ISRU Potential Water Mine Site Preliminary Evaluation for NASA Artemis Campaign . J. E. Kleinhenz[1] and G. B. Sanders[2], [1]NASA Glenn Research Center, Cleveland OH, 44135 [2]NASA Johnson Space Center, Houston, TX, 77058.

Introduction: The NASA Artemis Campaign aims to return to the Moon to maintain a sustainable presence [1], and In-Situ Resource Utilization (ISRU) is a key part of sustainability. The regions of interest for the Artemis campaign, as outlined in [1] and shown in Fig 1, are at Lunar the South Pole where water ice has been identified. The potential use of this water, and oxygen/hydrogen, for NASA and commercial applications such as refueling vehicles and power systems, and supplying life support consumables is one of the considerations the NASA Artemis team is using to evaluate these regions.

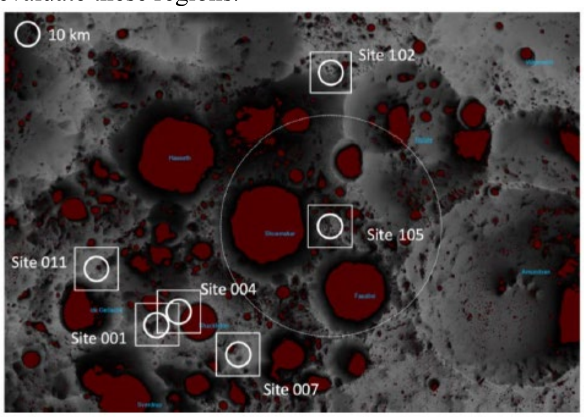

Figure 1. Artemis regions of interest from [1].

As such, analyses are underway to evaluate the ISRU ice mining potential of these regions of interest. To do so, a set of ground rules for ISRU sites have been developed to align with current assumptions for customer needs, hardware capabilities, initially limited infrastructure, and lunar environments/terrain. The customer could be a lander, habitat, or other asset that makes use of ISRU product within the Artemis architecture. At this time, four of the regions of influence (the 'western' cluster in Fig. 1) have undergone preliminary ISRU evaluation.

It should be noted that variety of other efforts have done similar evaluations of this nature with different assumptions or viewpoints, such as the most recent [2]. However, most evaluations focus on large permanently shadowed regions (PSRs) and craters due to orbital data resolution limitations, whereas early ice mining operations will likely occur in much smaller PSRs.

Assumptions : The ISRU architecture assumed for this evaluation is as published in [3], which necessitates two ISRU locations, a mine site where icy regolith is mined and where water is extracted, and a propellant production plant (PPP) where water is processed into mission consumables (the initial consumable target is propellant).

The mine site is assumed to be in a permanently shadowed region where shallow ice stability is possible. The ISRU baseline architecture requires water within the top 1 m, so regions where deeper (non-surface) water may be options depending on water extraction technology used. These are identified as Ice Stability Regions (ISRs) in the analysis, but were not evaluated as mine sites. At this time, only surface stabile PSR areas were used to increase confidence that ice is present. The mine site should support multiple years of resource extraction at metric tons a year. As a rough estimate, assuming ~3% bulk water content, a production cycle of 10mT of O2 per year from pit mines 30m square and a mine depth of 0.3m (not including overburden); a 1 km diameter ice region (PSR) could support 1000 production cycles.

The PPP site is located where there is high illumination so that solar power is an option for high power processes such as electrolysis [3]. This also ensures that the ISRU product is more readily accessible to customers, who typically have similar high illumination requirements. However, this analysis did not explicitly consider requirements for power architectures such as terrain requirements for power beaming, fission power, or cable routing.

Two traverse legs must be considered for this ISRU architecture; delivering water from the mine to the PPP (leg 1) and delivering the product (propellant) from the PPP to the customer (leg 2). Fully mobile assets are assumed to service these legs with no path preparation (e.g. roads) and using the most direct route possible. Other considerations such as path preparation, switchbacks, or alternate resource/product transfer methods such as pipes, gondolas, etc, will alter the site evaluation. The distance and slopes of these traverse legs were the key considerations in the analysis and are outlined in Table 1. Detailed path finding that includes finer scale hazard avoidance (e.g. rock abundance) is not covered here.

Another key factor not currently included in this analysis is earth visibility. The communications architecture is still being defined. For this study, direct to earth communication is not assumed to be required at all times for all locations.

Ground Rules: Table 1 outlines the ground rules used in this analysis. Traverse distances and slopes are based on current projected mobility capability/availably. However, an expanded distance criteria was evaluated to see how additional capabilities may influence the results. This evaluation was performed using imported datasets from LROC Quickmap [4]; LOLA 60m Sun Visibility and 240mpp Ice Stability maps, as well as high resolution (5mpp) digital elevation models (DEMs) from [5] which provided the slope and distance information.

Table 1. Ground rules for ISRU water site evaluation. Leg 1 is mine to PPP, leg to is PPP to customer.

Parameter	Baseline	Expanded
Traverse Leg 1	5 km	10 km
Traverse Leg 2	5 km	10 km
Traverse Total	10 km	20 km
Slopes	≤ 20 deg	
PSR size	> 1 km diameter (multiple pixels in the 240mpp ice stability product)	
Ice Stability	Surface ice stability corresponding to PSR region	
Sun Visibility	> 75% visibility	

Site Evaluations: The analysis of these regions is on-going, but four sites have undergone preliminary evaluation at the time of this publication. To help orient these sites, they are referred to the nearest large crater in addition to the numbers in figure 1: Site 001 "Shackleton Connecting Ridge", Site 011 "De Gerlache", Site 007 "Slater", and Site 004 "Shackleton Rim". Site 102 "Nobile" is currently in work and could be included in the presentation if ready. For each region, there is a cluster of highly illuminated sites as identified by [6]. The customer asset is assumed to be located at the highest ranked surface illuminated site within a cluster of points. The location of the PPP sites within the high sun visibility regions, and the location of the mine site within the ice stability region, are approximate. More detailed evaluations will be needed to optimize the best site coordinates within these areas.

It is difficult to provide a good summary of the evaluated areas without extensive figures and images. The list below is a top level overview and the readers are encouraged to reference the associated presentation for more information. In the following, a 'solution' refers to the location of PPP site with a mine site along with traverse legs that meet criteria.

Site 007; Slater: Slater provides one solution that meets all baseline criteria, but has limited alternative options for mine sites in proximity. Slopes in regions are generally favorable, and can come close to meeting even a <15 deg path criteria. Expanding criteria to 10 km per travel leg does not add much value. It would be necessary to go to 15 km or more for at least one leg to reach another PSR.

Site 011; De Gerlache: De Gerlache has more PSRs in the area and quite a few ISRs (some very near PPP locations). However, slopes in the region tend to require longer traverses for pathfinding and generally all PSR legs (leg 1) have high average slopes and would hit 20 deg at least for a portion of travel. No options fully meet baseline criteria, but one option is close and with finer pathfinding to avoid local high slopes, one PSR is acceptable. Traverse distance criteria would have to be ~15km to open up other options.

Site 001; Shackleton Connecting Ridge: There are multiple PPP and PSR options in the area with reasonable slope paths. There are 4 viable PSRs in the area, though all but one would require at least slightly expanded distance criteria (by 1-2 km) to do path finding around the higher slopes area to get off the connecting ridge to the 'north'. There is one clear 'best' option for PSR that full meets criteria and it is the same one used in [3].

Site 004: Shackleton Rim: There is ample illumination along the rim for PPP options, though only one PSR presents a solution; the same PSR that worked for Site 001. However this PSR could now be accessed from two directions. With expanded criteria, two more PSRs are possible. However, all traverses for Site 004 require careful path finding due to high slopes at the transition between Shackleton Ridge and Rim. (Note: Shackleton itself is not viable due to high slopes).

Conclusions: All of the sites presented have some options for ISRU ice mining. While some ground rule criteria are not fully met, it should be noted that the coordinates selected for this analysis were preliminary, so the distances and paths selected will shift with further analysis. It should also be noted that the PSRs selected for mine sites are smaller PSRs (a few kilometers). This is typically required to meet the baseline proximity criteria for near term missions. (Namely the proximity to highly illuminated area required for PPP and customer assets). Few large craters, such as those evaluated in [2], (except parts of DeGerlache) are able to meet the criteria due to slopes and/or traverse distances specified in the ground rules. The confidence of any of these mine sites as an ISRU water 'reserve' is not high due to limited data sets. This analysis should be considered as a way to focus exploration and reconnaissance efforts.

References:

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