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Living off the Land

How ISRU can benefit early habitation life support systems

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James E. Johnson

Ph.D. Candidate – Space Resources Program

COLORADO SCHOOL OF MINES

Advisor: Dr. Angel Abbud-Madrid
Co-advisor: Dr. George Sowers

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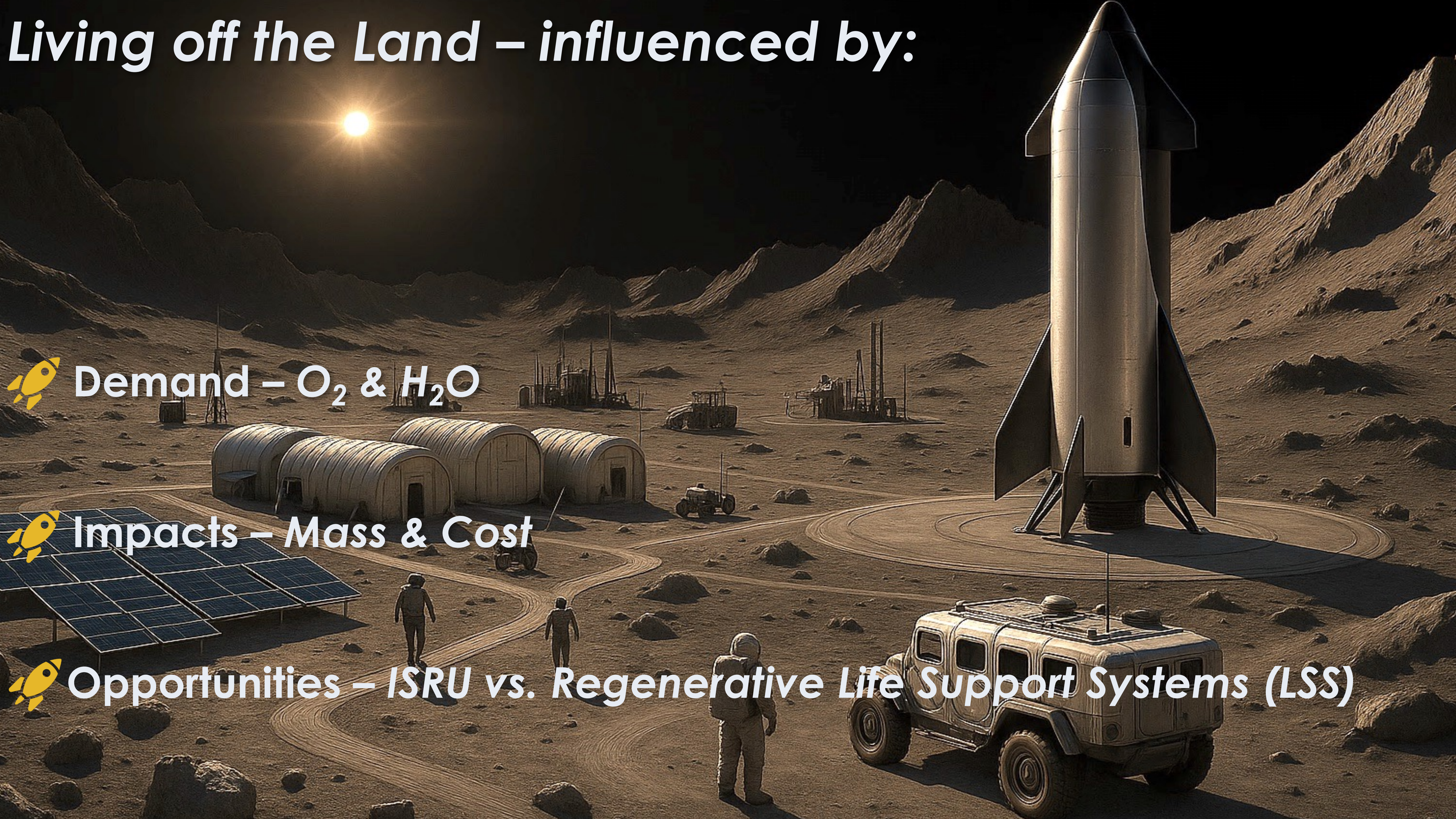
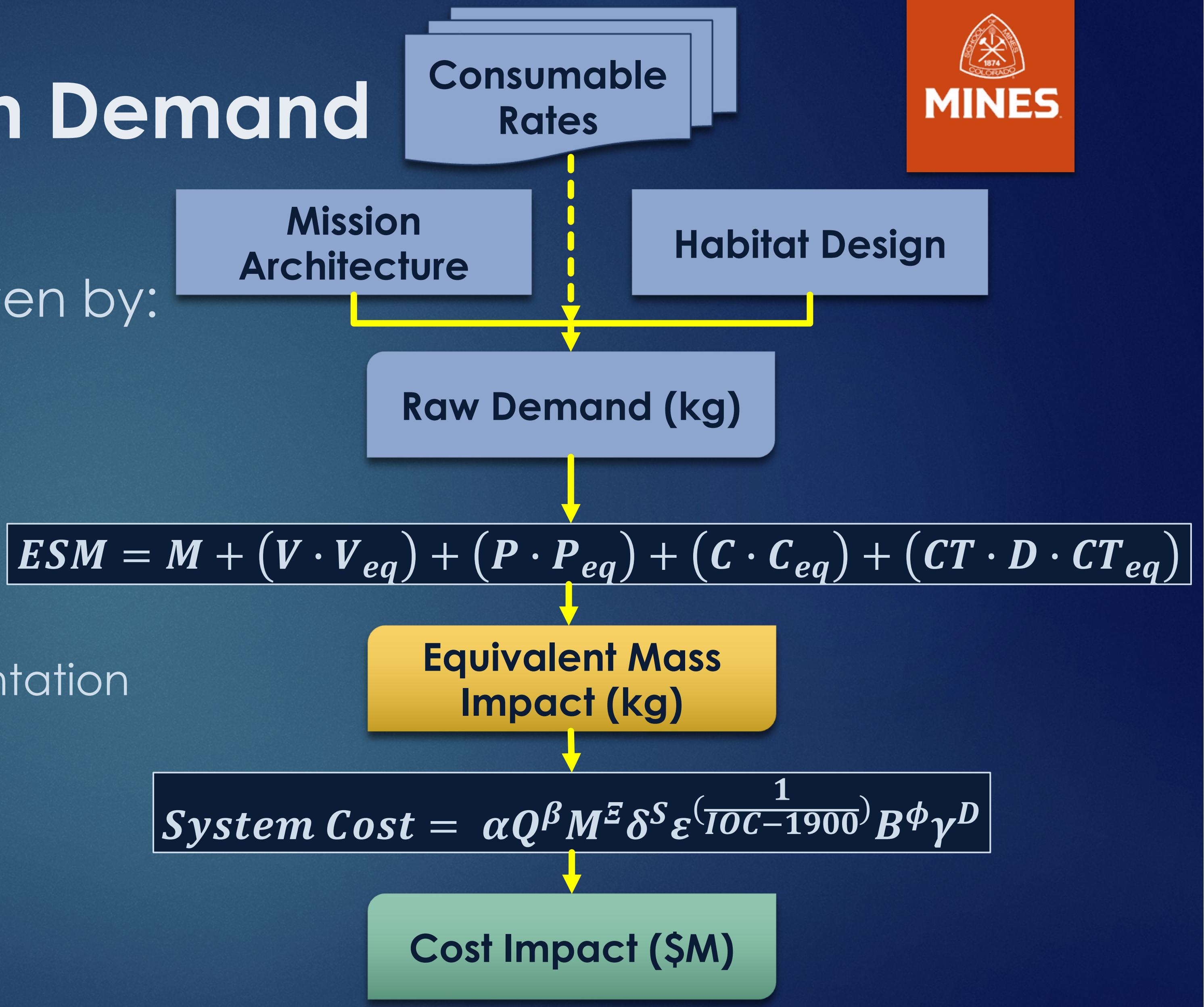
Living off the Land – influenced by:

- Demand – *O_2 & H_2O*
- Impacts – *Mass & Cost*
- Opportunities – *ISRU vs. Regenerative Life Support Systems (LSS)*



Modeling Habitation Demand

- Lunar living demand is driven by:
  - Mission architecture
  - Habitat design
- And quantified through:
  - Known consumable rates
  - Captured in NASA documentation
- Demand influences:
  - Mass impacts
  - Cost impacts
  - Breakeven analysis



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Early Habitation Concepts & Assumptions

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JAXA Pressurized Rover (PR)

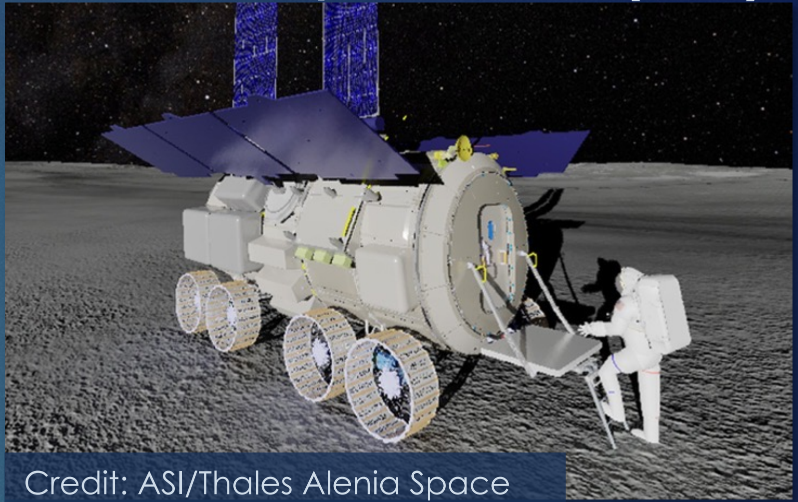
JAXA

TOYOTA

ASI Multi-Purpose Habitat (MPH)

ASI AGENZIA SPAZIALE ITALIANA

ThalesAlenia Space



NASA

ARTEMIS

Consumable Rates

- NASA Human Integrated Design Handbook (HIDH)
- NASA Baseline Values and Assumptions Document (BVAD)
- Logistics Rates and Assumptions for Future Human Spaceflight Missions Beyond LEO (Lynch et al., 2023)

Mission Architecture

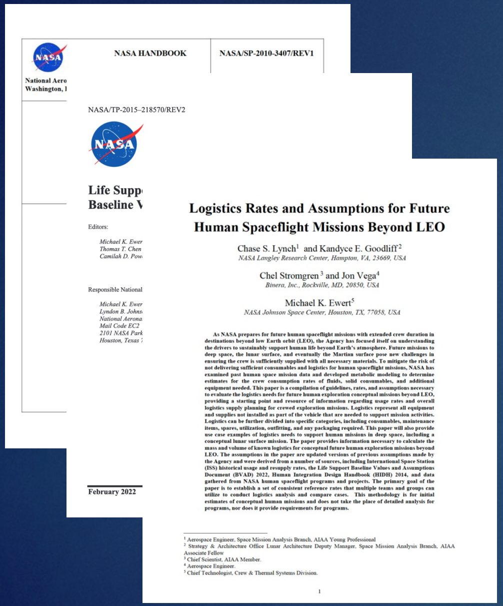
- 2 crew per element
- 1 mission per year with 7 to 28-day mission durations
- 3 Extravehicular Activities (EVAs) per 7-days
- Early 2030's, 10-year lifetime

Habitat Design

- Airlock (MPH)
- Cabin Depress (PR)
- 8.2 psia, 34% O_2
- Open-loop life support

Early Habitation Raw Demand

Consumable Rates → Mission Architecture Habitat Design → Raw Demand

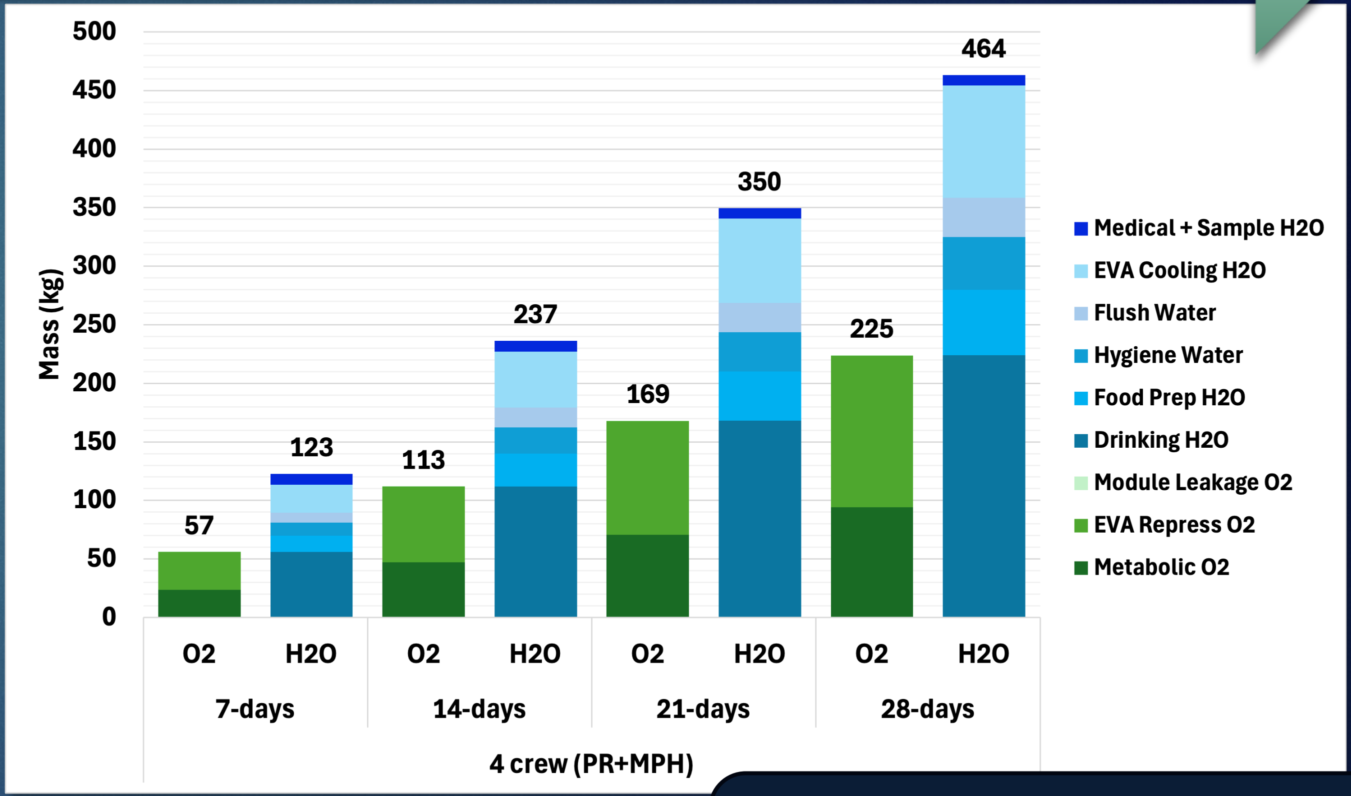


MISSION PARAMETERS

Crew Size	4	crew
Mission duration	28	days
Total EVAs	3	EVAs
EVA Duration	8	hours
Total Mission #	1	missions

HABITATION DESIGN PARAMETERS

Number of Modules	1	modules
Module (Cabin) Volume	30	m^3
Habitat Pressurization?	No	Yes/No
Airlock?	Yes	Yes/No
Airlock Volume	13	m^3
Air Save Pump?	No	Yes/No
Air Save Min Press	2.0	psia
Operating Press	8.2	psia
O_2 Concentration	34.0%	%
Nominal Cabin Temp	70	°F



H_2O — 62-68% of H_2O driven by drinking & EVA cooling

O_2 — >58% of O_2 based upon EVA architecture

Lifetime Totals (PR + MPH):
- 4,640 kg H_2O
- 2,250 kg O_2

Equivalent Mass Impacts

Earth-based resupply

$$ESM = M + (V \cdot V_{eq}) + (P \cdot P_{eq}) + (C \cdot C_{eq}) + (CT \cdot D \cdot CT_{eq})$$

Equivalent System Mass (ESM) = **Item mass** **Volume** **Power** **Thermal** **Crew Time**

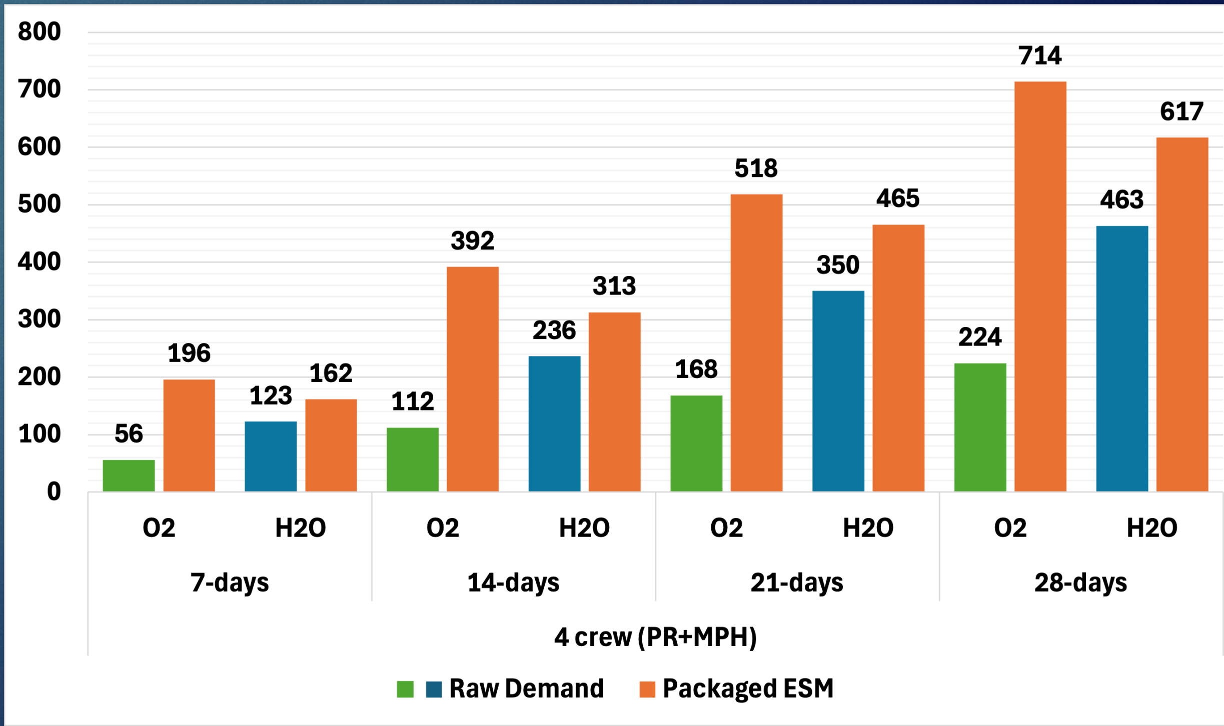
x Mass Equivalency Factor, X_{eq}= kg/X

- Delivered mass = raw consumable mass + container mass + packaging mass
- Pressurized volume and crew time are major factors in Earth-based resupply

H_2O ~18% mass increase for transport

O_2 ~160% mass increase for transport

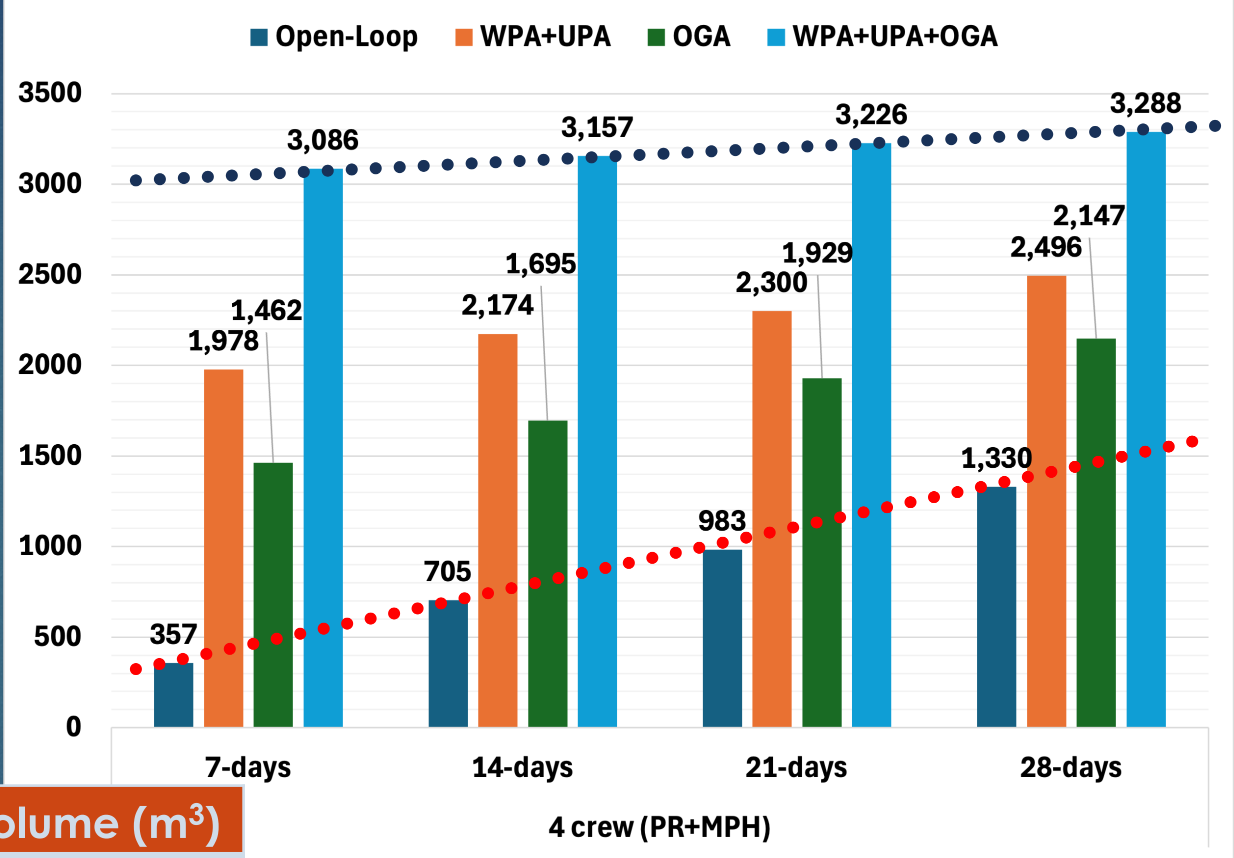
Lifetime (PR + MPH) mass impacts: ~12,000 kg



Equivalent Mass Impacts

Regenerative LSS Alternatives

- Major factors in regenerative LSS analysis
  - Pressurized volume
  - Power
  - Thermal
- Reliability & maintenance not modelled
- OGA assumes recurring H_2O demand
- WPA+UPA assumes recurring O_2 demand
- WPA+UPA+OGA has limited recurring H_2O demand

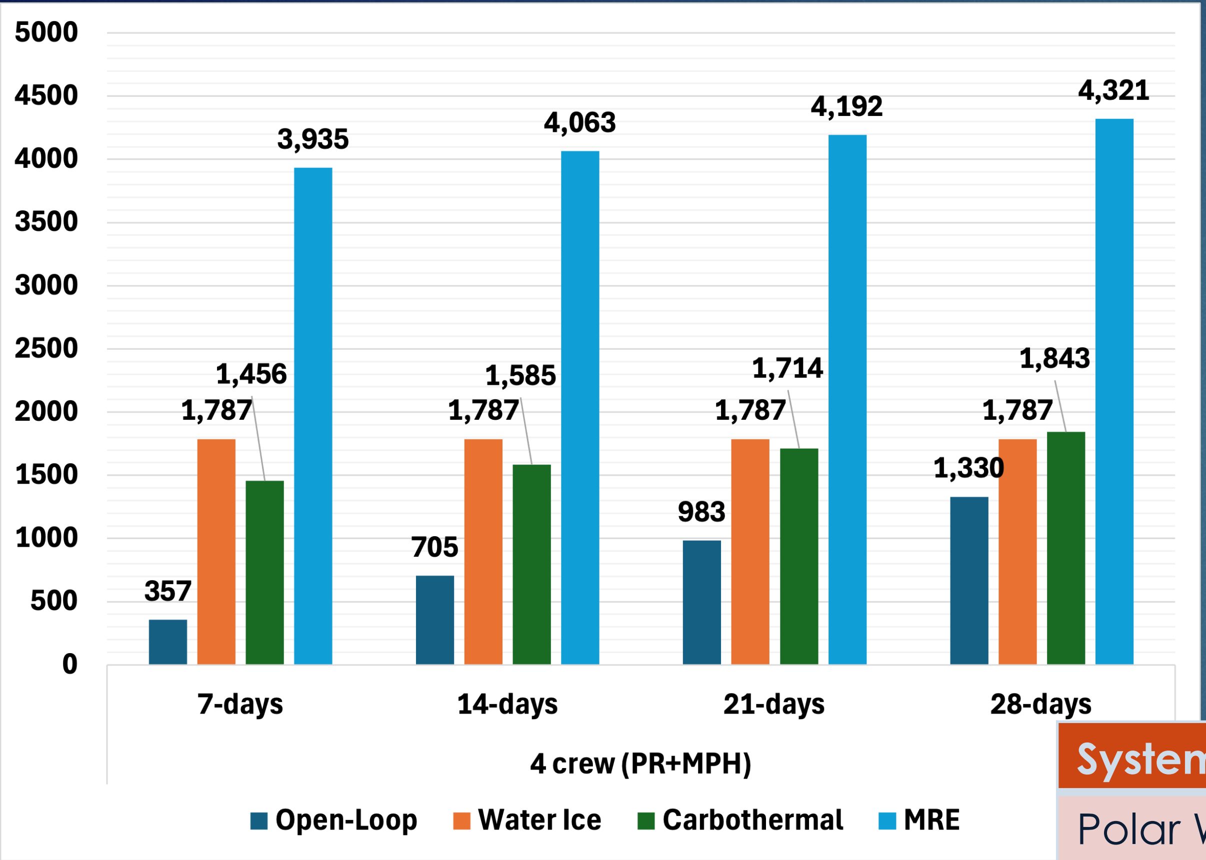


System	Mass (kg)	Power (W)	Volume (m^3)
Oxygen Generation Assy. (OGA)	676	3573	1.57
Water Processor Assy. (WPA)	1385	343	3.14
Urine Processor Assy. (UPA)		424	
TOTAL	**2,061**	**4,340**	**4.71**

Regenerative systems reduce *consumable* resupply mass by ~26-48%

Equivalent Mass Impacts

ISRU Alternatives



- Polar Water ISRU
  - Pilot-scale production (~1,125 kg/yr H_2O) provides all needed water and oxygen
- Carbothermal (O_2 from Regolith) ISRU
  - Recurring water delivery assumed
- Molten Regolith Electrolysis (MRE) ISRU
  - Recurring water delivery assumed

ISRU pilot concepts average ~60% less mass than regenerative LSS with O_2 production > 4x demand

System	Mass (kg)	Power (W)
Polar Water (Linne et al.)*	919	4880
O_2 from Regolith (Sanders et al.)*	906	2340
Molten Regolith Electrolysis (Schriener et al.)	518	18420

*Mass & power adjusted for deferment of liquefaction

Cost Impacts

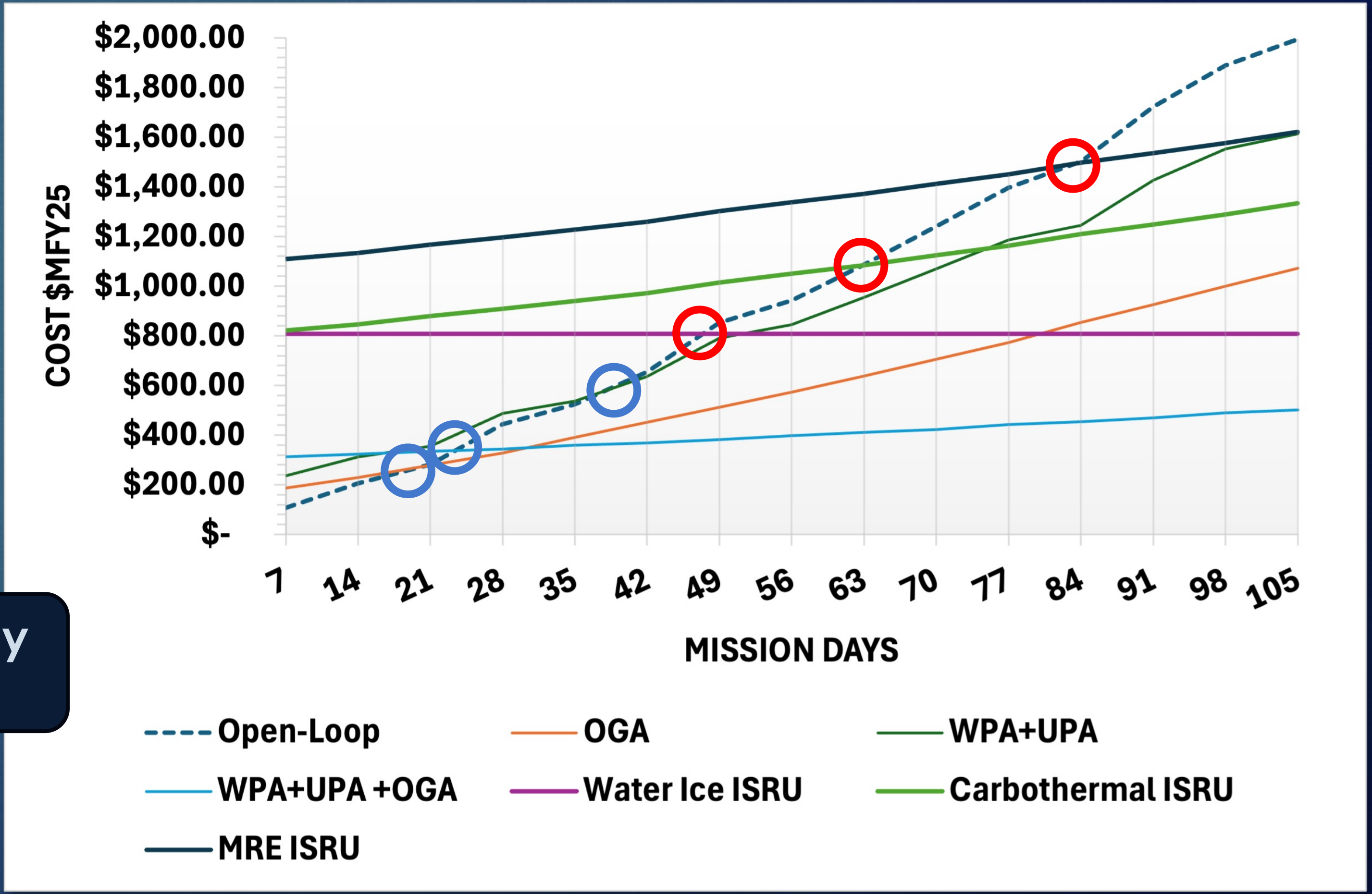
Assessing Benefits

Regression Coefficients
$\alpha, \beta, \Xi, \delta, \varepsilon, \phi, \Upsilon$

$$System\ Cost = \alpha Q^{\beta} M^{\Xi} \delta^{S} \varepsilon^{\left(\frac{1}{IOC-1900}\right)} B^{\phi} \gamma^{D}$$

Unit Quantity (*Q*) | Mass (*M*) | Specification (*S*) | Year (*IOC*) | Block (*B*) | Difficulty (*D*)

- Advanced Mission Cost Model (AMCM) is sensitive to difficulty (*D*) determination
- All regenerative LSS shows cost benefit <39 days
- Polar water ISRU begins showing benefit over WPA+UPA architectures in 49 days
- ISRU cost advantages arise within 49-217 days



Cost breakeven with Earth-based resupply
Regenerative LSS ◯ < ISRU ◯

...but mass breakeven suggests ISRU < Regenerative LSS...

Conclusion & Forward Work

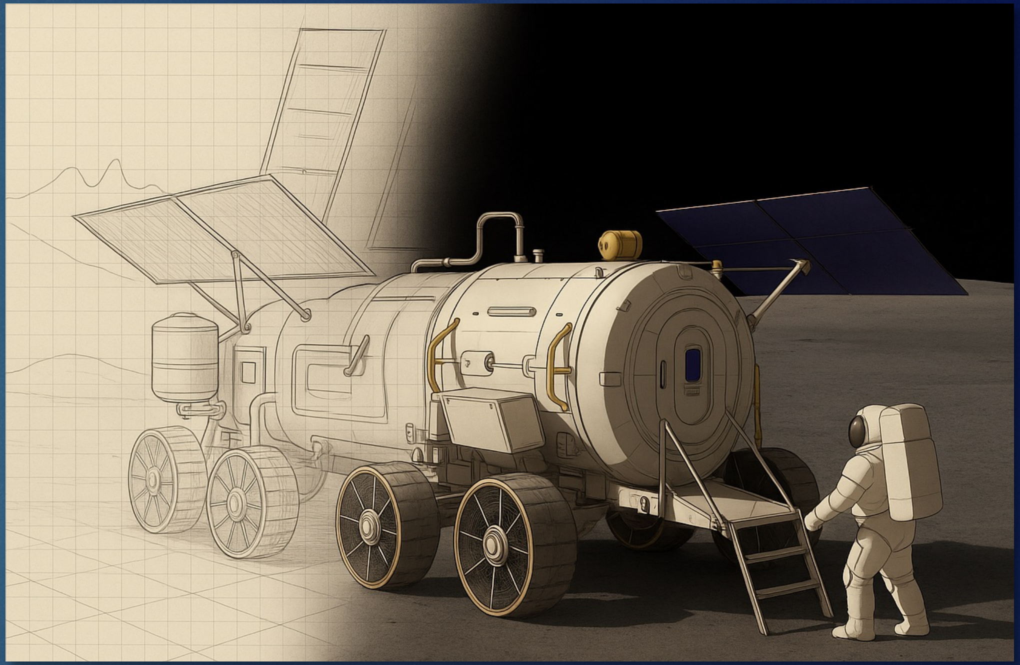
Key Takeaways:

- Early habitation concepts under development exhibit local, small-scale demand ***…may be addressed by ISRU***
- Impacts of habitation demand have non-trivial equivalent mass and cost impacts ***…mitigated by ISRU***
- ISRU & regenerative LSS both provide opportunity to minimize impact ***…but only ISRU is extensible to significant lunar economic development***

Earth-based resupply may approach >$1.5B USD (est.) within three 28-day missions & warrants transition to ISRU and/or regenerative solutions

Forward Work:

- Capture driving model sensitivities
- Include mass and cost impacts of reliability, spares, and maintenance
- Conduct model-based systems engineering (MBSE) trade space assessment



Thank You!

James E. Johnson

Ph.D. Candidate – Space Resources Program

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jejohnso@mines.edu

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