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The Value of Utilization of Extraterrestrial Resources for Propellant Production for Space Exploration - A Perspective

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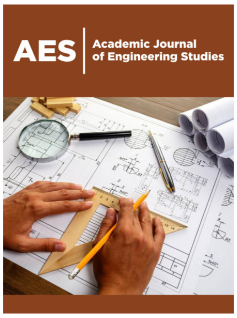

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Abstract

The main application of ISRU in the foreseeable future is production of propellants (ISPP). NASA funding has been inconsistent, inadequate and sporadic. There doesn't seem to be a plan, but rather a series of decisions of the moment, not well connected. While it has always been assumed that producing propellants remotely has innate value as measured by a reduction of mass in LEO, projections of further reduction in the cost of launch mass might well tip the scales in favor of bringing propellants from Earth. The question whether to "make it or take it" remains yet to be resolved.

Keywords: NASA; ISRU; ISPP; Propellants; Mars; Moon; Launch cost

Introduction

Discussion of utilization of extraterrestrial resources for space exploration originated in modern form with publication of the inspirational paper by Ash, Dowler and Varsi in 1978 proposing to produce propellants on Mars (in situ propellant production - ISPP) rather than bringing them from Earth [1]. Later, Jerry Sanders, a leader in ISPP, originated the term "ISRU" (in situ resource utilization) to cover a broader range of applications than propellant production based on indigenous resources on Mars or Moon.

Near Term and Far Term

In reviewing the literature on ISRU, it is found that most discussions fail to adequately distinguish between the time scales for implementation. Simpler concepts that seem appropriate to initial human landings are admixed with far more challenging concepts that might only be feasible for conceptual missions in later ventures into space [2,3].

The successful completion of the MOXIE project opens the door for near-term application of ISPP on Mars utilizing the atmosphere [4-6]. However, instead of continuing this program and filling in the gaps left by MOXIE, thus bringing first-generation Mars atmospheric ISPP to a state of readiness, recent NASA focus has been on obtaining water on Mars, which is likely to be a second generation application further down the road [7].

On paper, very imaginative ideas might seem attractive, but implementing them might not be feasible in this century? This creates confusion in planning development of ISRU technology in a logical sequence of gradually increasing complexity.

ISRU and ISPP

While the term "ISRU" has replaced "ISPP" in most current discussions, the main (and probably only) application in the foreseeable future is for propellant production, so we will mainly use "ISPP" in this document.

Is ISPP always Worth it?

A fundamental premise of most ISPP studies is that producing propellants on the Moon or Mars provides a net benefit compared to bringing propellants from Earth because use of

ISPP reduces the mass of materiel required in LEO [2,3]. A great deal of exuberance has been generated on this premise alone. NASA enthusiasts continue to periodically present PowerPoint slide presentations with many impressive concepts proposed for ISRU [8]. However, funding has yet to materialize in most cases.

A simplistic approach to justify ISPP for any conceptual mission is to compare the mass of the ISPP system in LEO to the mass of propellants in LEO that would be required if ISPP were not used. Lacking a means of estimating cost for hypothetical human missions to Moon or Mars, the mass required in LEO was taken as a very rough indicator of mission cost [2,3]. However, as H. W. Jones pointed out [9,10], launch costs for heavy lift to LEO have dropped remarkably in the last few years, and there are indications that launch costs will drop further in the next decade or two. A point is likely to be reached where mass in LEO is not the major driver for mission cost. The impact of this on ISPP is that the argument for producing propellants on Moon or Mars vs. bringing propellants from Earth is significantly weakened. While Jones analyzed the effect of lower launch costs of recycling for life support, his arguments apply equally well, perhaps even better, to ISPP. As launch costs come down, a point has to be reached where bringing propellants form Earth is cheaper and more reliable.

There are other issues in addition to mass that determine the merit of using ISPP in any application. These issues include the following:

Leverage: Martian ISPP has a fundamental advantage over lunar ISPP because it has much greater leverage. The gear ratio (mass in LEO required to deliver one mass unit to planetary surface) for delivery of cargo to the lunar surface from LEO is about 2.5, whereas it is about 8 to 10 for delivery to the Mars surface. In addition, a typical oxygen propellant load for ascent from the Moon could be 6-8 tons, while it is likely to be about 30 tons from Mars. Hence, if ISPP were to replace all the oxygen ascent propellants on one liftoff from each planet, the mass saving in LEO per liftoff would be about 15 to 20 tons for the Moon and about 240 to 300 tons for Mars. The inherent value of Martian ISPP per liftoff far exceeds that for the lunar ISPP [2].

Power: All ISPP systems are power hungry because they inevitably involve breaking strong chemical bonds to produce propellants that give off a great deal of energy when those bonds are reestablished. In some applications, the mass, cost, complexity and technical challenges involved in establishing such a power system could tip the scales against use of ISPP regardless of ISPP mass. However, there is an exception. If Mars ISPP is used to produce propellants prior to crew landing, then the power system used for ISPP can be used for crew support after the crew arrives, so there is no net attribution of power cost and other factors to ISPP, since the same power system for life support would be utilized without ISPP.

Complexity, Difficulty and Risk: Every proposed ISPP process involves complexity, difficulty, and risk, and a good indicator is the number and complexity of autonomous operations involved. At one end of this scale is processing the Mars atmosphere. A pre-packaged unit is delivered to the Mars surface, connected to the power source, turned on, and is allowed to simply run unattended [11]. A more complex process on Mars involves extraction of water from regolith by some form of mining followed by processing solids. A far more complex process is envisaged on the Moon where autonomous vehicles dig regolith, deliver it to reactors, remove spent solids, and deliver product propellants to distant depots, all based on beamed power to a harsh environment. Getting such a system installed and started is likely to prove to be a great challenge. Controlling operations over many hundreds of cycles without mishap would be even more difficult [12,13].

Cost to Prospect, Develop and Validate: Depending on the resource and the planet, prospecting can entail a considerable investment in funds and time to locate suitable pockets of resource. On the Moon, one can search for regolith endowed with iron oxides, or more likely, putative ice in Permanently Shadowed Regions (PSR) of polar craters, where prospecting, independent of processing, might require multiple landings and surface navigation, followed by actual gathering of surface material and processing for validation. In a sense, it requires a pilot plant on the Moon as the first step. On Mars, a search for and validation of usable sulfates or near-surface ice would also be a significant and costly effort. However, no prospecting or validation is needed for processing the Mars atmosphere.

Relationship to Planetary Mission Plans: It is clear that lunar ISPP has less leverage and is more challenging than Mars ISPP. Processing the Mars atmosphere is far simpler. However, NASA is currently engaged in a major return of human crews to the Moon and a human landing on Mars appears to be at least several decades distant in the future. Furthermore, current NASA plans for a future human mission to Mars involve a short stay without use of ISPP. Therefore, it is natural that most of the current efforts in ISPP are aimed at lunar ISPP rather than Martian ISPP. The work follows the funding. Mars atmospheric processing might be the simplest, most effective form of ISPP with by far the highest leverage and return on investment, and least risk, but humans are not going to Mars anytime soon, and current NASA plans for Mars bypass Mars ISPP.

Systems Issues and ISPP

There are significant systems issues regarding propulsion in space exploration that affect considerations for ISPP. It is not clear to what extent these have been investigated systematically. The first and overriding need is to put ascent and descent propulsion in perspective as elements of the overall mission: what portion of the total funding and logistics for the mission do they represent? What if ISPP is not used, and all propellants are brought from Earth? How much of a mission impact does that represent? There needs to be a zero-baseline mission defined, against which use of any ISPP concept must be compared. While the 2009 NASA study “DRA-05” performed some analysis related to this question, that study is outdated due to changes in launch costs, NASA mission plans, and other factors, and an updated analysis is needed with emphasis on factors other than mass [14].

It is notable that a related situation occurs regarding life support for planetary missions. The NASA literature for

Environmental Control and Life Support Systems (ECLSS) generally presupposes that the recycling system would provide essentially all the required life support except for a small backup cache to cover losses. The published papers do not usually provide estimates of total resources needed. However, ECLSS development has been mainly focused on percent closure rather than reliability. In order to provide adequate reliability, spares would be required to replace failed or depleted subsystems. H. W. Jones analyzed long-term reliability of ECLSS systems. He examined the effect of bringing along spares vs. redundancy using statistical analysis [15]. This also enters consideration of "take it or make it" for ECLSS.

The "Gateway"

Going beyond the near-term, some have proposed use of ISPP as a generic means of fueling various spacecraft through a so-called "Gateway". Descriptions of the Gateway vary from limited (used for ascent and descent to the Moon) to imaginative (provide fuel to all deep space spacecraft in the future) [16]. There seem to be some misconceptions there, because propellant supply is valuable in LEO but less valuable in cis-lunar space because significant propellants are used up in transporting mass from LEO to cis-lunar space. The main virtue of a Gateway would be to provide descent propellants for spacecraft prior to landing on the Moon. It remains unclear whether the complex system required to deliver descent propellants to a space station adjacent to the Moon would be worth the investment of time, funds and logistics.

To some extent, there is a tautology:

A. NASA goes to the Moon to produce propellants

B. NASA makes propellants on the Moon so it can get to the Moon

ISPP and Design of Ascent and Descent Capsules

Propellants are needed for descent to the surface and for ascent from the surface. Generally, heavier masses are landed so considerably more propellant is needed for descent than for ascent. From a system point of view, it is advantageous to minimize ascent propellants by employing a minimal capsule for liftoff and rendezvous with a much more elaborate Earth Return Vehicle (ERV) in orbit. That appears to be essentially mandatory for Mars. On Mars, there is a range of potential ERV orbits, with a circular orbit being favored if ISPP is not used, and an elliptical orbit if ISPP is used.

For the Moon, NASA appears to be planning a more substantial crew module for both descent and ascent so that the ascent vehicle can traverse all the way to LEO. That would increase the need for propellants, but it would simplify logistics. With large-scale ISPP, more elaborate ascent capsules can be tolerated. However, large-scale ISPP on the Moon will be very challenging (and expensive).

The choice of propellants is closely related to application of ISPP in connection to the resources that are accessible. On Mars, with carbon readily accessible, $CH_4 + O_2$ appear to be the propellants of choice. On the Moon, with only water as a possible resource, $H_2 + O_2$ would probably be mandatory.

In recent years, NASA has set nuclear propulsion as baseline for humans to Mars. It is not clear how use of nuclear propulsion would impact ISPP on Mars, but generating hydrogen might rise in priority? However, there remain today the same political impediments to application of nuclear propulsion in space that existed for the past fifty years.

ISPP History, Advocacy, Planning, and Funding

Over the past thirty or forty years, there have been several voices within NASA advocating that NASA should invest in various aspects of ISRU (with near-term emphasis on ISPP). For example, Gerald Sanders at NASA-JSC has been making yearly presentations at national and international meetings regarding the virtues of ISRU. Dianne Linne at NASA-GRC also contributed extensive plans for ISRU development. I, myself (in the years I was at JPL) advocated and participated in NASA investment in ISPP as far back as 1997.

Advocates for ISRU within NASA have generated several long-range plans, roadmaps, and system studies over the past couple of decades but these have generally been ignored by NASA [17-19]. Funding for ISRU technology has been sporadic and inadequate. In the Griffin era, funding for lunar ISRU was begun but that did not last when the lunar initiative was terminated by president Obama. The only significant funding for Mars ISRU was a one-time large investment in the "MOXIE" project, which did earn a successor program despite its huge success. In 2024 with NASA intent on making ISRU a centerpiece for its return to the Moon, the closed doors from the Griffin era are opening but the return on investment might nevertheless be zero. The European Agency has also developed a roadmap, and time will reveal whether it is implemented [20].

Summary

The main application of ISRU in the foreseeable future is production of propellants (ISPP). Middle managers at JPL have been advocates of ISRU for several decades but NASA funding has been inconsistent, inadequate and sporadic. There doesn't seem to be a plan, but rather a series of decisions of the moment, not well connected. While it has always been assumed that producing propellants remotely has innate value as measured by a reduction of mass in LEO, projections of further reduction in the cost of launch mass might well tip the scales in favor of bringing propellants from Earth. Valuing use of ISPP requires considerably more analysis than has heretofore been invested. The question whether to "make it or take it" remains yet to be resolved as launch costs decrease.

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