National Aeronautics and Space Administration

Mars Ascent Propellant Considerations

2024 Moon to Mars Architecture

white paper

Introduction

A human Mars architecture must deliver astronauts to the surface of Mars and return them safely to Earth. The rocket equation dictates that the further along a roundtrip mission a mass travels, the more massive its transportation system must be, increasing costs. Therefore, it is important to minimize the mass that must be delivered to Mars.

For most proposed human Mars architectures, the single largest category of mass that must be delivered to the Mars surface is the propellant required for the crew's ascent to Mars orbit upon completion of their surface mission. Production of ascent propellants from in-situ resources would significantly reduce the propellant mass that must be delivered. This is possibly the single most significant application for in-situ resource utilization (ISRU).

NASA's Moon to Mars Objectives call for the demonstration of "…Mars ISRU capabilities to support an initial human Mars exploration campaign."[1] Potential resources present at Mars include the Martian atmosphere, surface materials (i.e., regolith), and water in the form of buried ice sheets, ice mixed with near-surface regolith, or minerals containing chemically bound water. In addition to their potential for propellant production, these Martian resources could be used for applications including:

- breathing gases for crew cabin use, for extravehicular activity (EVA) life support, and to make up for airlock losses.
- water for crew consumption, radiation protection, and crop growth.
- building materials for landing/launch site berms, radiation protection, and habitat construction.

Not surprisingly, architectural concepts including ISRU have received a great deal of attention. Studies examining Martian ISRU for propellant production for robotic and human Mars missions began in earnest shortly after the Viking lander missions of the 1970s. More recently, NASA has undertaken a variety of studies to characterize the options available for the first crewed missions to Mars.[2, 3, 4, 5]

However — as with all architecture decisions — there are trade-offs involved. **NASA must understand how the transportation of propellant to or the manufacture of propellant at Mars will affect its overall exploration architecture.** Either option would require pre-positioning infrastructure (i.e., ISRU equipment or propellant and its associated fueling infrastructure). This white paper outlines ISRU considerations for Mars ascent vehicle propellant.

Figure 1: *Illustration of a large Mars ascent vehicle, astronauts, and ISRU infrastructure on the surface of Mars. (NASA)*

Literature Survey

NASA has performed numerous trade and architecture studies considering ISRU and non-ISRU Mars ascent propellant approaches. As an introduction to this research, this white paper summarizes three of those studies, which include a range of proposed landed infrastructure:

2009

Mars Reference Mission Architecture

This study[4] examined a campaign of three missions, with six crew each, to three different locations. It considered four scenarios for ascent propellant: no ISRU, two options that use a combination of the Martian atmosphere and Earth-origin resources, and an option that uses Martian atmosphere and water extracted from regolith. Overall, the study found that using Martian oxygen for ascent offered the best balance between mass savings, total volume required, and power generation needs and that ISRU generally lowered the overall mass that must be delivered while improving overall mission flexibility.

Note: This study predated the 2018 Mars global dust storms and their effects on power systems, which promoted lessons learned for subsequent architecture studies.

2021

Human Mars Architecture Study

This study[6] from the 2021 strategic analysis cycle considered a basic mission that does not manufacture propellant from Martian resources. However, it incorporates several important operational functions necessary for the previously described ISRU cases — specifically, transporting propellant across the surface and loading that propellant into an ascent vehicle. The study showed that architectures without ISRU are feasible, but have their own associated challenges. It also reveals that non-ISRU architectures can share important characteristics with ISRU architectures and could demonstrate capabilities that reduce associated risks.

2024

Strategic Analysis Cycle

This study[7, 8, 9] examined a single mission of four crew, two of whom would descend to the Martian surface. It considered three options for ascent propellant using pre-deployed infrastructure: using water from Earth, acquiring water from buried ice sheets, and acquiring water from the Martian regolith. While the ISRU options explored in this architecture offer significant mass savings and flexibility for mission planning, they also require significant energy, time commitments, and unique assets.

Mars Ascent Propellant Trade Space

These studies identified several options for Mars ascent propellant, including several different types of ISRU. Each option has its own specific requirements and trade-offs to consider when examining the trade space as a whole.

No ISRU

Architectures that Rely Exclusively on Earth-Origin Ascent Propellant

First is the option to use no ISRU at all. A non-ISRU architecture will land fuel needed for ascent before the arrival of the crew for safety reasons, as the crew should not arrive on the Martian surface until their means to return are in place.

This means that non-ISRU missions share some features with missions that use ISRU. This includes pre-placement of equipment, supplies, and power systems and — in cases where the ascent vehicle is not landed fully fueled — autonomous fueling operations.

Limited ISRU

Architectures Incorporating ISRU and Raw Material from Earth for Ascent Propellant

There are a range of ISRU options in which some supplies for propellant production are sent to Mars from Earth. Examples include using a combination of the Martian atmosphere and Earth-origin methane or the Martian atmosphere and Earth-origin hydrogen.

The 2024 study mentioned above examined sending water from Earth to make propellant on Mars. While this approach does not use Martian resources, the manufacturing and conditioning of the propellant takes place on the Red Planet, using many of the same processes and technologies as ISRU-intensive architectures (e.g., autonomous manufacturing, conditioning, and transportation of propellant).

Comprehensive ISRU

Architectures Where ISRU Generates Most or All Ascent Propellant

Finally, NASA has examined scenarios in which all components of Mars ascent propellant are sourced from Mars. Two options considered in the studies listed above use a combination of the Martian atmosphere and water extracted from water-bearing regolith or extracting water from buried ice sheets.

These options maximize the use of Martian resources, but also require the most support equipment. Harvesting resources and using them to manufacture propellant would also represent a significant time commitment. If initial human Mars missions maintain the requirement to have ascent propellant in place before the crew arrives, mission planning will need to account for this timeline.

Key Findings

The variety of ISRU (and non-ISRU) options that NASA has examined reveals a complex trade space with opportunities and challenges presented by all proposed architectures. Mission planning must account for a wide variety of needs, forcing architects to balance cost, risk, mass, power generation, crew safety, mission flexibility, site selection, mission timelines, and more when selecting an ascent propellant strategy.

Studies conducted thus far offer some important key considerations, with three of the most driving factors considered below: mass, site selection, and production rate.

Mass Considerations

The largest driver of cost for space exploration missions is mass. Any resources that do not need to be launched from Earth to Mars represent a potential cost savings. This makes the opportunity to manufacture propellant using resources partially or entirely sourced from the destination incredibly attractive from a propellant cost perspective.

However, ISRU does not always represent a total mass cost savings from a mission architecture perspective. Local ISRU requires extensive infrastructure to extract resources and manufacture, condition, and transport propellant. The cost of developing these systems and transport them to Mars can exceed the cost of sending propellant (especially if those systems cannot be used across multiple missions).

That said, these mass constraints are not exclusive to ISRU architectures; any mission that does not land a fully fueled ascent vehicle would need to devote some mass to systems for autonomous transportation and loading of propellant.

Site Selection Considerations

Choosing ISRU to manufacture ascent propellant naturally constrains site selection. The landing site must offer the resources necessary for the chosen ISRU strategy, constraining the mission to one site or type of sites, versus multiple diverse regions.

The investment in landed ISRU infrastructure could enjoy cost savings if multiple missions land at the same location to re-use emplaced infrastructure. However, this architectural limitation would reduce the diversity of regions available for study and which hinder NASA's ability to accomplish science and exploration objectives.

Site selection decisions might also have flow-down impacts on decisions about using ISRU. A mission that intends to primarily explore a single site might benefit from ISRU infrastructure, while a mission that explores multiple sites might benefit from landing of propellant.

Production Rate Considerations

ISRU options that rely more heavily on Martian resources usually require a significant time investment. The 2024 strategic analysis cycle study found that the most ISRU-intensive architectures could require NASA to emplace and operate infrastructure years before a crewed mission.

While some options do not require as much lead time, mission planning must account for the time required for ascent propellant to be ready before the crew arrives. The time between Mars mission availability windows (roughly 26 months) further complicates this consideration given the number of assets needed for comprehensive ISRU.

Summary

ISRU offers the opportunity to overcome one of the biggest challenges of a human Mars mission: the mass of ascent propellant. Recent studies have examined a range of options that use resources from the Red Planet to manufacture some or all of the needed ascent propellant from in-situ resources.

However, ISRU is not without trade-offs. Mission planners must carefully assess the potential mass savings against the necessary specialized infrastructure, constraints on site selection, and additional time that come with using ISRU. While ISRU capabilities have garnered interest from the spaceflight community, further study will be critical as NASA develops an architecture that will support the first crewed missions to the Red Planet.

Key Takeaways

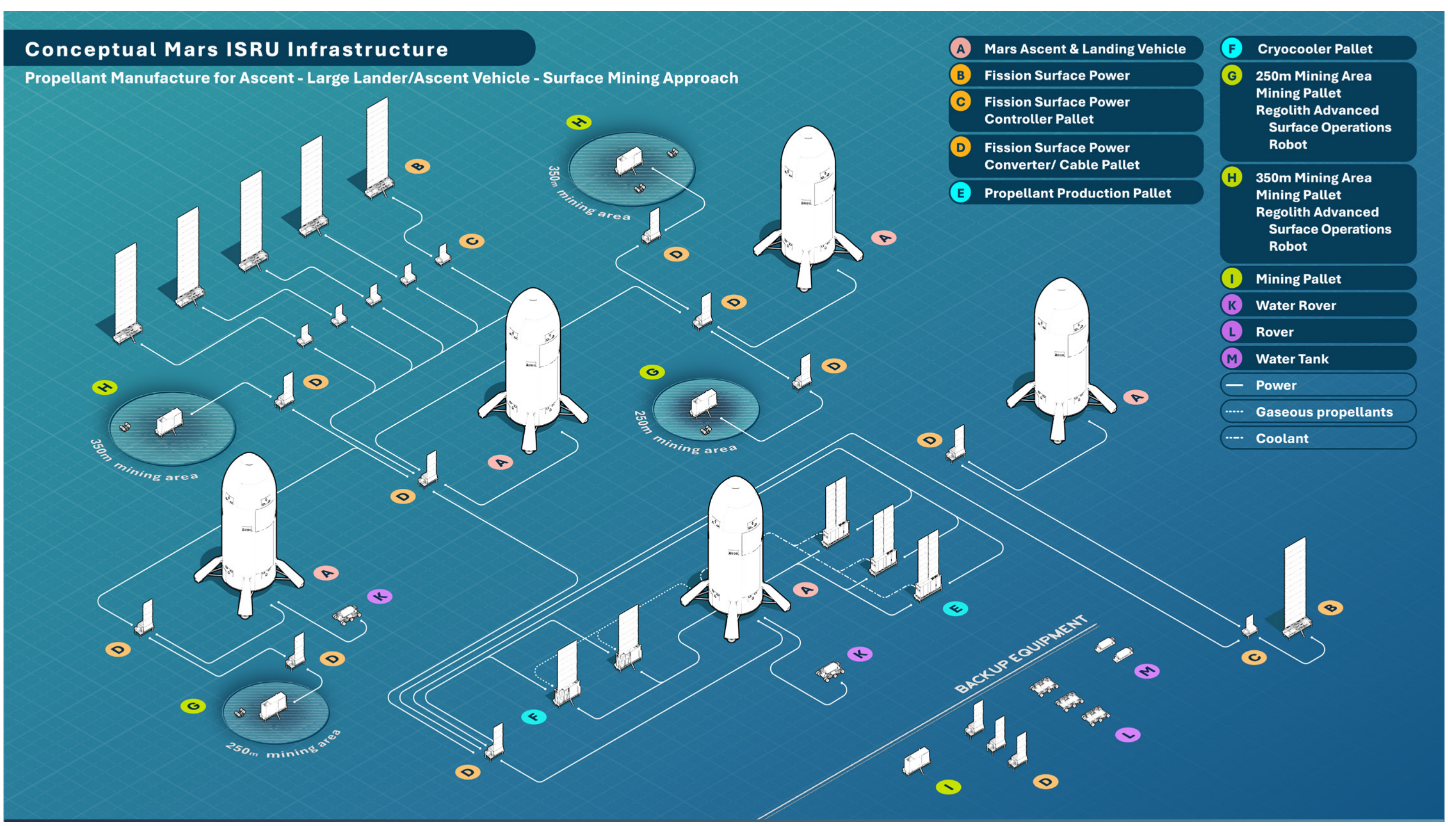
For most proposed Mars architectures, ascent propellant represents the single largest category of landed mass.

Production of ascent propellants from in-situ resources could significantly reduce the propellant mass that must be delivered, but ISRU has significant impacts on the overall exploration architecture.

Various ISRU options offer a wide range of trade-offs, including considerations of overall mass, site selection, and production rate.

NASA must thoroughly consider the ascent propellant trade space before selecting an approach to create an architecture that is achievable, objective-oriented, and extensible to future exploration.

Figure 2: *Illustration of a notional regolith-based ISRU surface infrastructure developed during the 2024 strategic analysis cycle ISRU study. (NASA)*



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