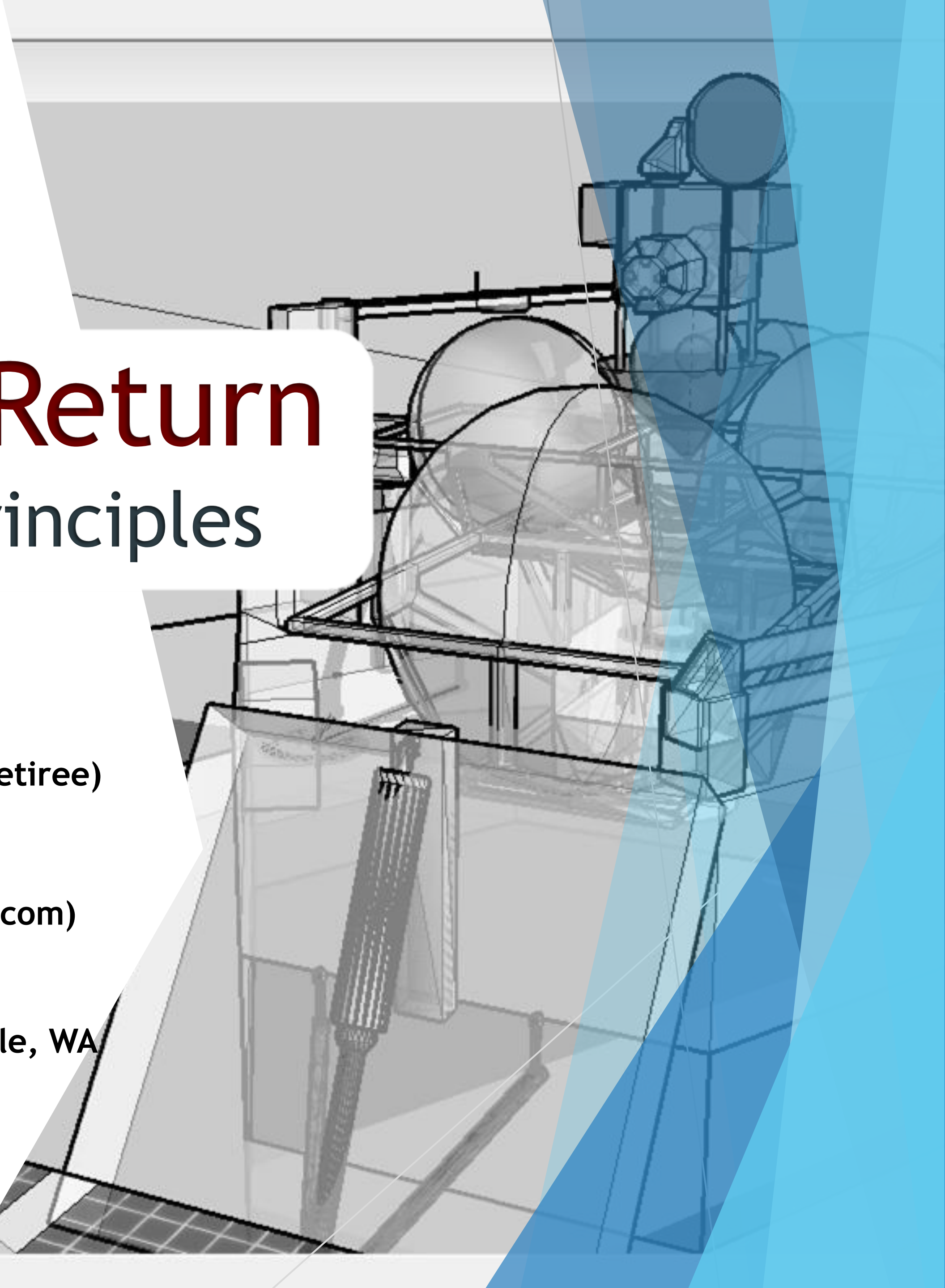
Mars Sample Return

New Ideas, First Principles



Dr. Tony Muscatello

(Mars Soc. Board, Steering cmte, NASA KSC Retiree)

Kent Nebergall

(Mars Soc. Steering Cmte Chair, MacroInvent.com)

Mars Society Conference, August 2024, Seattle, WA

Abstract

In the Spring of 2024, NASA realized that budget overruns and delays were untenable and put out a request for proposals to reduce the cost and/or accelerate the project. Tony Muscatello (NASA Red Dragon MSR concept co-author) and Kent Nebergall (Project Rigel MSR designer) spent several weeks researching this problem and creating new ideas before deciding it wasn't viable to submit a concept under the rules as written. That said, the research of past designs and concepts for new designs are certainly worth exploring and comparing in detail at this critical time.

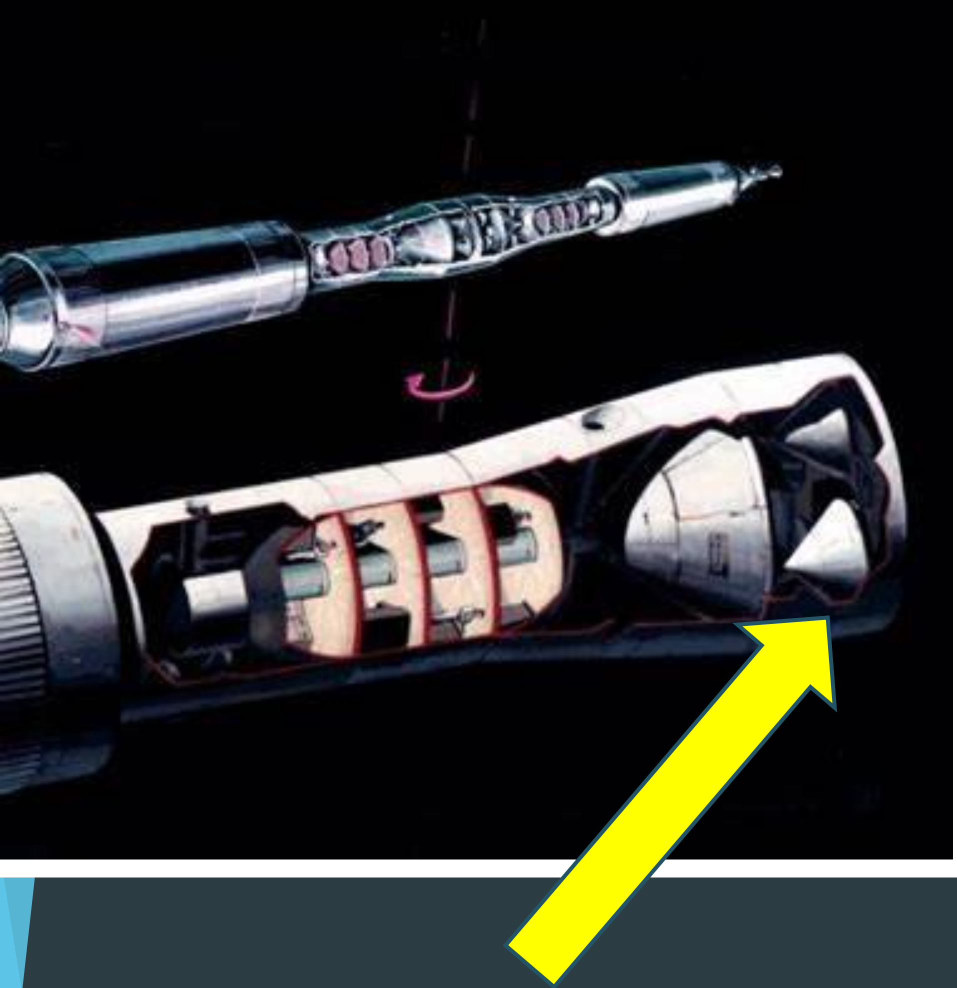
This talk will explore past designs and new concepts from the authors. We will also do an analysis of why MSR is such a strangely difficult problem from an engineering standpoint. The two new designs by the authors are as follows:

1) Kent's revised Red Dragon lander with an ascent vehicle derived from Rocket Lab's Electron second stage and using oxygen-only in situ propellant production.
2) Tony's Starship test vehicle version with a mission plan that lands the prototype Starship near Perseverance, does a demo ISRU for a small ascent vehicle, and includes more extensive surface robotics allowed by the larger vehicle payload. This allows SpaceX to flight test ISRU technology prior to crewed missions.

The talk will end with a key performance indicator analysis of all presented designs and any conclusions that can be derived from the four-decade history of these proposals.

Introduction

- Traditional Efforts
  - History of MSR Designs and Comparison
  - Why is this so hard?
  - Recent Designs
- Starship has entered the chat…
  - Our design
  - SpaceX updates



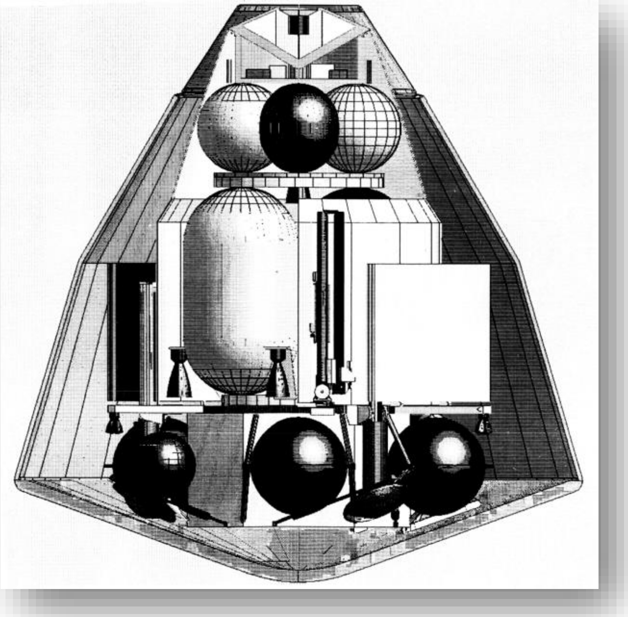
History of MSR Concepts

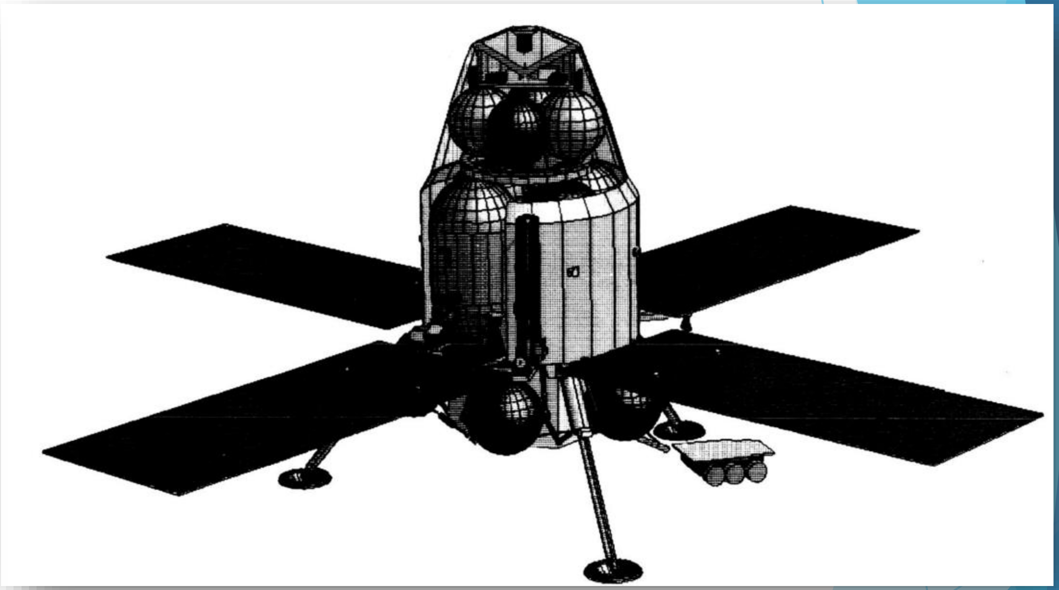
Proposals for Low-Cost Mars Sample Return Missions

Image credit – NASA

Lockheed Martin for NASA

(Zubrin, 1995)





533.7 Million USD (2024)

Mass: 560 kg

Direct Earth Return

$2.13 M/g

Cost per gram

250 g

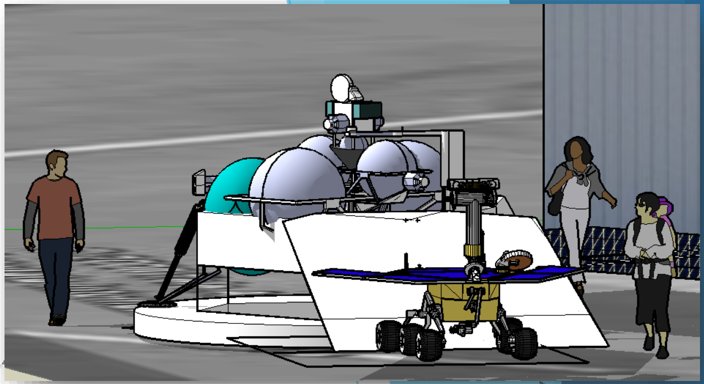
1995

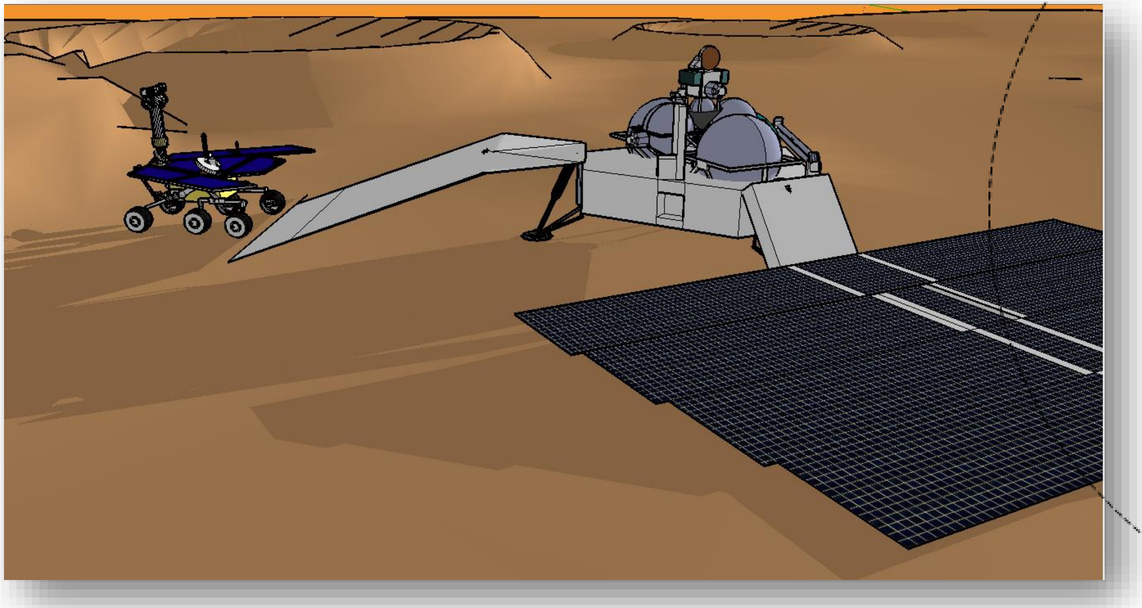
ISRU-Methane/LOX

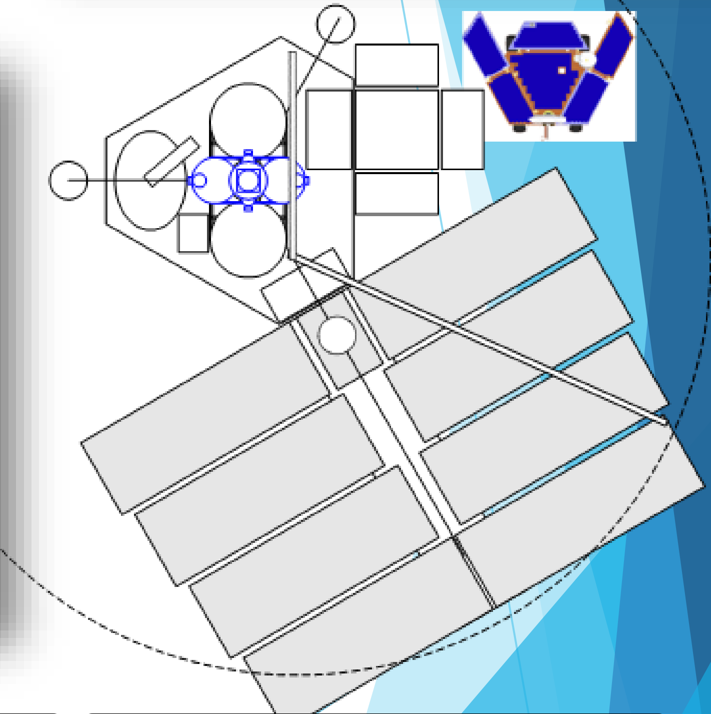
Image credit – Lockheed Martin

Project Rigel

(Nebergall, 2008, MarsDrive)







$2.92 Billion USD (2024)

Mass: 1700 kg

Direct Earth Return

$5.83 M/g

Cost per gram

500 g

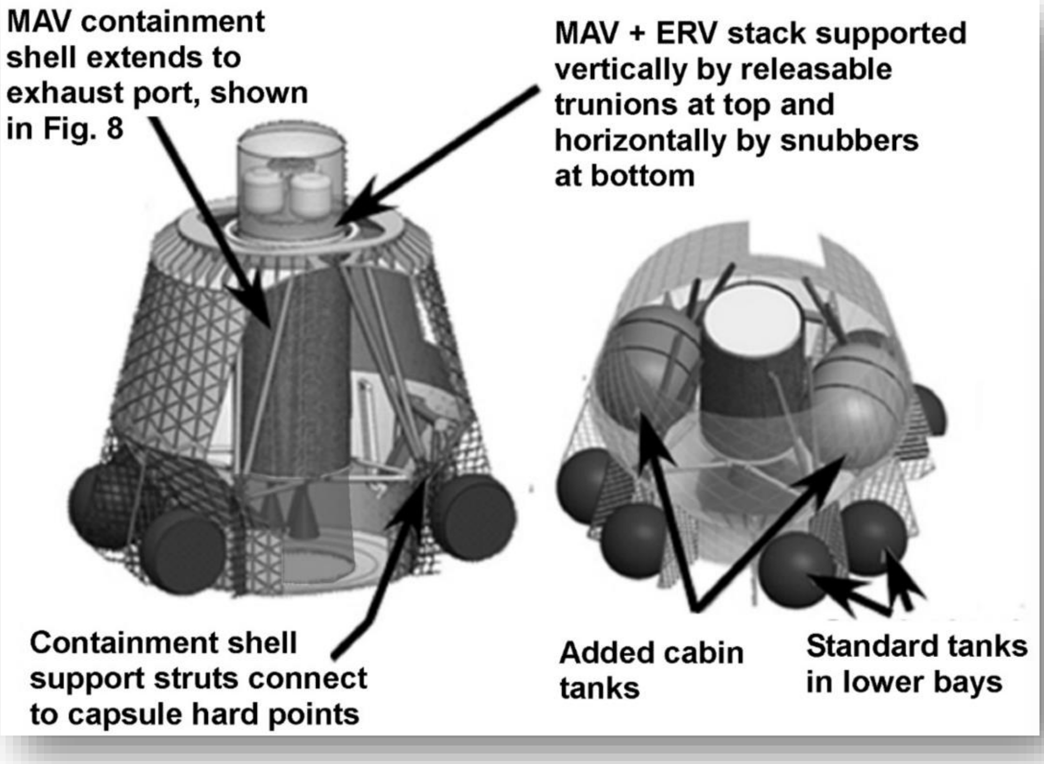
2008

ISRU- Ethylene/LOX

Image -Kent Nebergall

Red Dragon 3 MSR

(3 NASA Studies, 2011-17)



1.00 Billion USD (2024- est.)

Mass: 6500 kg

Direct Earth Return

$2.00 M/g

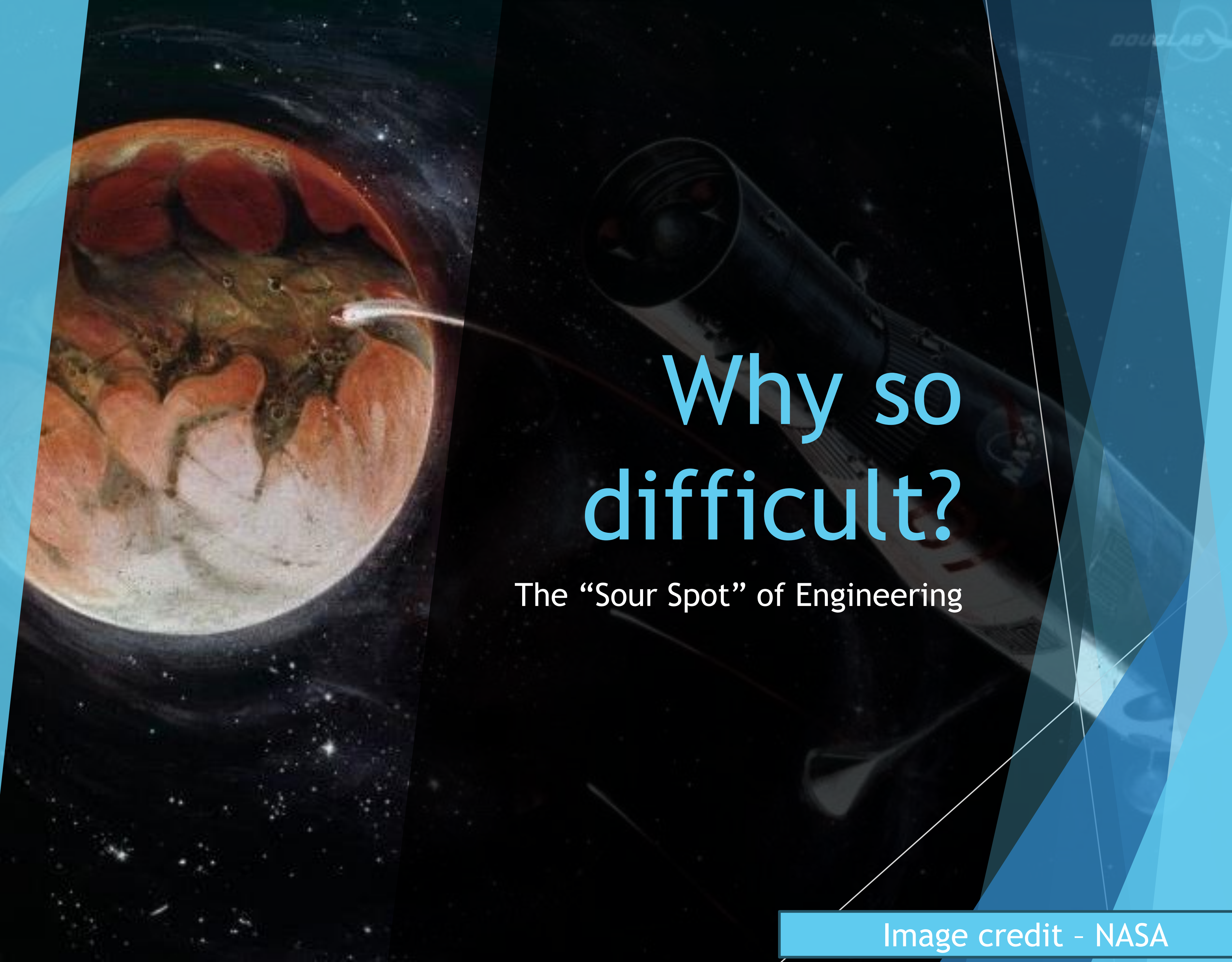
Cost per gram

500 g

2013

Hypergolic, 2 stage

Image credit - NASA



Why so difficult?

The “Sour Spot” of Engineering

Image credit – NASA

Engineering Problems

Engine Pump Design

- Needs to be the size of a grapefruit
- Yet handle extreme temperature/pressure

Engineering Problems

Engine Pump Design

- Needs to be the size of a grapefruit
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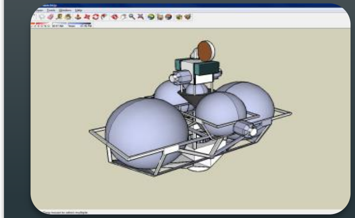
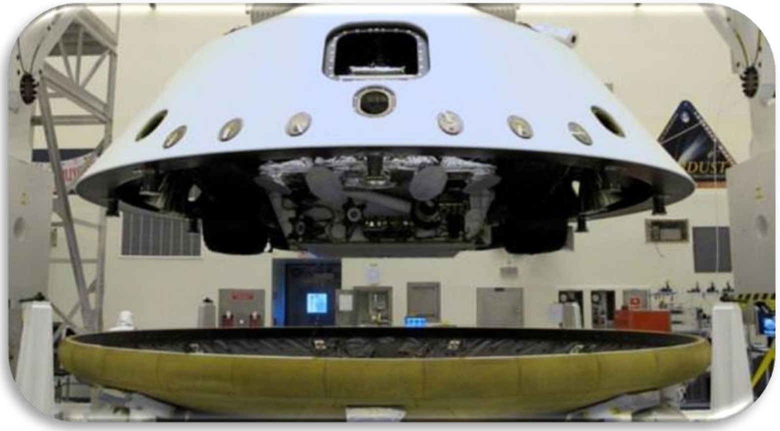
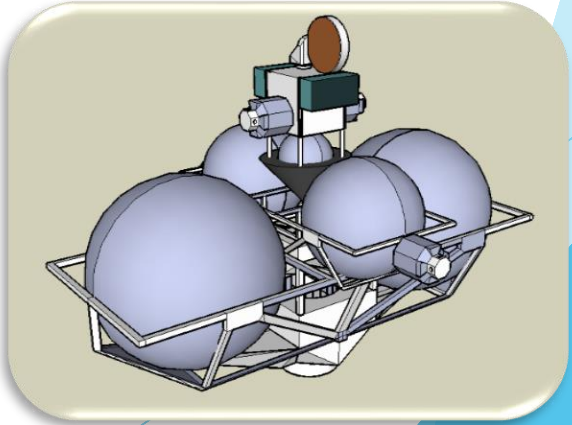


Capsule/Rocket Geometry

- Mars entry capsules are wide and flat
- Rockets want to be tall and thin for stability

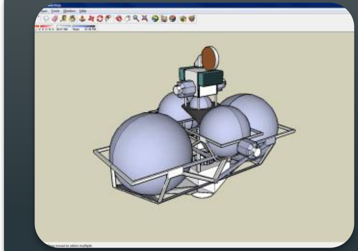




Engineering Problems

Engine Pump Design

- Needs to be the size of a grapefruit
- Yet handle extreme temperature/pressure



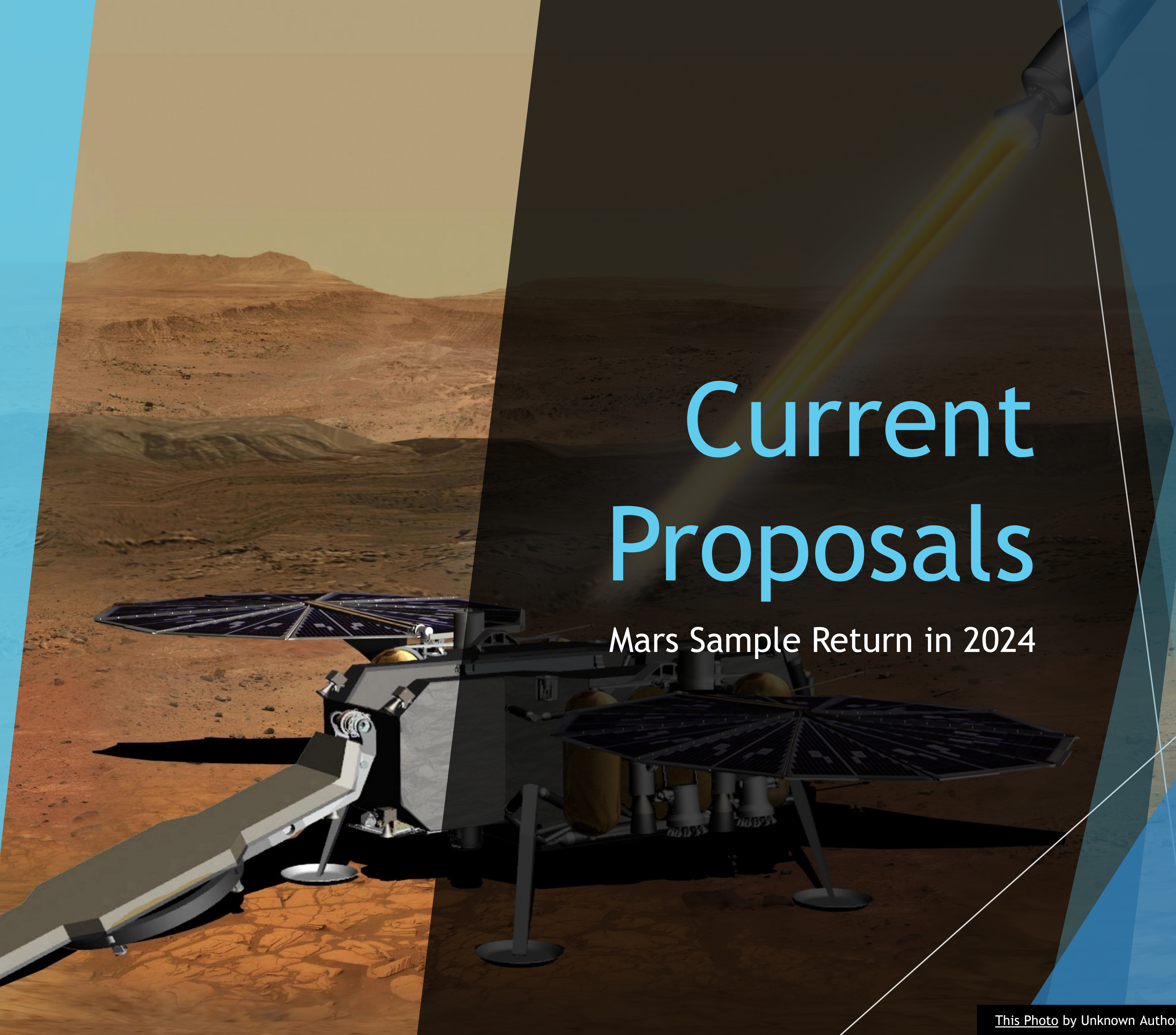
Capsule/Rocket Geometry

- Mars entry capsules are wide and flat
- Rockets want to be tall and thin for stability

$$= v_e \ln \frac{m}{m}$$

Propellant

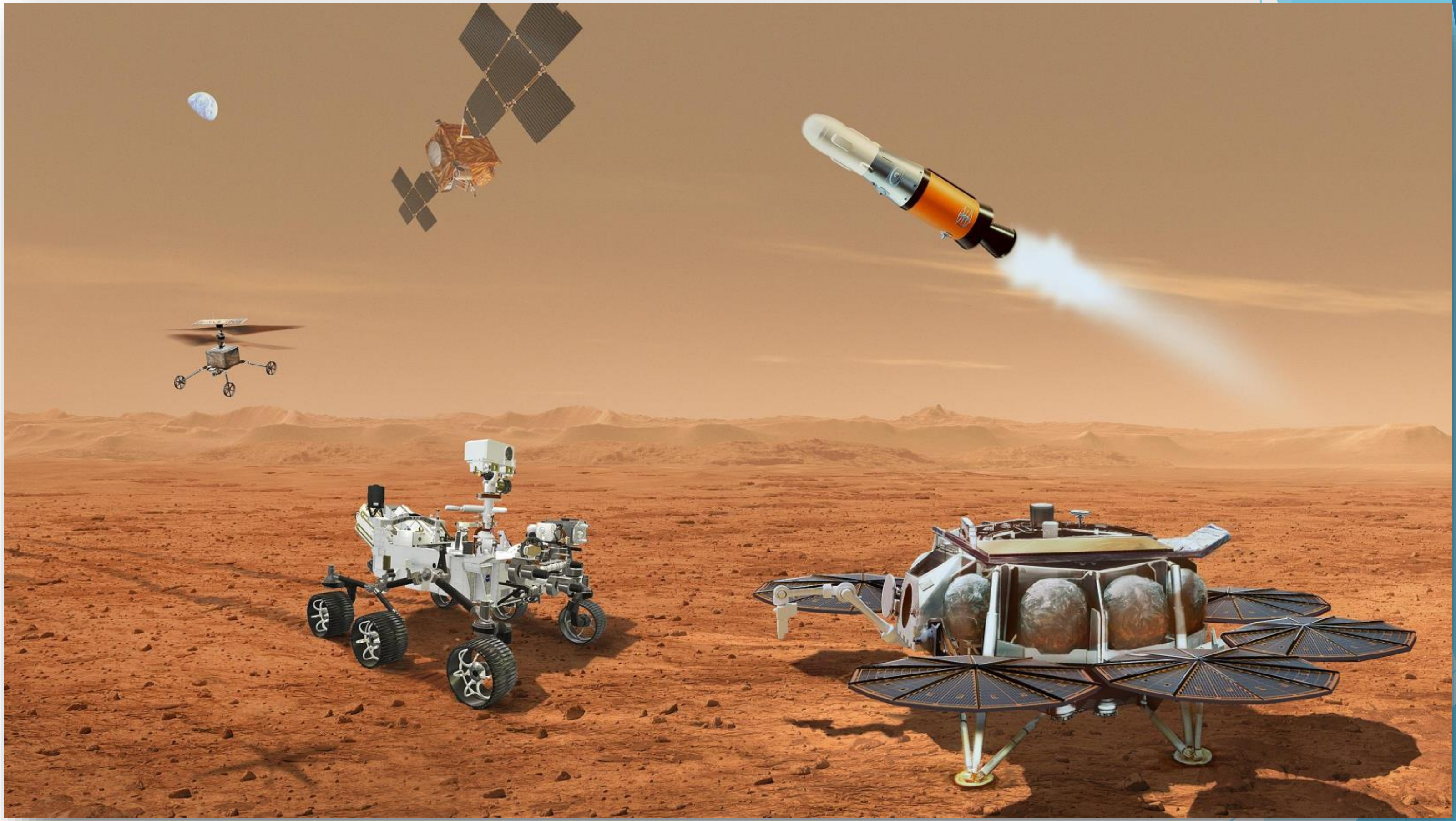
- Can barely land enough fuel to make it back
- Making fuel requires heavy hardware



Current Proposals

Mars Sample Return in 2024

NASA Reference Mission



10 Billion USD (est.)

Mass: 3375 kg

Mars Orbit Exchange

$5.0 M/g
$20.0 M/g

2000 g
500 g

2024

Solid Rocket (450 kg)

Image credit - NASA

Skycrane/MSR (Zubrin)

Article Published in Space News (May 6, 2024)

Illustration from earlier NASA/MSR proposal (SciTechDaily)

5 Billion USD (est.)

Mass: 1700 kg

Direct Earth Return

$1.0 M/g

Cost per gram

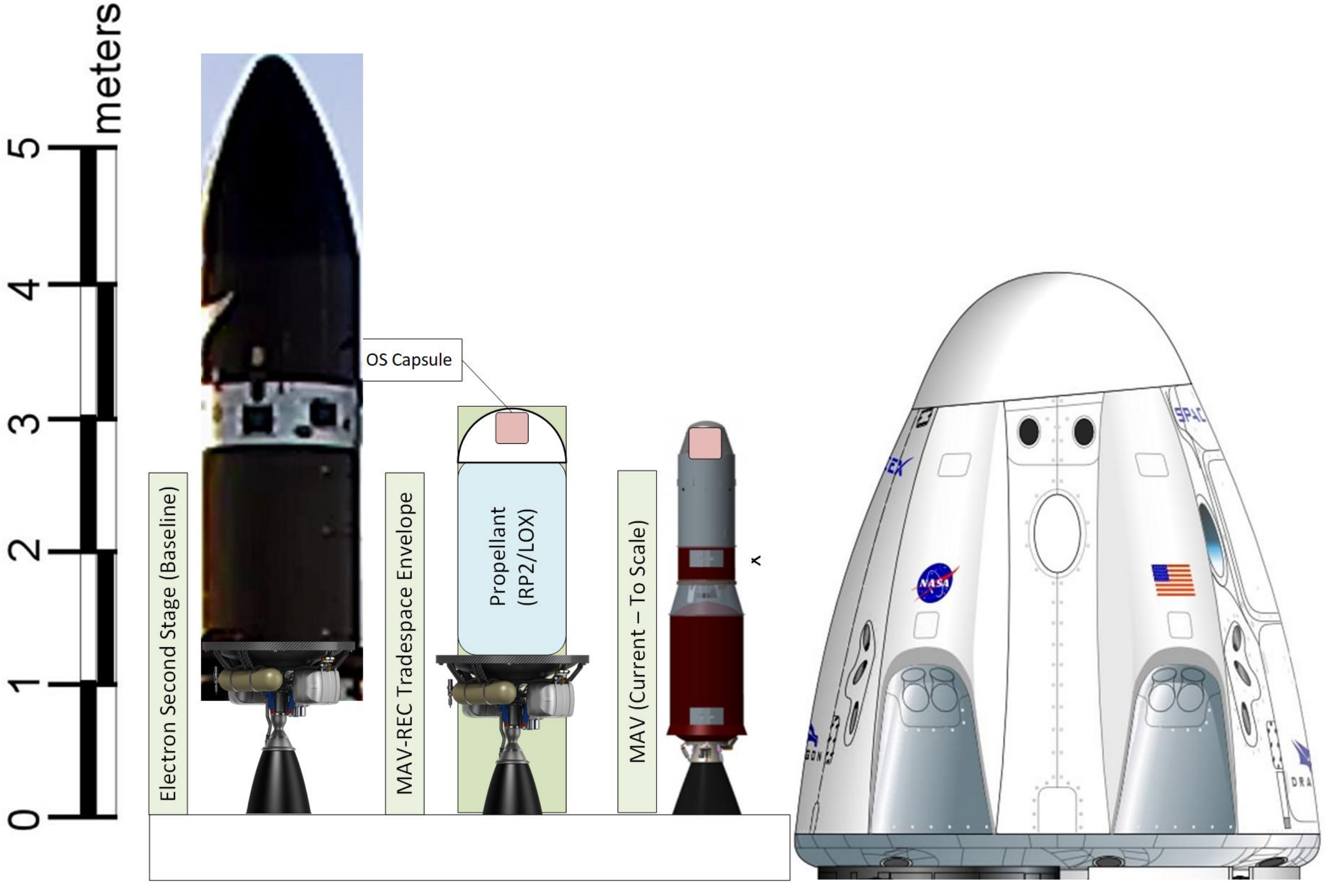
5000 g

2024

Hypergolic or ISRU, 2 stage

Image credit - SciTechDaily

Project MAV-REC (Nebergall)



4 Billion USD (est.)

Mass: 6500 kg

Mars Orbit Exchange

$2.0 M/g

Cost per gram

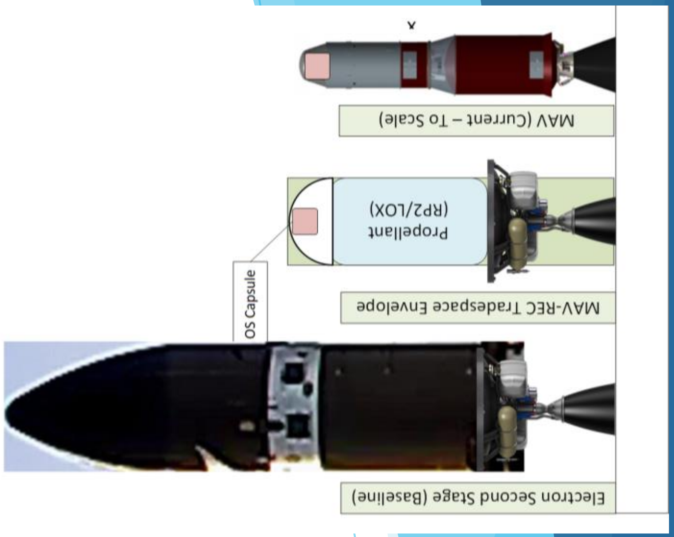
2000 g

2024

ISRU LOX + RP1

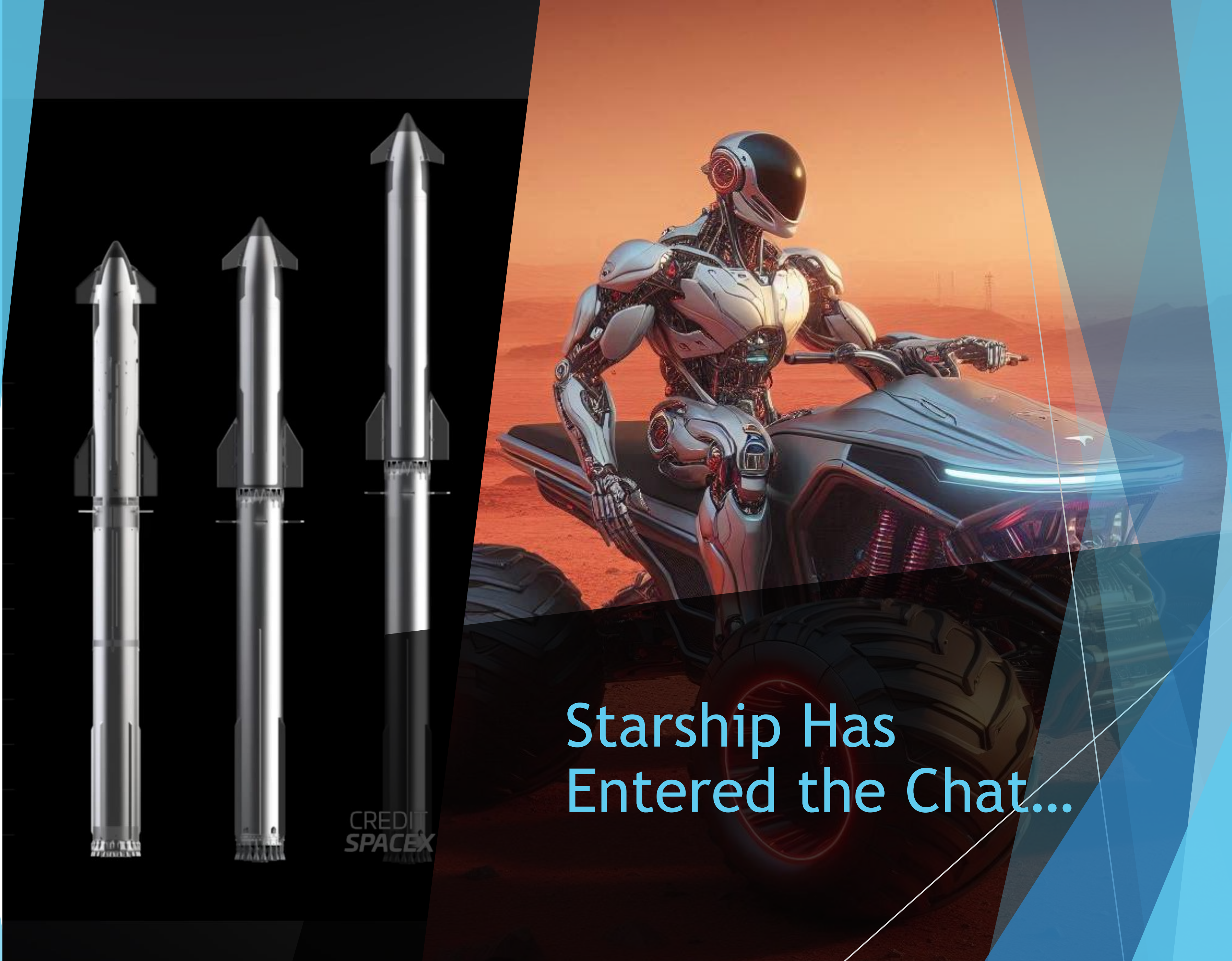
Image credit – Rocket Lab, WikiMedia, NASA, Kent Nebergall

Mars Ascent Vehicle Comparison



Component Mass (kg)	Mars Orbit		Escape to Earth	
	MAV-REC	Electron	MAV-REC	Electron
Total Propellant Mass	628	1999	668	1997
Liquid Oxygen	383	1218	383	1218
RP-1	245	781	245	781
Fully Fueled/Loaded Mass	903	2874	781	2335
Post-Burn Mass	275	875	113	338
Empty Vehicle Mass	150	250	150	250
Sample/Capsule Mass	125	625	-37	88

Image credit – Rocket Lab, Wikimedia, NASA, Kent Nebergall



Starship Has Entered the Chat…

Image credit – SpaceX, MS Copilot AI

Fast Return Capsule

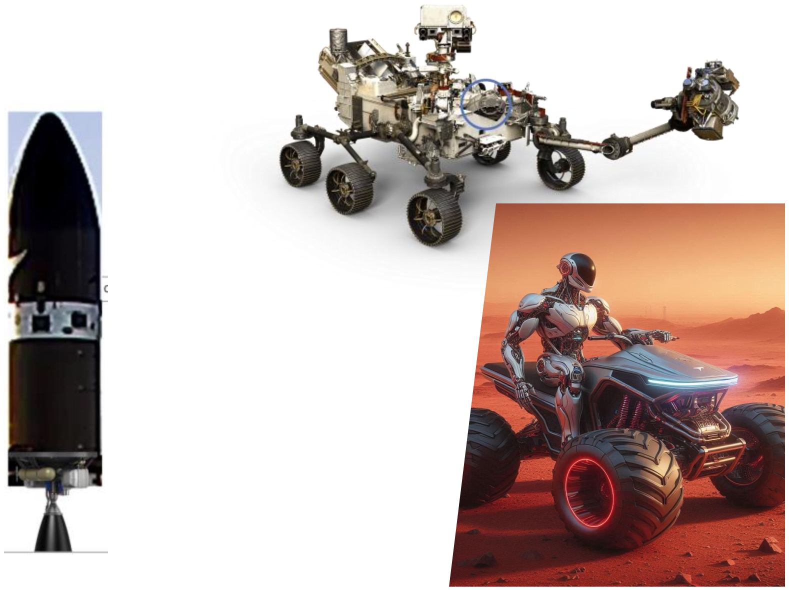
Landing + ~ 14 Sols

Launch Perseverance Samples Directly to Earth-Moon L5 and Gather Robotically

Image credit – SpaceX, NASA, Rocket Lab,

Slow Return Capsule

Landing + ~ 14 Days



Launch Perseverance Samples Directly to Earth-Moon L5 and Gather Robotically

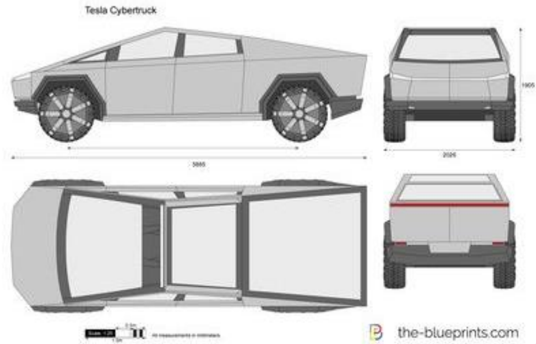
Landing + 480 Sols (492.5 Days)

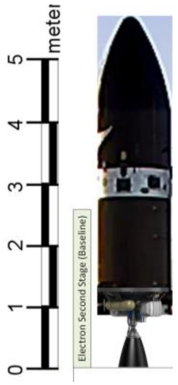
Launch New Samples from Optimus Robots over Much Larger Range, depth

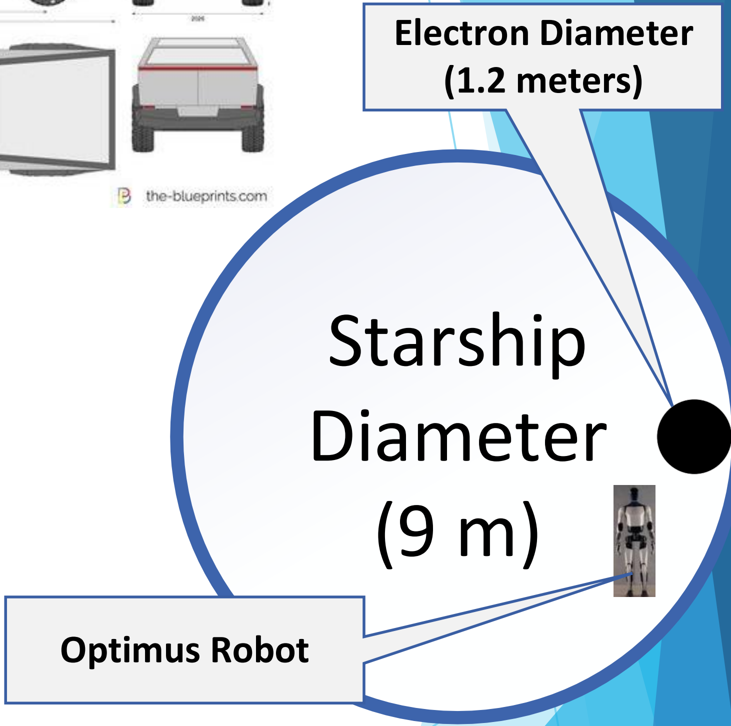
Image credit – NASA, Rocket Lab

Starship MSR (Muscatello/Nebergall)

- Two Electron Stage 2 on Starship, along with solar plant, Optimus robot crew of 4+2 spares, and two Cybertruck ATVs
- In the first return to Earth window, launch 40 kg directly to Earth-Moon L5. Collect them with an Optimus-crewed Falcon Heavy/Dragon.
- Gather an additional 400 kg of samples over next 500 days and return in next window.







Electron Diameter (1.2 meters)

Starship Diameter (9 m)

Optimus Robot

6 Billion USD (est.)

Mass: 150 MT

Earth-Moon L5 (tbd)

$150,000/g
$15,000/g

L1 - 40 kg
L2 - 400 kg

2024

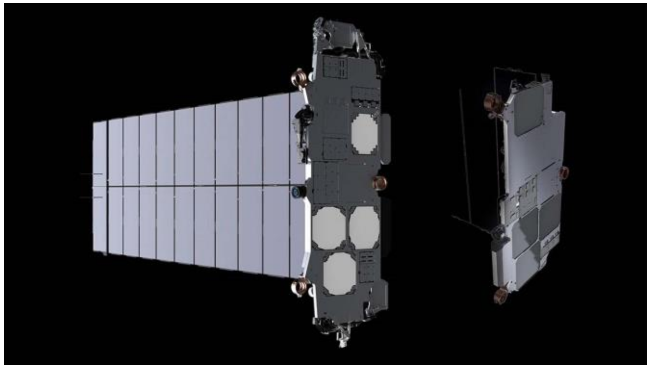
ISRU: LOX + Methane or RP1

Power Demand, Solar Array

	Hrs/Sol	kWh/Sol	Array (M^2)	Mass (kg)
8 Optimus Robots	12	100	156	1719
ISRU Plant	24	48	74	815
Cybertruck	8	180	274	3028
2 ATVs	6	115.2	173	1908
Starship (base)	24	720	1071	11,785
Total		1163.2	1691	18,598
			~42 x 42 meters	**18.6 MT**

Landed Cargo Mass

	Mass (kg)	Quantity	Support ratio	Total Mass
Optimus Robots	57	40	2	4560
Electron/ Fuel	1000	2	2	4000
Cybertruck	3050	1	2	6100
ATVs	370	2	1.5	1110
Solar Panels	18600	1	1	18,600
ISRU Plant	100	1	1	100
Landing Pads	1000	2	1.1	2200
				44,670



Parameter	Starlink V2 Mini	Starlink V2	ERO
Mass (kg)	740	1250	7000
Solar Panel (m^3)	105		144
Wingspan (m)	30		38

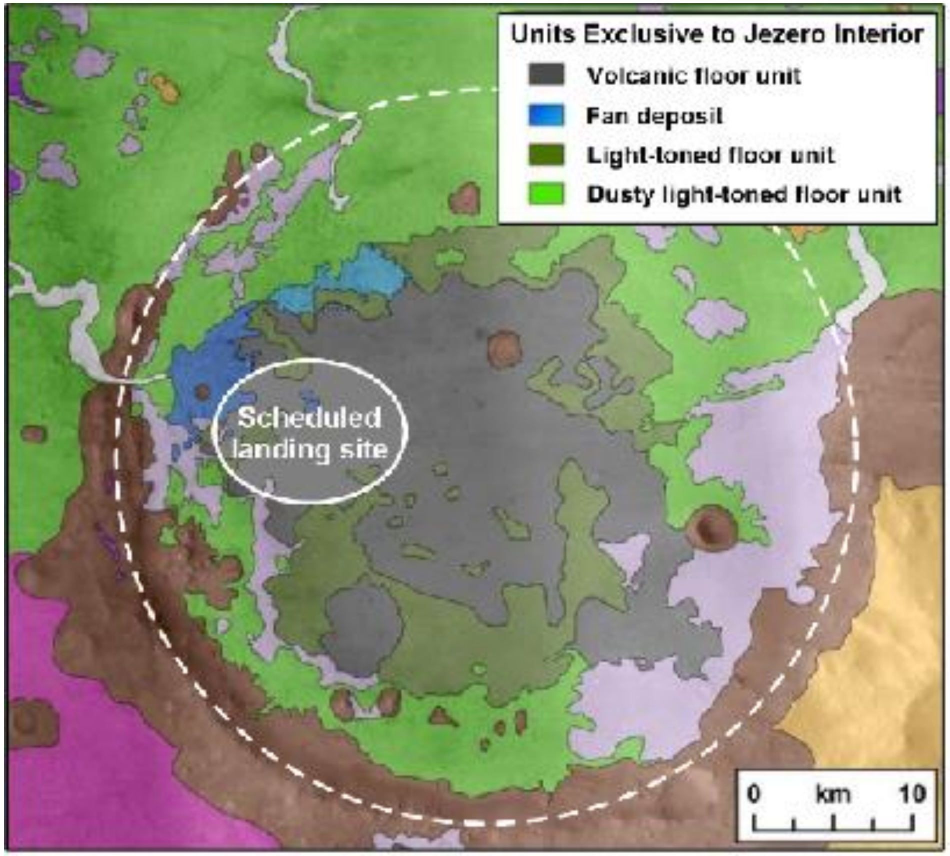
Comms/Earth Return Orbiters

Image credit – SpaceX, ESA

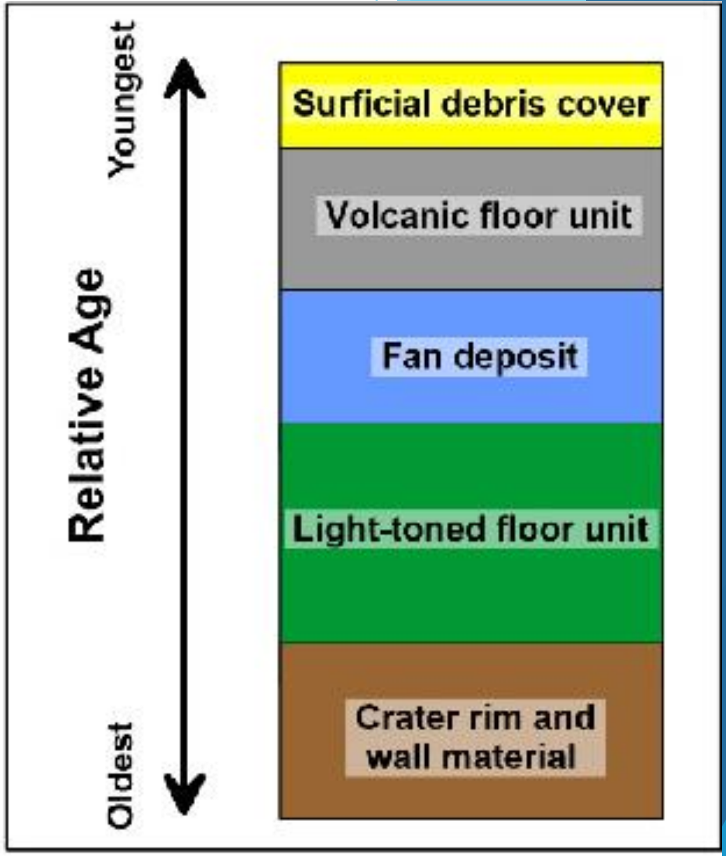
Original Proposal	Alternative	Benefits
Electron Rutherford Engine (RP-1/LOX)	Lunar Starship Landing Engine (Methalox)	ISRU capacity test, Long life fuel storage
Oxygen only ISRU	Make Methalox with water brought from Earth	Could also test water shielding prior to consumption
Optimus Robots	Other Options (Drones, Rovers, Spot, etc.)	Could offer “ride share” testing of other mobility systems.

Other Design Options

Landing Site



(a)



(b)

2024 Oct/Nov	**Escapade**	USA- Dual Rocket Lab magnetosphere probes on New Glenn Debut launch
2026 Nov/Dec	**MMX**	Japan - mission to sample return Phobos, fly-by Demos, and examine Martian atmosphere. Also European Phobos rover.
2028 Dec 2029 Jan	**Rosaland Franklin**	ESA rover (previously ExoMars). 300 kg. Note much of the life detection hardware "descoped" so It's another geologist now.
	Mars Orbiter Mission 2	India – follow up orbiter to MOM 1.
2030	**Tianwen-3**	China – Mars Sample Return

Other Near-Term Missions

Thank you!
Questions?

Kent’s Mars Design portfolio below.

27th Annual International Mars Society Convention -
University of Washington - Seattle, WA
August 8-11, 2024

Mars Sample Return Using SpaceX Starship-ISRU Demonstration

Tony Muscatello, Ph.D.
Member of Mars Society Board of Directors
Steering Committee Member
Mars Technology Institute Advisor
Former Mission Support Director
NASA KSC Retiree

Aurora CO

Disclaimer

Although I used to work for NASA at the Kennedy Space Center, this presentation is only my own personal opinion and should not be interpreted in any way shape or form as being representative of NASA policy.

---Tony Muscatello

Introduction

On April 22, 2024, NASA issued a call to solicit "industry proposals to carry out rapid studies of mission designs and mission elements capable of delivering samples collected by the Mars Perseverance rover from the surface of Mars to Earth."

Kent Nebergall asked me to work with him on a proposal that would use a Rocket Lab Electron 2nd stage to boost the samples to Mars orbit for collection

One option we discussed was to use a SpaceX Starship to land near the samples to deliver a fetch rover and the Electron to launch them

An option was to leverage the opportunity to produce liquid oxygen to fuel the Electron and prove the feasibility of part of Robert Zubrin's Mars Direct architecture and SpaceX Mars settlement plans based on Mars Direct

After we initiated our study, Robert Zubrin published his recommendations in Space News (May 6, 2024), based on the proven Sky-crane landing system used for Curiosity and Perseverance

We ultimately dropped out of the competition because the scope was much more than we could accomplish, but we decided to present our work at the Mars Society Convention

SpaceX was awarded one of the grants, so it will be interesting to compare their approach to ours, once it's available

Mission Requirements

- Launch at least __ kg of Mars Sample Tubes into Mars Orbit
- Rendezvous with sample return vehicle
- Transfer samples for return to earth
- OR launch samples directly to earth if feasible

Starship Lander Approach

- Assume Electron 2nd Stage (E-2) can be configured to launch from the surface of Mars to Mars orbit
- Estimate propellant requirements for E-2 to orbit (Kent)
- Select an existing rover (Spirit-class, as proposed by Zubrin) to fetch samples or use Tesla android robots to gather samples
- Compare mass, power and volume for carrying LOX and kerosene for launch E-2 to synthesizing LOX on Mars (TM)
- Evaluate any issues of landing with E-2 in Starship payload bay and remote control deployment and launch of E-2 (TM)

Calculations

- The Electron users guide states: “The 1.2 m diameter second stage has approximately 2,000 kg of propellant on board.”
- In the RP-1 webpage, Wikipedia says “Oxidizer-to-fuel ratio 2.56”
- Mass(O2) + Mass(RP-1) = 2000 kg
- Mass(O2)/Mass(RP-1) = 2.56
- Mass(O2) = 2.56xMass(RP-1)
- Mass(O2) = 1438 kg; Mass(RP-1) = 562 kg

Starship Lander Approach: Summary of ISRU Options

ISRU Technology	O_2 Production Rate (for 492.5 days)	Mass, kg	Power, W	Volume, m^3
O2 Production Rate Goal	3.22 kg/day	Minimize	Minimize	Minimize
NASA RWGS/Water Electrolysis (2015)	3.6 kg/day	57 kg	**1328 W**	NA
Pioneer Astronautics RWGS/Water Electrolysis (1997)	5 kg/day	66 kg	4110 W	NA
Modified Pioneer Astronautics IMISPPS (RWGS/WE) (2013)	3.275 kg/day	270 kg	4000 W	0.875 m^3
Scaled Up MIT/Oxeon Mars Sample Return-Scale MOXIE (2018) (24 units calculated based on 18 unit design)	**3.22 kg/day**	**56 kg**	2117 W	**0.0242 m^3**

Conclusions

The modified O2-only production design based on 24 MOXIE-scale stacks has the lowest mass and volume

It has the second lowest power compared to the NASA RWGS/WE system

It is based on TRL 9 hardware, i.e. the MOXIE device that has been successfully demonstrated on Mars on the Perseverance Rover

Therefore, it has the lowest technical risk, as well

The 24 MOXIE + 2 pumps design is recommended for the Starship-based Mars Sample Return design

Figure 6. 1 stack of 18 MOXIE cell

24 × 24 × 31 cm

Electron Propellant Mass Requirements and Production-Alternate Technology: Mars Sample Return-Scale MOXIE

Supporting Information Slides

Electron Propellant Mass Requirements and Production- <u>NASA RWGS/Water Electrolysis</u>

- **Mass(O_2) = 1438 kg; Mass(RP-1) -- <u>1582 kg O2 w/10% margin</u>**
  - 2000 kg total propellant (Electron Users Guide)
  - Assumed mass ratio of 2.56 (Wikipedia)
- Sanders *et al.* (including ACM) (AIAA SPACE 2015) published a study of ISRU methods of producing propellant for a Mars Sample Return Mission including **Oxygen-only via RWGS/Water Electrolysis (WE)**
- Sanders et al. specified 480 sols (=492.5 earth days) to prepare ISRU propellant
- Required production rate for E-2 **(w/+10%)** = **3.22 kg/d** = **0.134 O2 kg/h**
- Sanders et al.'s O_2-only w/RWGS/WE production was **0.15 kg/h (1.12 x MSR)**
- **A close match**
- Sanders et al.'s RWGS/WE option masses **57 kg** and uses **1,328 W** power
- **Volume of the hardware was not given, but should not be an issue for a Starship**

Electron Propellant Mass Requirements and Production-Pioneer Astronautics RWGS/Water Electrolysis

- Zubrin, Frankie, and Kito (1997) reported the design of an RWGS system to produce O2 (or both O2 and methanol with a 2nd reactor) for a total of 1 kg/d (0.0417 kg (CH4+O2)/hr → **0.0273 kg O2/h**)
- They estimated the mass and power for other rates, e.g. **5 kg O2/day → 80 kg mass and 13,540 W power including O2 liquefaction**
- One of these 5 kg/d units would be able to meet the required 3.22 kg/d with a 55% margin or 55% shorter time
- **Volume was not estimated, but it should fit easily into a SpaceX Starship**

Electron Propellant Mass Requirements and Production-Pioneer Astronautics RWGS/Water Electrolysis Prototype (2001)

- **Larger-scale RWGS built for NASA KSC by Pioneer Astronautics-** ***Mass and Volume Not Available***

Electron Propellant Mass Requirements and Production (Cont.)

- Zubrin, Muscatello, and Berggren (2013) published the design of a combined Sabatier/RWGS (IMISPPS) system to produce both O2 and CH4 in a single reactor for a total of 1 kg/d (0.0417 kg (CH4+O2)/hr → **0.655 kg O2/d**)
- Five of these units would be able to meet the 3.22 kg O2/d requirement
- **Five flight units ~270 kg and 3500 W power, rounded up to ~4000 W due to loss of heat from Sabatier catalyst**

Photos and Drawing of Pioneer Astronautics Prototype IMSPPS Unit

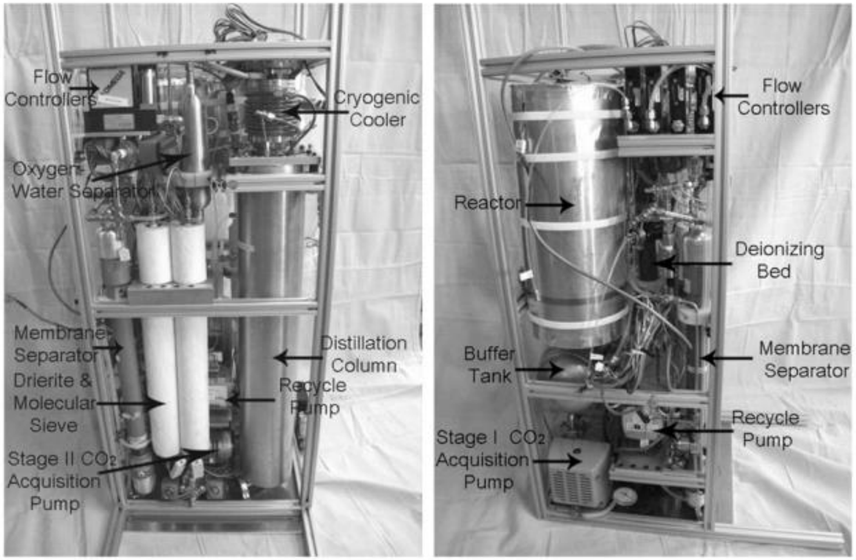


Fig. 11. Pictures of the flight-like IMISPPS

- 16”x18”x37”
- 40.6 cm x 45.7 cm x 94 cm
- **= 0.175 m³ each = 0.875 m³ total**
- 115 kg each (**54 kg** flight version)
- **270 kg for 5** total flight versions

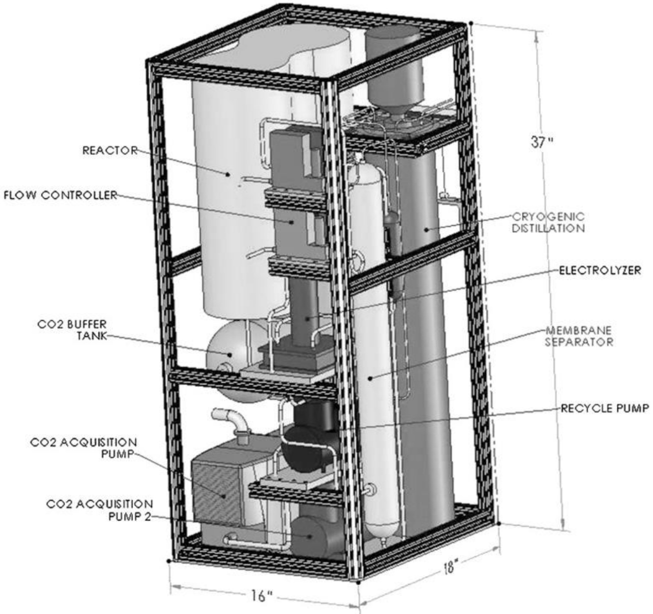


Fig. 10. CAD drawing of flight-like IMISPPS

Electron Propellant Mass Requirements and Production-Alternate Technology: Mars Sample Return-Scale MOXIE

- E-2 required production rate (+10%) = **3.22 kg/d** = **0.134 kg/hr** [assuming 24 hr ops]
- For a potential Mars Sample Return Mission with a SpaceX Red Dragon (later cancelled by SpaceX), Nasr, Mayen and Hoffman (2018) designed a scaled-up O2 production system based on the MOXIE prototype which was later successfully demonstrated on the Perseverance Rover on Mars
- **Their design would produce 955 kg of O2-only in 10 months at a rate of 0.0981 kg O2/h in a single reactor for a total of 2.35 kg/d <u>(errata: really need 0.131 kg/h for 10 months)</u>**
- **18 MOXIE-sized units would be combined** to produce the O2 for their Mars Sample Return design. **18 MOXIE units plus scroll compressor: Mass 15 kg + 18 kg = 33 kg, Dimensions 24 × 24 × 31 cm each unit, Power consumption (SOXE = 404 W + Pump 789 W = 1,193 W. Volume = 0.0179 + 0.00386 m^3 = 0.22 m^3**
- **Each MOXIE-size cell generates 0.005585 kg/h → 0.134 kg/h/0.005585 = 23.5 MOXIE cells**
- **24 units + 2 pumps would be required for the E-2 MSR**
- **24 MOXIE Units + 2 pumps: 20 kg + 36 kg = 56 kg, 539 W + (2x789)= 2,117 W, stack of 24x24x42 cm MOXIE (@) units (volume = 0.0242 m^3 + 2 pumps = 0.00791 m^3) = 0.0321 m^3**

Options Not Included

The following slides partially describe OxEon development studies for much larger SOXE oxygen production systems

However, not enough information was included in the papers to evaluate them relative to the designs above.

They are based on TRL 9 technology (MOXIE), but they have not been tested on Mars itself

Therefore, they would introduce additional risk without clear benefits

Electron Propellant Mass Requirements and Production-Alternate Technology: OxEon Full-Scale Version of MOXIE (33x)

- Hollist, Elwell, Hafen, Pike, Hartvigsen, and Elangovan co-authors (2023)
- E-2 Required production rate (+10%) = 3.22 kg/d = **0.134 kg/hr** [assuming 24 hr ops]
- OxEon design goal = **2.3 kg/h = 17.2 x required rate → way oversized**
- **Design is for production of both CH4 and O2 from water and CO2, so it is difficult to determine the O2-only mass, power and volume**
- **CO2 + 2 H2O → CH4 + O2 (Direct Co-Electrolysis), 50% of O2 is from H2O**
- **Therefore, the production rate w/o water is 1.15 kg O2/h, still 8.6 x the goal so operation power could be reduced to by dividing by 8.6**
- OxEon CH4/O2 System: **18.2 kg Cell Stack, 5,400 W, 65-cell stack** has a size of 13 x 13 x 2 cm = **m^3**
- **Tested for 100 h in JPL Mars Chamber -**
- **See next slide for Methanation Reactor specs**

Figure 5. ISRU design variant 65-Cell SOXE, internally manifolded with sealed perimeter.

Figure 6. Size comparison of SOXE stacks from MOXIE and NextSTEP projects.

Electron Propellant Mass Requirements and Production-Alternate Technology: OxEon Full-Scale MOXIE - Photos

Electron Propellant Mass Requirements and Production-Alternate Technology: OxEon Full-Scale MOXIE

- Hollist, Elwell, Hafen, Pike, Hartvigsen, and Elangovan co-authors (2023)
- Required production rate (+10%) = 1.3 kg/d = **0.053 kg/hr** [assuming 24 hr ops]
- OxEon design goal = **2.3 kg/h** – **43.4 x required rate** → **way oversized**
- **Design is for production of both CH4 and O2 from water and CO2, so it is difficult to determine the O2-only mass, power and volume**
- **CO2 + 2 H2O → CH4 + O2 (Direct Co-Electrolysis), 50% of O2 is from H2O**
- **Therefore, the production rate w/o water is 1.15 kg O2/h, still 21.7 x the goal so operation power could be reduced to by dividing by 21.7**
- **A very rough approximation would be to use 50% of the OxEon other system parameters**
- OxEon CH4/O2 System: **18.2 kg Cell Stack, 5,400 W, 65-cell stack** has a size of 13 x 13 x 20 cm = 0.00338 m^3
- **Volume = 0.97% of IMISPPS version (not including pump and electronics)**
- **Mass = 17% x IMISPPS version**
- **Power = 3.9 x IMISPPS version**
- **See next slide for Methanation Reactor specs**

Electron Propellant Mass Requirements and Production-Alternate Technology: OxEon Full-Scale CO_2 Electrolysis Reactor

- Hollist, Elwell, Hafen, Pike, Hartvigsen, and Elangovan co-authors (2023)
- Required production rate (+10%) = 1.3 kg/d = **0.053 kg/hr** [assuming 24 hr ops]
- OxEon design goal = **2.3 kg/h – 43.4 x required rate → <u>way oversized</u>**
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- **<u>A very rough approximation would be to use 50% of the OxEon other system parameters</u>**
- OxEon CH4/O2 System: **18.2 kg Cell Stack, 5,400 W, 65-cell stack** has a size of 5 x 10 x 2 cm = **0.0001 m^3**
- **Volume = 0.029% of IMISPPS version (not including pump and electronics)**
- **Mass = 17% x IMISPPS version**
- **Power = 3.9 x IMISPPS version**
- **See next slide for Methanation Reactor specs**

Electron Propellant Mass Requirements and Production - Alternate Technology: OxEon Full-Scale Methanation Reactor Photo & Specs

- OxEon Methanation System:
- Tubular Reactor dimensions: 60 x ~5 cm O.D. = ~0.0017 m^3 -Mass = ~4.5 kg
- Volume = 0.34% of IMISPPS version (not including pump and electronics)
- Mass = 4.2% x IMISPPS version
- Power = x IMISPPS version

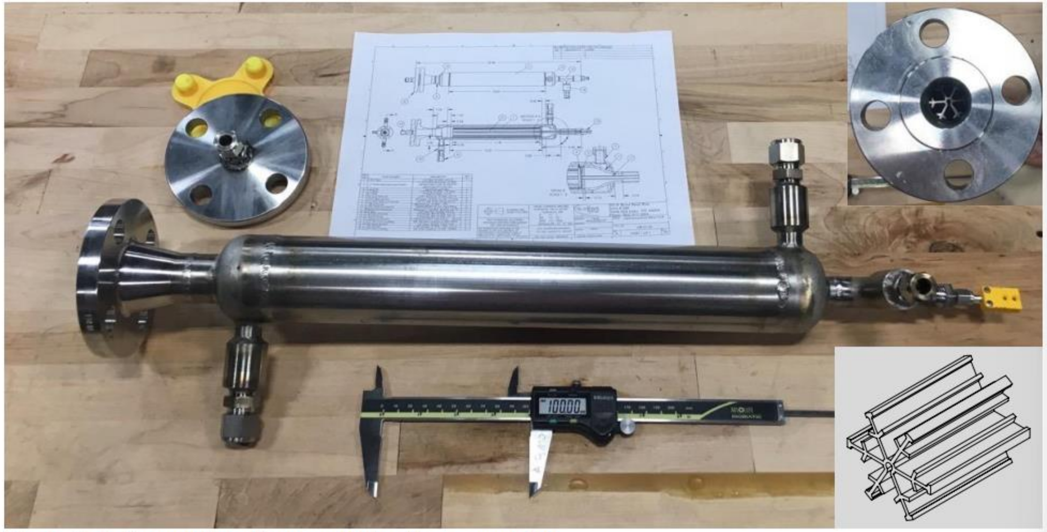

Figure 7. OxEon methanation reactor hardware assembly.

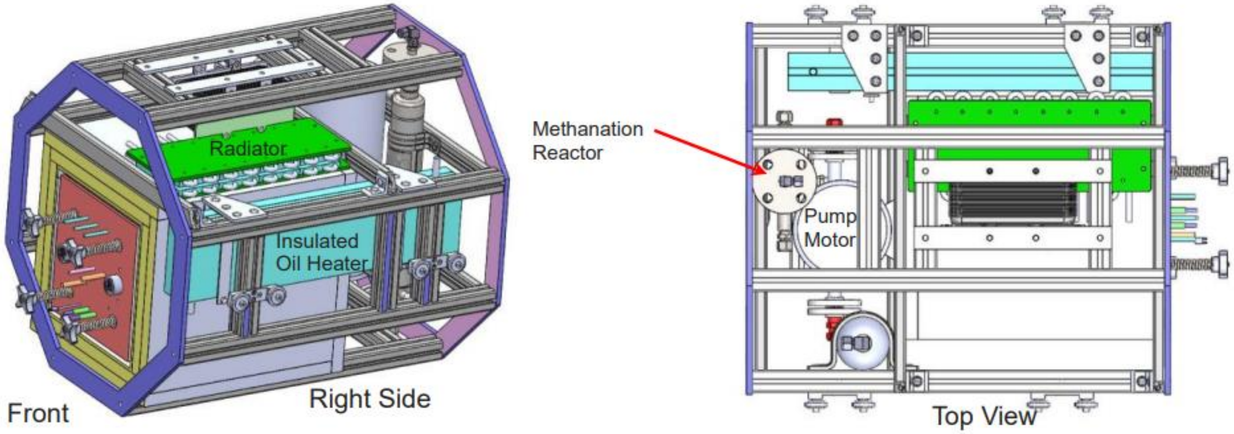

Figure 9. Integrated co-electrolysis methanation breadboard system configuration.

Electron Propellant Mass Requirements and Production-Alternate Technology: OxEon Full-Scale MOXIE-Methanation Reactor Drawing

Electron Propellant Mass Requirements and Production-Alternate Technology: OxEon Full-Scale CO_2 Electrolysis Reactor Modeling

- Rapp and Hintermann co-authors (2023): 30 metric tons of liquid oxygen in 14 months @3 kg/h
- Required production rate (+10%) = 1.3 kg/d = **0.053 kg/hr** [assuming 24 hr ops]
- Model Rate = **3.0 kg/h** – **56.6 x required rate → way oversized**
- **Design is for production of O2-only from CO2**
- **CO2 → CO + O2 (Direct Electrolysis)**
- **Therefore, mass, size, and operation power could ge obtained by dividing by 56.6**
- OxEon O2 System: **18.2 kg Cell Stack, 15,450 W, 84-cell stack (O2 LIQUEFACTION NOT INCLUDED)** has a size of 5 x 10 x 2 cm = **0.0001 m^3**
- **Volume = 0.029% of IMISPPS version (not including pump and electronics)**
- **Mass = 17% x IMISPPS version**
- **Power = 3.9 x IMISPPS version**

Electron Propellant Mass Requirements and Production- Alternate Technology: NASA Human Mars Mission - CO_2 Electrolysis Reactor System Modeling

- Co-authors Kleinhenz and Paz (2017): **28 metric tons of liquid oxygen** (including life support) in 16 months (480 days)
- Required production rate (+10%) = 1.3 kg/d = **0.053 kg/hr** [assuming 24 hr ops]
- Model Rate = **2.43 kg/h = 15.2 x required rate → way oversized (3 modules)**
- **Each module = 0.81 kg/h = 15.2 x required rate → way oversized**
- **Design is for production of O2-only from CO2 (methane brought from Earth)**
- **CO2 → CO + O2 (Direct Electrolysis)**
- **Therefore, mass, size, and operation power could ge obtained by dividing by 15.2**
- 2017 NASA Model CO2 Electrolysis O2 System: **300 kg total mass, 11,333 W Volume = Not Given (see notional drawing on next slide)**
- **Scaled down version (x1/15.2) = 19.74 kg mass, 746 W**

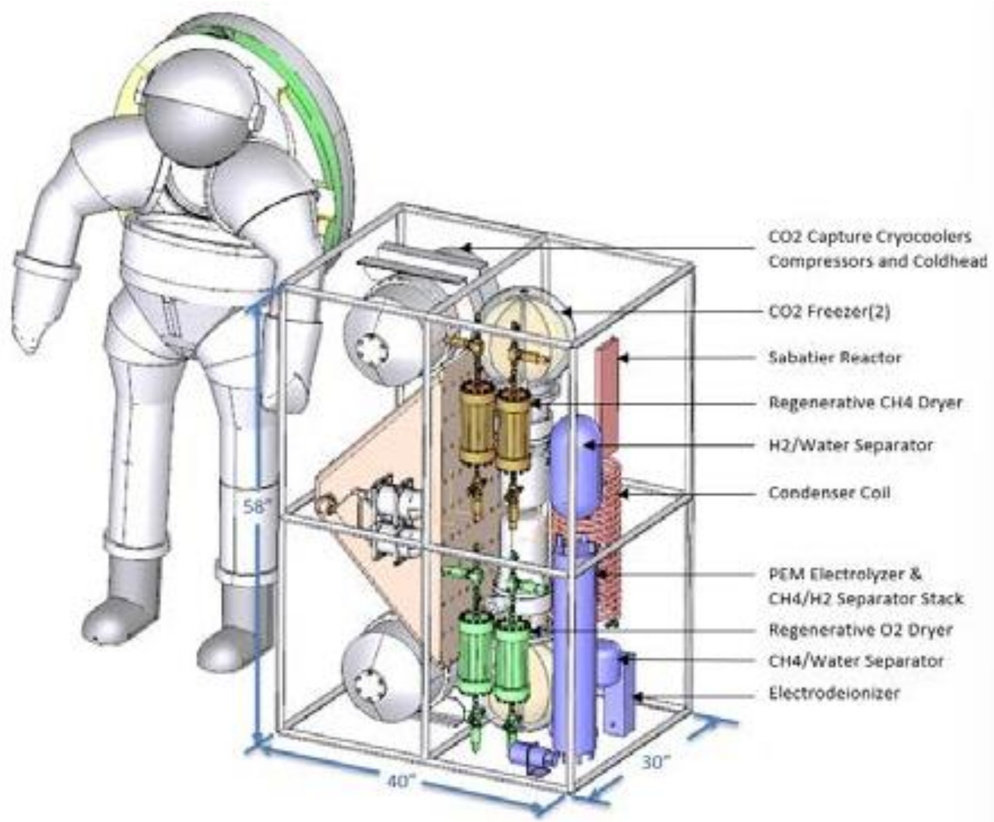

Figure 8. Notional packaging of the propellant production subsystems.

Electron Propellant Mass Requirements and Production-Alternate Technology: NASA Human Mars Mission - CO_2 Electrolysis Reactor System Modeling-Notional Drawing