Lunar ISRU for Human Mars Exploration Missions

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Introduction

- Recent human Mars exploration plans require large quantities (10s to 100s of tonnes) of propellant in cis-lunar space
- Lower gravity for launching from Moon relative to Earth suggests potential savings from making propellant on the Moon
- Recent evidence indicates potential for lunar ice in polar craters
- NASA has been directed to return humans to the Moon
- One possible means for providing propellant: lunar In-Situ Resource Utilization (L-ISRU)

Future human exploration plans will require significant quantities of propellant in cis-lunar space, which could come from lunar ISRU.

This Study

- **Goal**: Compare architectures for supplying propellant to cis-lunar space from Earth and from the Moon **<u>on the basis of cost</u>**
- **Important considerations**
  - **Annual demand**: How much propellant is needed annually in cis-lunar space?
  - **Time horizon**: How many years of propellant demand are needed for lunar-based propellant to trade favorably with Earth-based propellant?
  - **Concepts of operations**: How should propellant be delivered from the Moon, and how should the lunar infrastructure be emplaced?
  - **System performance**: How effective do the systems of the lunar infrastructure (landers, in-space stages, propellant production systems) need to be for lunar-based propellant to trade favorably with Earth-based propellant?

Key question: How does propellant delivered from Earth compare to propellant delivered from the Moon on the basis of cost?

Baseline Analysis

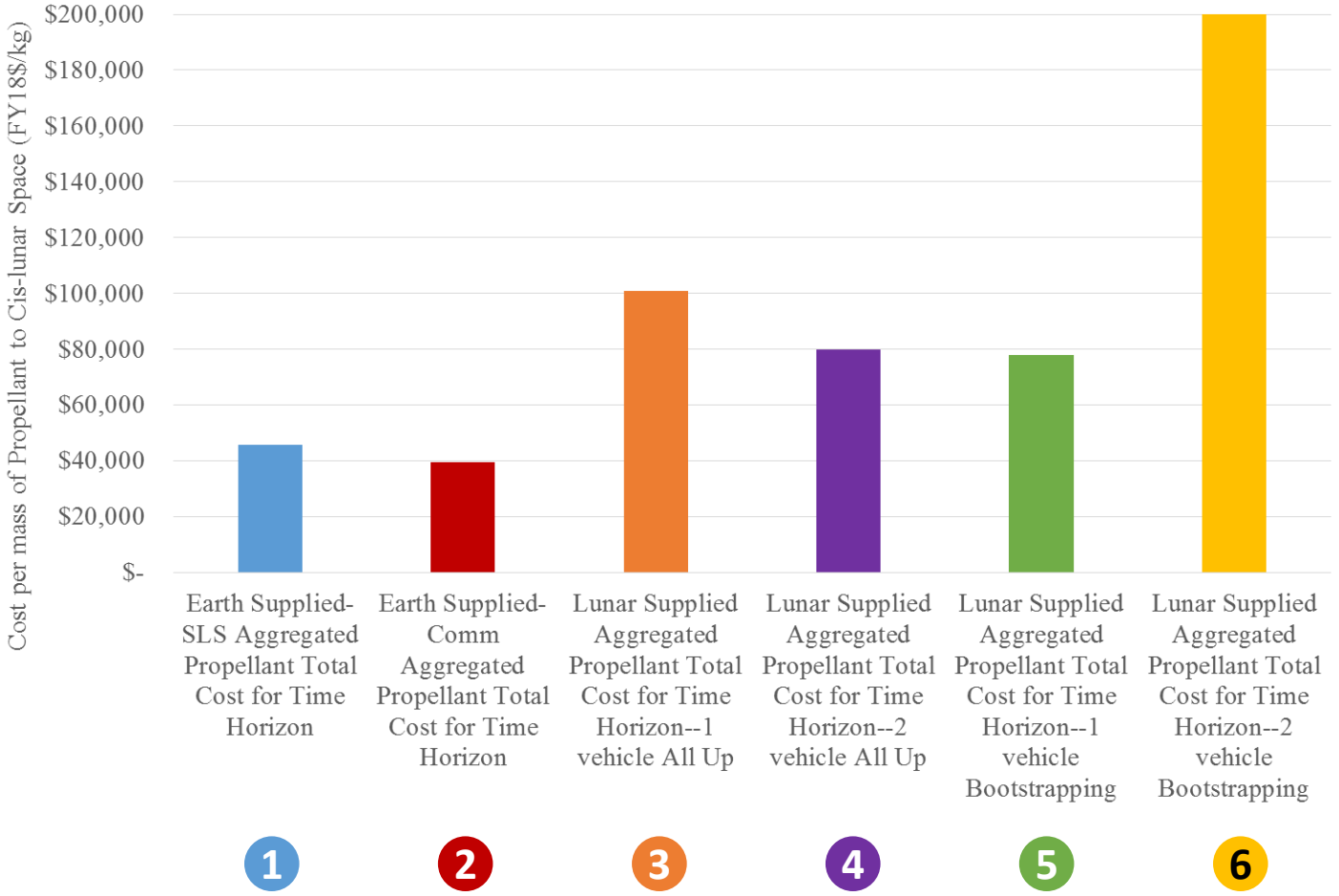
- 59 t/yr for 14 years

2 **Best**: Commercial delivery from Earth at $40,000/kg

5 **Best ISRU**: Bootstrapping with 1 vehicle at $78,000/kg

Propellant Efficiency
(Propellant usable for Mars / propellant produced on Moon)

3	4	5	6
15%	19%	15%	10%



With favorable assumptions for the lunar ISRU architectures, propellant from Earth still has lower cost in the baseline scenario.

Summary of Findings

For propellant requirements derived from the Evolvable Mars Campaign…

- Lunar ISRU is 97% more expensive than Earth-based propellant in this model
- Breakeven point for time horizon is 35 years for baseline
- Breakeven point does not depend on propellant demand in space
  - Increases in costs for more ISRU exceed increases in costs for more launches from Earth
- Propellant efficiency (propellant delivered to cis-lunar space vs propellant produced on the moon) varies from 10% to 20%
- In this model, commercial launch is $40,000/kg to cis-lunar space
  - For ISRU to trade favorably, need to produce propellant at $4,000 - $8,000/kg on the Moon

Based on the pro-ISRU modeling assumptions here, lunar ISRU is not a cost-effective approach to providing propellant in cis-lunar space in the near term.