and other findings and data products, to form recommendations. The preliminary results of this synthesis will be available for presentation and feedback at LPSC.

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