ISRU ROBOTIC PRECURSOR MISSION OPPORTUNITIES BASED ON RECENT EVENTS.
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Introduction: Learning to use the resources at the site of exploration to make propellants, power, and life support consumables, commonly known as In-Situ Resource Utilization or ISRU, to reduce mission cost and risk is considered an important goal for human space exploration. However, since ISRU hardware has never flown in space, mission architecture planners are hesitant to rely on ISRU for mission success. If mission architectures and the elements in them do not rely on ISRU products or services, they are designed differently such that the benefits of including ISRU later into the architecture can be greatly reduced. Therefore, ISRU is not considered 'Critical' by mission planers for the architecture and implementation is delayed. But one of the main goals for human space exploration is to learn how to use the resources of space . . . It has been the goal of ISRU developers inside and outside of NASA to break this "Catch 22" cycle of logic. To do this, mission planners must be convinced that ISRU systems and capabilities are possible, can provide the products needed for mission success in the quantity and quality required, and can do so under applicable mission environments and durations.

Risks of ISRU Incorporation into Missions: There are five main risks to incorporating ISRU into mission architectures. One, the resource of interest is not at the site of exploration. Two, the resource is available but it is in a form or location not expected, or there are unexpected impurities with the resource that can cause problems (ex. small amounts of chlorine, and sulfur in lunar regolith can create acids with hydrogen). Three, the ISRU process does not operate properly in the actual environment compared to Earth-based testing (gravity, vacuum, temperature, radiation, etc.). Four, the ISRU process does not operate when actual space resources are acquired. Five, the products and services of the ISRU system are not compatible with the end-user (i.e. quantity and quality problems, or interface issues).

Earth-Based Testing: To convince mission architecture planners that ISRU systems are viable for use in missions and to address the five main risks of incorporating ISRU systems in mission critical applications, a combination of extensive Earth-based laboratory, environment simulation/vacuum chamber, and analog field testing is required, along with one or more robotic precursor missions to demonstrate ISRU under applicable mission environments is required. To address the risks associated with ISRU systems not operating with planetary resources (Risk 4) and not providing the quantity and quality of products needed for the mission (Risk 5), lunar simulants with physical and mineral/chemical attributes have been created by NASA and others over the last several years which are continuously being improved. Also laboratory testing of technologies and systems at relevant scale has begun, however only short duration tests have been performed to date, To address the risk of ISRU systems not operating properly in actual environments, vaccum/environment simulant chambers, parabolic-flight aircraft that can simulant partial gravity, and analog field testing can be used. While a lunar vaccum chamber that can allow lunar regolith simulant for testing is not available at this time, $1/6^{th}$ and $3/8^{th}$ gravity parabolic test flights with ISRU experiments examining lunar regolith simulant flow and fluidization properties are being performed that are providing engineers with critical information to be used in subsequent generations of ISRU hardware development.

NASA, in partnership with international space agencies, has also recently initiated ISRU-focused analog field tests to demonstrate techniques that can be used to locate and characterize resources that may be available for use (Risks 1 and 2), and that ISRU systems can be built at relevant scales for mission applications and the products can be utilized by other surface elements such as propulsion, fuel cell power, and life support systems (Risk 5). In June 2008 at Moses Lake and September 2009 at Flagstaff, NASA tested a large area clearing blade called LANCE on the Chariot crew rover as a first step in understanding the hardware and operational aspects associated with potential ISRU site preparation tasks, such as building berms and creating a landing pad. In November 2008 and in February 2010 on Mauna Kea in Hawaii, NASA and the Canadian Space Agency (CSA) tested lunar polar volatile resource prospecting and oxygen extraction from regolith hardware and operations at a scale relevant to early human lunar mission plans. At the Feb. 2010 field test, more site preparation tasks were performed as well as interaction between the ISRU system and fuel cell power, cryogenic oxygen storage, and liquid oxygen/methane propulsion systems were tested culminating in demonstrating all the steps from regolith excavation to oxygen production to use of the products produced in power and propulsion systems. This complete cycle and linkage to other systems was called "Dust to Thrust". To continue to evolve and expand the integration of ISRU into science and exploration mission scenarios and surface system designs and operations, NASA and CSA are currently discussing the objectives and hardware for a future third joint field test tentatively planned for November of 2011.

Recent Robotic Precursor Need and Opportunities: Earth-based laboratory, environment chamber, parabolic flight, and analog field testing alone however can only go so far in reducing the risk of incorporating ISRU into future human missions. While high fidelity simulants and vacuum/environment simulation chambers can be used to test hardware before flight, the wide range and combination of actual materials and environments can never fully be simulated on the Earth. Therefore, before ISRU is used in a mission critical role for human exploration, robotic precursor missions with ISRU demonstrations may be important to adequately address all five risks. Since robotic precursor missions will be mass constrained compared to potential human missions, ISRU demonstrations will need to focus on one or more of the following: what resource is there (Science & Prospecting), how to process the resource (Proof of Concept), and how to scale up to human mission needs (Engineering Data and Verification). If mass and power allow, all three aspects should be pursued. An example of an ISRU demonstration that covered the latter two aspects was the Mars In-situ propellant production Precursor (MIP) that was built and certified for the 2001 Mars Surveyor Lander.

Within the last several years, and especially recently, activities inside and outside of NASA have led to the growing possibility of robotic precursor missions which may host ISRU demonstrations. Since June of 2009, the International Space Exploration Coordination Group (ISECG), consisting of fourteen space agencies around the globe, established an International Architecture Working Group (IAWG) with the purpose of creating a Global Point of Departure (GPoD) human lunar architecture by mid 2010. The purpose of the GPoD activity was to allow all the space agencies to jointly collaborate on examining and defining exploration goals, requirements, and mission scenarios associated with human lunar exploration in a voluntary, nonbinding manner. ISRU was consider as an important element of the GPoD objectives, and to minimize development and mission risk for eventual human exploration missions to the Moon, a series of robotic precursor missions were considered which included ISRU demonstrations. In Sept. 2007, the $30 M Google Lunar XPrize was established to challenge teams to land successfully on the lunar surface before Jan. 1st 2015 to excite the public and foster development of lunar landers that could subsequently be used for commercial, scientific, and exploration precursor missions to the Moon. Several teams have released Requests for Information (RFIs) for potential payloads on the XPrize and subsequent missions of their lander. Should one or more XPrize teams be successful, flight of ISRU demonstrations from a few kilograms to much larger payloads may be possible. Recently, in February, 2010, the US President released a new plan for NASA that cancelled the Constellation Program and replaced it with a renewed focus on use of the International Space Station (ISS), developing technologies, and performing ground analog demonstrations, robotic precursor missions, and Flagship mission demonstrations that could lead to a potentially more capable and sustainable human exploration program to multiple destinations in our solar system. Again, resource characterization and ISRU demonstrations may be major objectives for these new programs.

Conclusion: For over fifteen years, NASA has invested (internally and externally) in Mars and lunar In-Situ Resource Utilization (ISRU) technologies, system development, and Earth-based testing applicable to robotic precursor and subsequent human exploration missions. With a new emphasis on technology development and demonstrations along with international and commercial interest in robotic exploration and ISRU rising, chances for actually performing one or more ISRU demonstrations on robotic missions and the International Space Station have never been greater.