EARLY IN-SITU RESOURCE UTILIZATION (ISRU) LEADING TO ROBUST SAMPLE RETURN AND HUMAN EXPLORATION MISSIONS. G. B. Sanders[1], M. A. Interbartolo[1], W. E. Larson[2], R. P. Mueller[2], A.C. Muscatello[2], [1]NASA Johnson Space Center, Houston, TX, [2]NASA Kennedy Space Center, Florida

Introduction: In 1978, a ground breaking paper was published proposing the concept of Mars in-situ propellant production (ISPP) based on Viking atmosphere data entitled, "Feasibility of Rocket Propellant Production on Mars"[1]. This paper discussed how ascent propellants could be manufactured on the Mars surface from carbon dioxide (CO_2) collected from the atmosphere to reduce launch mass. Since then, numerous studies have been performed examining how incorporating Mars In-Situ Resource Utilization (ISRU) systems into robotic and human exploration missions impacts mission mass, cost, and risk. In all cases, significant mission mass, cost, and risk reductions were found to be possible.

Overview of Mars ISRU Technologies and Systems: In-Situ Resource Utilization involves the extraction and processing of mission destination resources, both natural and discarded, into useful products and services. Most mission studies involving ISRU focus on the ability to extract and make propellants, life support consumables, fuel cell reagents, and radiation shielding from local resources.

Because the knowledge of water on the surface of Mars was solely based on information from the Viking missions until data from Mars Odyssey and subsequent Mars robotic missions became available, robotic Mars sample return and human mission studies until the early 2000's that examined using ISRU were limited to the investigation of processing Mars atmospheric resources into propellants and life support consumables needed for Mars ascent propulsion and long term surface exploration. Without a viable water or hydrogen source on Mars, two propellant production approaches were considered: 1) Make only oxygen (O_2) from Mars atmospheric CO_2 and bring the fuel from Earth, or 2) Make both oxygen and fuel using Mars atmospheric CO_2 and hydrogen (H_2) brought from Earth. With increased knowledge of the potential availability of water on Mars, a third propellant production approach has been added, 3) Make both oxygen and fuel using Mars atmospheric CO_2 and water (H_2O) from hydrated soils or subsurface ice on Mars.

Producing propellants on Mars is a two-step process. Step 1: Collect and separate CO_2 from the Mars atmosphere. Step 2: Process the CO_2 to make O_2 and possibly fuel (methane: CH_4). While the Mars atmosphere is ~95% CO_2, it is at a very low pressure (6 to 10 torr). For Step 1, to collect CO_2 and raise the pressure to at least 760 torr (14.7 psi) three technologies have been considered separately or in combination: mechanical pumps, CO_2 freezing, and rapid-cycle CO_2 adsorption/desorption. For Step 2, there are several processes that have been examined including CO_2 electrolysis via solid oxide or ionic liquid cell ($2CO_2 \rightarrow O_2 + 2CO$), Sabatier ($CO_2 + 4H_2 \rightarrow 2H_2O + CH_4$), Reverse Water Gas Shift ($CO_2 + H_2 \rightarrow H_2O + CO$), and Bosch ($CO_2 + 2H_2 \rightarrow 2H_2O + C$). All reactions besides CO_2 electrolysis require additional H_2/H_2O processing reactions.

Benefit of Mars ISRU on Mars Sample Return and Human Missions: In the 1990's and early 2000's a number of studies were performed examining Mars Sample Return (MSR) by NASA and Lockheed Martin Astronautics (LMA) and human Mars Design Reference Missions (DRMs) by NASA with in-situ production of propellants from Mars atmospheric CO_2. For MSR missions, both Direct Earth Return (DER) and Mars Orbit Rendezvous (MOR) missions were studied, while human Mars DRMs only considered MOR concepts. In all cases, launch mass was reduced by at least 25% with ISRU propellant production, and in the case of MSR missions, a larger sample mass could be returned to Earth. In 2001, an MSR DER study by NASA utilizing ISRU with MOR to an Earth Return Vehicle (ERV) that utilized electric propulsion was able to return samples to low Earth orbit at a launch payload mass of less than 4,000 kg and with~75% mission success confidence compared to much heavier missions with lower mission success [2]. In 2007, Mars DRM 5.0 for the first time examined using ISRU for crew ascent using both Mars atmospheric CO_2 and surface water. Results from the study showed that making oxygen alone and bringing fuel from Earth (Approach 1) would reduce the lander mass by over 25 MT, and that making both oxygen and methane fuel with Mars CO_2 and water from the Mars soil (Approach 3) at only 3% H_2O by weight would further reduce the lander mass by another 5 MT while enabling other mission benefits for life support, fuel cell power, and radiation shielding [3].

Need for Early ISRU Demonstration: While Mars ISRU can provide significant benefits in reducing mass, cost, and risk, mission planners are hesitant to incorporate ISRU into missions until it has been adequately tested and demonstrated. For incorporation into human Mars exploration missions, a prerequisite to eliminating risk has been the assumption that a precursor mission with ISRU performing similar mission critical operations, such as making and storing propellants for a MSR or surface hopper mission, at similar surface mission durations and at a production rate scalable to the human mission would be performed 6 to 8 years before the preliminary design review (PDR) of the crewed mission. Performing a Mars ISRU demonstration in 2018 could enable a robust, low mass MSR mission as the precursor to incorporation into future human Mars mission architectures. As stated in a recent presentation by Steve Squyres on the Planetary Decadal Survey, "New Mars missions that lead directly to sample return have high priority."[4].

Mars ISRU is Synergistic with Science, Human Exploration, and Office of Chief Technology Objectives: To perform a successful demonstration of Mars ISRU atmospheric and/or soil processing, not only does the hardware need to be tested under applicable mission environments, but the characteristics and collection of the resource itself need to be understood and measured. Collection of Mars CO_2 for ISRU requires sample collection of the Mars atmosphere as well as filtration before processing. This process would allow atmospheric constituent and dust samples to be collected and analyzed including use of a dust particle counter. Processing Mars soil to extract water requires acquisition of the soil, heating the soil at different temperatures to determine energy/quantity release data, and analysis of the soil and constituents in the water before cleaning, Data from ISRU atmospheric and soil collection and processing measurements supports science objectives as well as engineering data for subsequent design efforts.

Technologies for Mars atmospheric and soil processing systems are synergistic with life support, trash processing, and fuel cell reactant regeneration. Furthermore, work being performed to acquire and process surface/subsurface samples to characterize water/ice and other volatiles at the lunar poles is synergistic with Mars ISRU and lunar science objectives. Discussions have started between personnel in NASA's Human Exploration and Operation (HEOMD) and Science Mission Directorate (SMD) to examine combining prototype lunar polar ice/volatile experiment (RESOLVE [5]) and Mars ISRU hardware and concepts with astrobiology and subsurface soil collection technologies. Since development of RESOLVE is supported by NASA's Human Exploration and Operation Mission Directorate (HEOMD), Office of Chief Technology (OCT), and the Canadian Space Agency, and Mars astrobiology and sample acquisition hardware is under development by SMD, coordination of objectives and funding is possible for Mars ISRU.

Potential ISRU Demonstrations for 2018 and Beyond: The Mars ISRU demonstration that is eventually flown will be a function of several factors: i) long-term MSR and human mission plans, ii) available payload mass and power, iii) available funding, and iv) allowable risk. The first factor will determine the number and importance of ISRU and other critical technology demonstrations possible before MSR and human missions. The other factors define scale, level of ISRU process completeness, and level of advanced technologies used in the demonstration. For a 2018 demonstration it is recommended that an ISRU demo:

- Be of relevant scale to reduce the risk of an MSR mission
- Leverage past and on-going technology and system development activities to minimize cost and risk
- Be coordinated between HEOMD, SMD, and OCT

With respect to past Mars ISRU work that can be leveraged, NASA developed a very subscale Mars ISRU flight demonstration called MIP (for Mars In-situ propellant production Precursor) for the 2001 Mars Surveyor Lander that incorporated CO_2 electrolysis technology, began development a larger Sabatier/water electrolysis flight demonstration with CO_2 freezing and cryogenic O_2/CH_4 storage with Lockheed Martin called PUMPP, developed and demonstrated microchannel chemical/thermal processing technologies, and built and tested integrated Sabatier/water electrolysis and Reverse Water Gas Shift/water electrolysis system breadboards at JSC and KSC. Recently, NASA JSC and KSC designed and built a 1st generation PUMPP-like atmospheric processing system breadboard along with a Mars soil/dryer and water cleanup system breadboard (based on lunar oxygen extraction from regolith technology). Other recent work that can be leveraged involves concepts and hardware from Small Business Innovative Research (SBIR) contracts with Paragon Space Development, Pioneer Astronautics, Orbital Technologies, and Honeybee Robotics. From this past and current Mars ISRU hardware and system development work, a wide variety of demonstration scale and completeness are possible. It is recommended that a design based on past and current work be leveraged once a joint near-term/long-term objectives and architecture with HEOMD, SMD, and OCT has been established.

References:

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