Highlighting the Need for In-Situ-Derived Propellants for Cislunar and Near-Earth Applications

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Introduction

In-situ derived propellants have recently become a larger focus of NASA attention. In particular, cryogenic fluid management has received significant funding in recent years, as shown in the example of Figure 1. But, little attention has been given to in-situ propellants for the infrastructural missions which will enable life around the Moon to flourish and persist in the coming decades. These will include Lunar observation and transport missions, and may involve smaller spacecraft and long periods of propellant storage. Such missions are an excellent opportunity for near-term Lunar-resource based fueling.

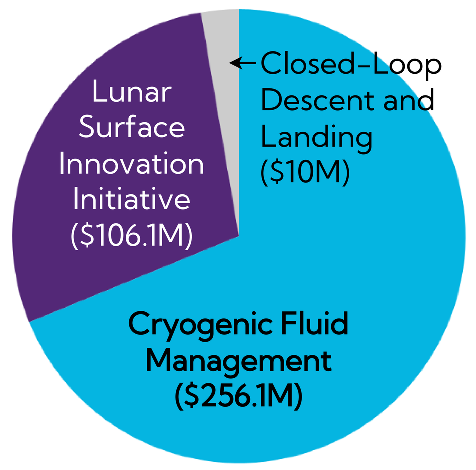

Figure 1. Distribution categories of 2020 NASA Tipping Point award.[1]

A previous Orbit Fab publication established that **hydrolox and HTP are the only two high-impulse propellants known to be readily available from Lunar resources.**[2] Each propellant occupies a distinct role in the cislunar economy. Any comparison of the two propellants should consider available volume, power, and budget, storability requirements, and available mass for cryogenic fluid management. It is also important to consider the development capital requirements and timeline for relevant technologies (such as HTP generation and compact cryogenic storage solutions) to reach a high TRL on or near the Moon.

In this poster we present **three notional concepts of operations** (conops) that represent anticipated missions around the Moon in the next ten years. Each of these missions would benefit from in-situ derived propellant, and this poster attempts to illuminate the most effective Lunar-derived propellant for each. By analyzing these conops we hope to **bring more clarity to the role of HTP and hydrolox with respect to various spacecraft size classes, storage requirements, risk margins, and anticipated market needs currently expected to emerge**.

In-Situ HTP Production

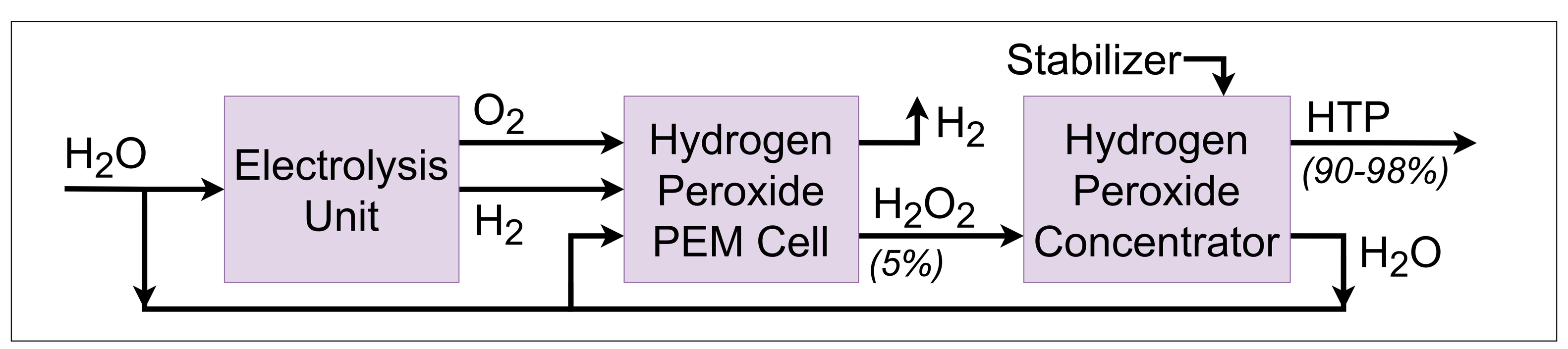

Figure 2. High-level block diagram of Orbit Fab HTP Production System for in-situ production of HTP propellant from Lunar water.

Figure 2 shows a high-level diagram of the Orbit Fab HTP Production System. This system is being developed in order to **address the unfulfilled market need described in this poster for alternative ISRU propellant options** for many Lunar and cislunar conops. This system is currently the only system capable of producing HTP in a portable form factor. Previous publications have described this system in detail.[3,4]

Concerns are frequently raised about the stability and storability of HTP, usually stemming from the early work on HTP performed in the 1950s and 1960s. Due to advances in understanding of materials compatibility and stabilization techniques, HTP has become a far more stable and storable propellant than it was during its early use.[5] To ensure safety in the HTP Production System, all components are selected and tested for material compatibility prior to assembly, stabilizers are added as HTP is produced, and the system is equipped with pressure monitoring to gauge decomposition rates.

Example conops 1: Lunar observation satellite refueled from Lunar resources

Satellite dry mass	1000 kg
Delta-v requirement	150 (m/s)/yr for stationkeeping in a polar orbit[6]
Monopropellant HTP mass for 5 years of stationkeeping	489.1 kg
Hydrolox mass for 5 years of stationkeeping	184.7 kg + cryo management mass

Lunar satellites, due to their proximity to the Moon, are prime candidates for ISRU-derived refueling. **Until cryogenic fluid management systems reach an affordable, small form factor (in the low hundreds of kilograms to breakeven in this conops) and are capable of year-scale propellant storage, a storable propellant such as HTP is the more compelling in-situ-derived option**. HTP has a high density, and would require 0.35 m3 propellant storage volume for this conops, whereas hydrolox, despite its lower mass, would require a higher volume of 0.58 m3.

Example conops 2: Mars transport vehicle with Lunar fueling

Vehicle dry mass	100 t
Delta-v requirement	4.4 km/s for journey from Lunar orbit to Martian surface[7,8]
Monopropellant HTP mass for transfer	930 t
Hydrolox mass for transfer	170 t + cryo management mass

As expected, for a conops with a large vehicle mass and high delta-v requirement, such as a Moon-to-Mars mission, **a storable monopropellant such as HTP is not a feasible option, even when considering the added mass of a cryogenic fluid management system**. In addition to hydrolox, methalox (the cryogenic bipropellant of methane and oxygen) has been considered due to the availability of carbon dioxide on the Martian surface,[9] and could become a viable Lunar ISRU fueled bipropellant if a form of carbon or pure methane is brought from Earth to the Moon.

Example conops 3: Lunar sample return with Lunar surface refueling

Lunar ascent vehicle dry mass	500 kg
Delta-v requirement	2.3 km/s for transfer from Lunar surface to Earth surface[8]
Monopropellant HTP mass for transfer	1,195.5 kg
Hydrolox mass for transfer	340.9 kg + cryo management mass

In this case, neither HTP monopropellant nor hydrolox is an ideal option for in-situ refueling: **HTP requires a high launch mass due to the amount of propellant required, and hydrolox requires a high launch mass due to the cryogenic fluid management equipment required.** An HTP bipropellant system should be considered as an alternative to a cryogenic or storable monopropellant system:

Bipropellant HTP-kerosene mass for transfer	745.0 kg
Mass of HTP oxidizer	651.9 kg
Mass of kerosene fuel	93.1 kg

Due to their high oxidizer-to-fuel ratio (~7),[10] HTP bipropellants are a compelling option for certain classes of missions. As shown above, this conops would require 745 kg of HTP-kerosene bipropellant, of which only 93.1 kg is fuel. The other 651.9 kg of propellant mass can be provided as HTP in situ on the Lunar surface. **Rather than launching with a large cryogenic fluid management system, or relying on one to be available on the Lunar surface, the Lunar ascent vehicle can instead use a storable HTP-kerosene propulsion system and reserve just 93.1 kg of mass at launch for its return journey to Earth.**

Conops assumptions:

- *HTP monopropellant Isp: 192 s [11]*
- *Hydrolox bipropellant Isp: 451 s [12]*
- *HTP-kerosene bipropellant Isp: 257 s [10]*
- *Mission conops considered involve no staging*

Discussion

This work aims to show how ISRU-derived propellants could be used for missions beyond the archetypal Moon-to-Mars missions. Infrastructural missions, such as those described in the conops here, will benefit from other propellant options. Orbit Fab is developing their HTP Production System to fulfill this need for another ISRU-derived propellant. Such a system will prevent sole reliance on cryogens in situ and open new markets on the Moon. Ultimately, we should avoid relying exclusively on ISRU propellant architectures involving cryogenic storability, as such cryo management systems are likely to be excluded from many classes of missions due to their large SWaP-C.

Conclusions

- Distinct market segments exist for different ISRU-derived propellants.
- ISRU-derived propellant supply for long-duration and small missions cannot be accomplished with hydrolox only.
- Creative propellant choices (such as HTP-kerosene) may prove to be a compelling option for certain classes of in-situ fueled missions.
- HTP represents a low-cost and low-risk development that requires greater attention, as it is the only high-impulse Lunar-ISRU storable.

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