ENGINEERING ANALYSIS OF CANDIDATE ORE CASES FOR ISRU WATER PRODUCTION ON MARS: THE M-WIP STUDY, PART 2.

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Introduction: The Mars Water ISRU Planning (M-WIP) Study was undertaken in response to the first Human Landing Site Selection Workshop (HLS[2]), held October 2015, at which a number of candidate Mars Exploration Zones were proposed. (see http://mars.nasa.gov/multimedia/webcasts/human-landing-site-selection-workshops/)

This study began with a survey of candidate resource classes proposed at the HLS[2] workshop, and developed candidate engineering approaches for the production of water from each. Four primary reference cases were defined. In each case, a preliminary engineering sizing analysis was conducted for the ore hypothesized in order to produce water adequate to be processed into a fuel load (methane plus liquid oxygen) for NASA's current reference architecture for human exploration of Mars [1,2].

Candidate Ores and Key Characteristics: The M-WIP Study focused on four cases, which represent the most important of the potential water sources available on Mars: A) Subsurface Ice, B) Polyhydrated sulfate Minerals, C) Phyllosilicate (Clay) Mineral Deposits, and D) Regolith – representative of the typical materials present at effectively any landing site that might be selected. For subsurface ice, two extraction strategies were considered: A1) "Open pit" surface mining or A2) Subsurface ice extraction by drilling down through the overburden and melting/subliming the ice before recapturing the vapor via a cold trap at the surface. For cases B, C, and D, the mining operation is assumed to involve collection of naturally available granular material at the surface, transportation to a central processing facility (co-located with a large power source) and heating the material to release water (Fig. 1).

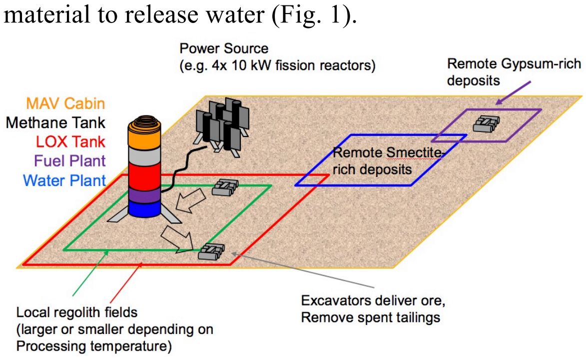

Fig. 1. Concept of Operations of collecting feedstock and extracting water to produce Oxygen and Methane on Mars.

Based on the need for 16 metric tons (mt) of H2O and 19mt of CO2 per 480 sols to create 7mt of CH4 and 28mt of O2 (7mt CH4 and 23mt O2 for the Mars Ascent Vehicle), we evaluated the required feedstock and power required to produce this from hypothetical reserves in each of the four cases. For each case, in order to be specific enough with our calculations, a mineral content was assumed—this allows the corresponding processing temperature at which the desired water content would be released to be determined [3]. Power use for excavation, transportation and processing was added for the needed amounts of feedstock. The technology for buried ice extraction (case A) is much less mature and thus no good estimate could be made at this time. Fig. 2 shows the resulting numbers for cases B, C and D. Case D has two subcases for different processing temperatures (150 C and 300 C respectively). It was found that a natural concentration of gypsum (a reference mineral for Case B) would yield the required amount of water for the least amount excavated material (186 mt) and power. In addition, the higher processing temperature for case D did not yield any energy advantage (reduced amount of feedstock required was offset by the increased energy needed).

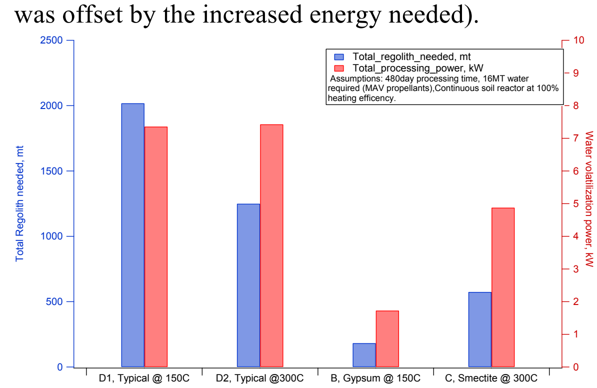

Fig. 2. Mass of feedstock and processing power needed to extract water from the feedstock for the four resource classes identified.

Excavation of Granular Deposits: The excavator chosen to do an initial baseline study is the Rassor 2.0 [4], developed at Kennedy Space Center Swamp-Works. This excavator was chosen because we have data for its relevant performance specifications, such as traverse speed, excavation speed and depth, storage volume, excavator mass, and power use. With an excavation depth of 5 cm, the required mass shown on Fig. 2 has been translated into an area to excavate (one pass depth only). The results vary from 1,860 m^2 to 20,513 m^2 for cases B to D2 respectively as shown in Fig 3.

	Mass (kg)	Volume (@ 2t/m^3)	Area (at 0.05 m depth)	Football Fields (@ 5400 m^2)
Gypsum	186,047	93	1,860	0.3
Smectite	583,942	292	5,839	1.1
Regolith@300	1,269,841	635	12,698	2.4
Regolith@150	2,051,282	1,026	20,513	3.8

Fig. 3. Comparison of area to excavate for cases B to D2.

Distance to Resource Deposit: Assuming Rassor 2.0 traverse and excavation speeds, as well as reasonable models for ore excavation, ore transport, and the removal of spent tailings, it was concluded that a single excavator with the size and capabilities of Rassor 2.0 could excavate sufficient material for cases B (up to 1,200 m distance), and C (up to 120 m distance). For cases D1 and D2, 3 and 2 excavators would be required respectively at a distance of 100 m. One concern is the number of trips required by a single excavator (>2,000 for case B and >25,000 for Case D1). Potential solutions are larger excavators or a separate hauling robot or processing on-site and only transporting the water. None of these trade-offs were considered here and would require further study.

Buried Ice Deposits: Despite low TRL, we did carry out some preliminary analysis. If an open pit excavation strategy is used, a significant amount of material would have to be removed before reaching the ice deposit. As shown in Fig. 4, the volume of overburden removal at 2.2m depth exceeds the volume of gypsum granular materials (in our assumed Case B) and 6.4m depth for the worst regolith D1 case.

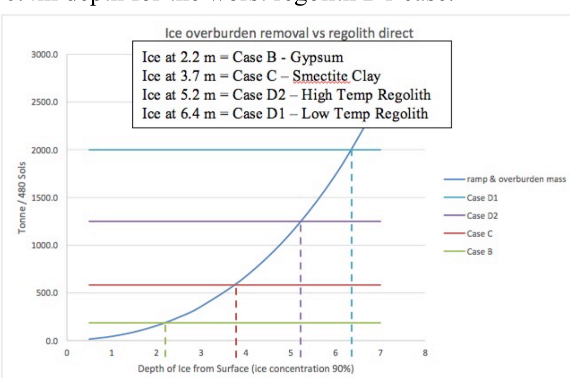

Fig. 4. Comparison of mass of overburden removal for case A to total required mass for cases B, C and D.

An additional complication with this approach is excavating the overburden which might contain large rocks and/or ice-cemented regolith. Also, the thermal and pressure equilibrium disturbance may lead to the loss of large quantities due to sublimation over time. An alternative approach to open pit methods is shown in Fig. 5. This would require much less removal of overburden, and may allow improved control of the thermal and pressure environment with regards to the ice.

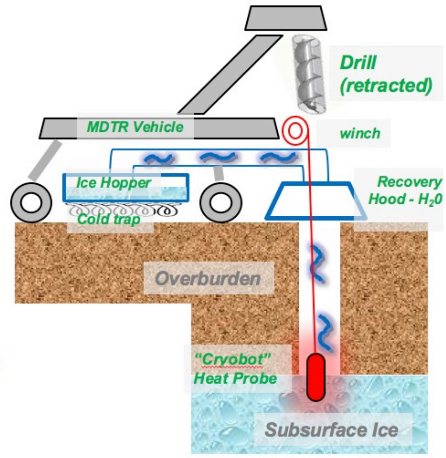

Fig. 5. A possible down-hole ice extraction method

Conclusions: A reasonable argument can be made that small excavators (<100 kg class) could excavate the required amount of feedstock to produce 16 mt of water in 480 sols, from any of several different classes of potential ore deposits. Although we don't yet know the configurations, grades, sizes, etc. of water deposits available on Mars to be discovered, all other things being equal, among the granular material group of options, it would be most advantageous to discover a granular gypsum deposit. However, we do not yet have a good feel for how subsurface ice would compare to any of the granular materials cases. More trade studies are required to determine the optimal solution regarding mass, power and complexity.

References:

[1] Drake, B. G., ed., 2009a, NASA Special Publication -2009-566, 100 p. [2] Drake, B. G., ed., 2009b, NASA Special Publication -2009-566 Addendum, 406 p. [3] Abbud-Madrid, A., Beaty, D.W., Boucher, D., Bussey, B., Davis R., Gertsch L., Hays, L.E., Kleinhenz, J., Meyer, M.A., Moats, M., Mueller, R.P., Paz, A., Suzuki, N., van Susante, P., Whetsel, C., Zbinden, E.A., 2016, Report of the Mars Water In-Situ Resource Utilization (ISRU) Planning (M-WIP) Study; 90 p, posted April, 2016 at http://mepag.nasa.gov/reports/Mars_Water_ISRU_Study.pptx [4] Mueller, R.P., Smith, J.D., Schuler, J.M, Nick, A.J., Gelino, N.J., Leucht, K.W., Townsend, I.I. and Dokos, A.G., Regolith Advanced Surface Systems Operations Robot (RASSOR) 2.0, Proceedings of ASCE Earth & Space 2016, ASCE