THE IMPACT OF LUNAR POLAR VOLATILES ON IN-SITU RESOURCE UTILIZATION.

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Introduction: The ability to extract and utilize resources at the site of exploration, known as In-Situ Resource Utilization or ISRU, can significantly reduce the launch mass and cost of robotic and human exploration missions while also reducing risk if properly considered early in the mission development phase. Based on resource data from the Apollo missions, NASA has focused to date on the extraction of oxygen, metals, and solar wind volatiles. Oxygen can be utilized for propulsion and life support, metals can be used for fabrication of spare parts, and solar wind implanted volatiles can supplement propellant and life support consumable production activities. The Lunar Prospector and Clementine missions of the '90's brought to light the existence of higher concentrations of hydrogen-bearing materials (possibly water/ice) at the lunar poles. However, these resources have not been readily considered in human exploration plans due to the uncertainty in the form and distribution of these resources as well as the terrain and environment in which these resources would be found. Recent findings from the Chandrayaan-1, Lunar Reconnaissance Orbiter (LRO), and Lunar Crater Observation and Sensing Satellite (LCROSS) missions have provided greater understanding of the resources, environment, and terrain at the polar regions of the Moon to the extent that new possibilities on harnessing and utilizing these resources can be pursued.

Recent Lunar Resource Findings [1]: The Moon Mineralogy Mapper (M3) instrument on Chandrayaan found that hydroxyls/water at concentrations up to 1% are possible on the surface of the Moon in the polar region, but that this is transitory. The neutron spectrometer, radiometer, and laser altimeter on the LRO satellite has provided information on hydrogen concentrations, surface temperatures, and surface topography such that locations that have high concentrations of hydrogen, have long periods of cold temperature near sunlit regions, and have reasonable terrain for roving and direct communication to Earth are possible. The mini-SAR on LRO has identified areas of potential ice sheets in permanently shadowed craters. Lastly and most importantly, the LCROSS mission identified large amounts of volatiles in the regolith in Cabeus crater (up to 20% by mass) with large concentrations of carbon monoxide, water, and hydrogen, and lower concentrations of ammonia, hydrogen sulfide, carbon dioxide, and other hydrocarbons such as methane, ethane, and methanol.

Impact on Recent Findings on ISRU: The volatiles found at the lunar poles opens up resource extraction and production possibilities that had not previously been considered in defining lunar exploration architectures. The ability to readily acquire water/hydrogen on the Moon can significantly impact transportation and life support system development and deployment by enabling reusable landers/hoppers and cis-lunar transportation systems, reducing the complexity of life support systems, providing radiation shielding, and enabling large scale food production. However, the other volatiles found by LCROSS are equally important. Ammonia can be used as a coolant for thermal control systems, as a fuel for electric propulsion and fuel cell applications, and the production of fertilizers. Carbon monoxide/dioxide and hydrocarbon volatiles can provide a ready source of carbon for fuel, plastic, and food precursor production.

The first step in incorporating these newly identified polar volatiles into future human missions is to perform surface prospecting to not only identify the form, concentration, and distribution of these volatiles, but also to determine the amount of energy to excavate and extract the volatiles and better understand the environment in which future ISRU systems must operation. A joint exploration/science mission to 'ground truth' the volatiles at the lunar poles while providing the engineering data to design subsequent mission hardware is highly recommended. While work proceeds on developing a resource prospecting experiment, further work on excavation, regolith heating, and volatile collection and separation must be pursued. To date, work on these technologies has assumed operation in sunlit areas for oxygen extraction from regolith, so design and material considerations for colder conditions and potentially harder/bound regolith must be considered. The large fraction of water/ice in the regolith opens up possibilities of utilizing microwave heating devices, and while power beaming is much less efficient than other forms of power generation and storage, it may make long-term operation in shadowed regions practical in comparison to other power system options.

References: [1] Information obtained directly from Dr Rick Elphic, Dr. Larry Taylor, Dr. Tony Colprete, and Dr. Paul Spudis.