ISRU Planning for Mars Exploration. J.O. Elliott[1] R. Easter[1], S. Surampudi[1], and G. Voecks[1]
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Introduction: There are many possible ways that Mars in-situ resources could be used to support both robotic and human exploration of Mars. The Applications section below identifies some of the possible applications, in rough chronological order, and notes some of the options for resource use. Given this range of alternatives, programmatic in-situ resource utilization (ISRU) development must be accompanied by continuing analysis to identify optimal investment strategies.

At present, however, there are at least 3 key ISRU technology areas that offer high payoff almost independent of the eventual Mars exploration campaign that is chosen: Resource prospecting technologies, advanced conversion technologies, and resource retrieval (drilling/excavation). These are described in the Key Technologies section.

The potential payoff of ISRU cannot be captured without an integrated approach involving all elements of NASA plus private sector and international partnerships. The final section in this abstract briefly describes what's needed.

Applications of Mars ISRU: Some potential uses for ISRU in Mars exploration:

1. Propellants for proposed robotic return to Earth of samples of surface materials from Mars and/or Martian moons
2. Propellants for mobility on the Mars surface, in the Martian atmosphere, and/or in Mars orbit (E.g. propellant for hoppers, reactants for fuel cell powered rovers and flyers)
3. Materials for building radiation shielding walls, shelters, landing sites, etc.
4. Materials for manufacture of spare parts
5. Consumables for human crew life support
6. Propellants for human crew return to Mars orbit from the Martian surface, and to Earth from Mars orbit
7. Lunar-derived propellants for travel to Mars from Earth orbit, or from Cis-lunar staging points

Several options exist for accomplishing most of these applications, e.g., in terms of resource utilized:

1. O_2 from atmospheric CO_2, and/or
2. H_2 and O_2 from surface hydrates or
3. H_2 and O_2 from surface and subsurface H_2O ice, and/or
4. CH_4 from H_2O and CO_2

Moreover, ISRU applications could and should evolve over time, as the campaign sequence of Mars robotic and human missions progresses.

It is worth noting that NASA's most recent Design Reference Architecture study (DRA 5.0) [1] identified ISRU as an *enabling* technology for the first human mission. DRA 5.0 proposed recovery of O_2 from the martian atmosphere for crew consumption as well as ascent propellant.

Appropriate system, mission and campaign analyses are needed to identify the optimal paths for ISRU development and utilization, given the possible application alternatives and the options***;*** this analysis should be driven by the constraint that the cost of ISRU development, emplacement and utilization should be less than the cost savings realized from the employment of ISRU**.**

Key Technologies: Although more analysis is needed to support choices among Mars ISRU applications and options, there are certain key technologies or classes of technologies that would have major roles to play, no matter what specific future missions or campaigns emerge as optimal:

1. Any utilization of extraterrestrial H2O would require Prospecting Technologies. These prospecting technologies would be needed to identify, characterize, and quantify the extent of the raw resources. Much of this technology may be the same as, or derivable from, existing scientific measurement instrument technology, but needs demonstration in the ISRU prospecting application. Certain mission related technologies may also be especially suited to prospecting, such as wireless power transmission, depending on the nature of the terrain being investigated.
2. Once resources are located and their accessibility confirmed, it would be necessary to employ Robust and High Volume Resource Retrieval and Transport technologies to enable beneficiation on a scale of use to surface missions. Much work has been performed in this area and technologies are closely related to terrestrial counterparts, but significant work remains to develop systems appropriate to the environment, and extent of autonomy required.
3. Many choices exist for processing CO_2 and/or H_2O into useable propellants and consumables, and some of the more traditional terrestrial

processes have been demonstrated in analog environments on Earth. Recent research on terrestrial CO_2 conversion, however, suggests the possible applicability of advanced conversion techniques, such as artificial photosynthesis. This terrestrial R&D may perhaps be leveraged to provide simpler, lower power approaches to production of H_2, CH_4 and/or O_2.

ISRU Implementation Plan: A systematic and measured approach needs to be developed to provide a plan for the efficient inclusion of ISRU in future exploration of Mars. The enabling nature of ISRU for exploration missions has been recognized, but considerable groundwork must be laid before it can be realized. Now is the time to perform an evaluation leading to a logical path for finding, retrieving, and processing martian resources on a scale sufficient to support future human exploration. Consideration and prioritization of technologies and a roadmap of precursor missions in support of this goal is a necessary first step that cannot afford to be delayed if we hope to see human exploration of Mars in the next decades.

References:

[1] Mars Architecture Steering Group, Bret G. Drake, editor, (2009), NASA/SP-2009-566, Human Exploration of Mars Design Reference Architecture 5.0.

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