Mars Sample Return with ISRU. Geoffrey A. Landis[1,2], P. Cunio[1], T. Ishimatsu[1], J. Keller[1], Z. Khan[1], and R. Odegard[1], [1]MIT, Department of Aeronautics and Astronautics, 77 Massachusetts Avenue, Cambridge MA 02139 [2]NASA John Glenn Research Center, 21000 Brookpark Road, mailstop 302-1, Cleveland OH 44135, geoffrey.a.landis@nasa.gov

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Introduction: Production of rocket propellants from the in-situ resources of Mars (known as "In-situ resource utilization," or ISRU) is a technology that can significantly enhance robotic sample return missions, and is enabling for sustained human missions. The atmosphere of Mars is a resource that can be used as a resource to manufacture rocket fuel. By reducing or removing the requirements for Earth-return propellant to be transported to Mars, landed mass can be reduced, and hence a mission may be performed at lower cost.

Returning samples of the surface of Mars is a high-priority scientific investigation for understanding Mars. Mars Sample Return ("MSR") is an expensive and technologically challenging project because the required ΔV is large. Conventional approaches to this project are capable of returning only a small sample at high cost. Production of Mars-derived propellants may decrease the cost for a given sample size, or increase sample mass returned per flight. The ability to manufacture rocket propellant from Mars resources would represent a revolutionary improvement in our ability to perform all Mars return missions. With propellant manufacture on Mars, more samples could be returned from a larger variety of sites. Ultimately, developing the ability to manufacture and use propellants on other planets is a necessary technology for cost-effective human exploration.

ISRU for Mars Sample Return: An argument has is sometimes made that since Mars propellant production is as-yet an unproven technology, it is too risky to be baselined for the first sample return mission, but instead should be inserted into a later sample return mission. I disagree with this argument for several fundamental reasons.

Since NASA has been directed to work toward a human Mars mission, and Mars propellant production is an enabling technology for a human Mars mission, propellant production from Mars resources must be developed in any case. Safety-oriented mission planning requires that this technology be demonstrated on Mars well in advance of a human mission. Developing a second technology and mission plan to do a sample return mission without Mars propellant production, and then abandoning this technology to do a sample return mission with Mars propellant production, makes little sense. In this view, Mars propellant production is not viewed as a technology to be developed for sample return mission, but exactly the reverse: Mars Sample Return should be viewed as a benefit of a Mars Propellant production demonstration mission.

A second argument is that a sample return mission using Mars propellant production is in fact scientifically valuable. Mars propellant production allows a larger sample to be acquired at the same landed mass, or allows a smaller landed mass to be used to produce the same sample return.

Finally, use of Mars propellant for a MSR actually reduces overall mission risk. The high ΔV for a sample return means that a conventional mission architecture has very little margin. This leads to a mission design of high complexity and high risk, pushing all the components to the limits of performance. Inserting Mars propellant into the architecture increases the margin, and hence reduces the complexity and the risk.

For these reasons, it is desirable to investigate the baseline technology for Mars propellant production for a sample return mission. To show that this is feasible, several architectures are examined that can do Mars propellant production with existing technologies.

CO_2 Electrolysis Architecture for Mars Sample Return: A conceptual design study was done at MIT to compare the mass of a Mars sample return mission that makes propellant on the surface of Mars with a mission that uses propellant from Earth [1]. This design study looked the use of a solid-oxide electrolysis (SOE) process to produce oxygen from the Mars atmosphere [2]. The Oxygen produced is then liquefied to use as an oxidizer with fuel brought from Earth.

The solid-oxide electrolysis process was chosen because a demonstration flight unit was built for the 2001 Mars lander mission [3]. Although the throughput of the flight hardware for this mission was small (0.5 standard cubic centimeters of O_2 per minute), a demonstration unit for flight was built and flight-qualified before the 2001 lander mission was cancelled. The study assumed use of the solid oxide electrolysis system developed for this project.

The mission design used a hybrid rocket vehicle for the ascent, using the Mars-generated oxygen with a solid fuel brought from Earth. This is an extremely simple system. The vehicle was sized to launch a 1-kg sample in a lightweight canister to rendezvous in Mars orbit with an Earth Return vehicle.

Table 1 shows the calculated landed mass for the Mars ascent vehicle (MAV) and propellant, for both the ISRU mission, which generated oxygen on Mars, and for the non-ISRU version, which brought the propellant from Earth. The mass includes the power system and the cryocooler required to liquefy the propellant. As can be seen, the total mass landed on Mars, including both the ascent vehicle and the Oxygen Generation System (OGS), is considerably lower for the case of the Mars-generated propellant. The table also shows the mass margins assumed in the mission: for both the missions, a 10% propellant margin was assumed. In addition, the oxygen generation system for the ISRU mission was sized to produce 30% more liquid oxygen (LOX) than required for the mission, and also assumed a 15% mass margin.

The result is that a lower mass system landed on Mars could be used to launch the sample into Mars orbit. Conversely, if the non-ISRU system was designed to launch a minimum 1-kg payload into orbit, for the same landed mass on Mars, the ISRU system could return over 2 kg of sample.

Component	**Mass (kg)**		**Margins**
	ISRU mission	**Non-ISRU**	
MAV	14.7	40.5	10% propellant
OGS	12.5	-	30% LOX, 15% mass
Total	**27.2**	**40.5**	

Table 1: Mass summary of MSR Ascent vehicle for Mars Oxygen generation and baseline mission [1]

Sabatier/Electrolysis Process: An alternate technology for Mars propellant production is the Sabatier production of methane/oxygen fuel from hydrogen and Carbon dioxide. As proposed for a human mission [4], the process produces methane from reacting the Martian atmosphere with hydrogen:

(1) $CO_2+3H_2 \rightarrow CH_4+½H_2O$ (Sabatier process)

followed by electrolysis of the generated water to produce hydrogen and oxygen:

(2) $2H_2O \rightarrow 2H_2+O_2$ (electrolysis)

where the H_2 is recycled back to the first step to produce further methane. Since this process does not produce sufficient oxygen for stoichiometric combustion of the produced methane, a third step is typically added, consisting of solid-oxide electrolysis of additional carbon dioxide to produce oxygen:

(3) $2CO_2 \rightarrow 2CO + O_2$ (solid-oxide electrolysis)

to produce the remainder of the required oxygen. The process makes eighteen kilograms of methane/oxygen rocket fuel per kilogram of hydrogen from Earth.

Bringing liquid hydrogen (LH_2) from Earth is a technical challenge, since the LH_2 must be kept at cryogenic temperature. Long space storage of LH_2 is not yet demonstrated. For a human mission, where tons of propellant is required, a small amount of boil-off in transit is acceptable; this process has been proposed for human Mars expeditions, by Zubrin *et al.* [4] in the "Mars Direct" proposal, and also in the NASA Mars Reference Mission [5]. For the small amounts required for MSR, the overhead required for LH_2 transfer is likely to overwhelm the mass advantage.

Sabatier Process for Sample Return: For a robotic sample return mission, a simpler process is proposed: water instead of hydrogen is used. While it does not produce the 18:1 mass leverage achieved with H_2 from Earth, it does yield 2.2 kg of propellant produced on Mars for each kg of propellant brought from Earth. A simple two-step process sequence then produces methane/oxygen propellant (reactions (1) and (2) above), in stoichiometric ratio without the requirement for oxygen produced by solid oxide electrolysis.

The process has several operational advantages:

1. 220% mass leverage
2. High I_{sp} methane-oxygen propellant
3. Reactants are brought from Earth in the form of water (a dense, non-corrosive liquid with no requirement for cryo storage)
4. Use of simple, well-demonstrated technology
5. Simple two-step process
6. Demonstration of same methane/oxygen technology proposed for human mission

Calculated results for the Sabatier/electrolysis process for Mars fuel production are very similar to the mass results for the MIT study shown in table 1; and the lower mass of propellant brought from Earth results in a doubling of the sample mass that can be returned for the same landed mass on Mars.

Conclusions: In the past, propellant production Mars has not been used in plans for a Mars sample return because it has not been considered ready for immediate implementation. This study shows that extremely simple, well-demonstrated propellant production technologies would enhance the science value of a Mars sample return mission. It is recommended that the manufacture of propellants from Mars resources should be an high-priority goal of the NASA Mars exploration program, and baselined for a sample return mission at the earliest feasible date.

References: [1] P. Cunio *et al.* (2007, to be published) AIAA Space 2007 Conf., Long Beach CA, Sept 18-20 2007. [2] K.R. Sridhar, C.S. Iacomini and J.E. Finn (2004) *J. Propulsion and Power, 20,* No. #5. [3] D. Kaplan, *et al.* (2000) paper AIAA-2000-5145. [4] R. Zubrin, D. Baker and O. Gwynn (1991) paper AIAA 91-0326 [5] S.J. Hoffman and D.L. Kaplan, eds. (1997), *Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team*, NASA Johnson Space Center, July 1997; plus Addendum (1998).