Methane Propulsion Elements for Mars

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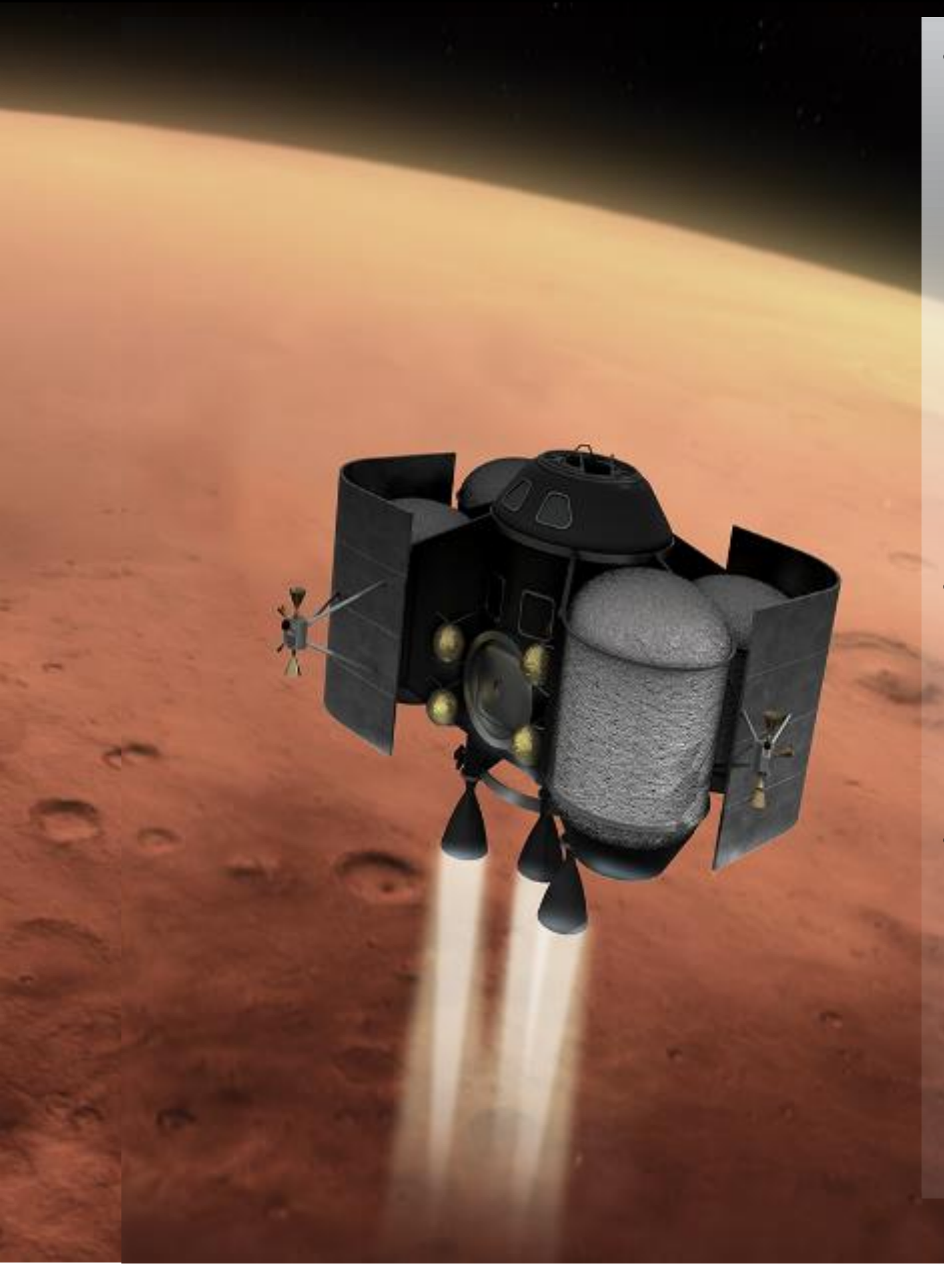
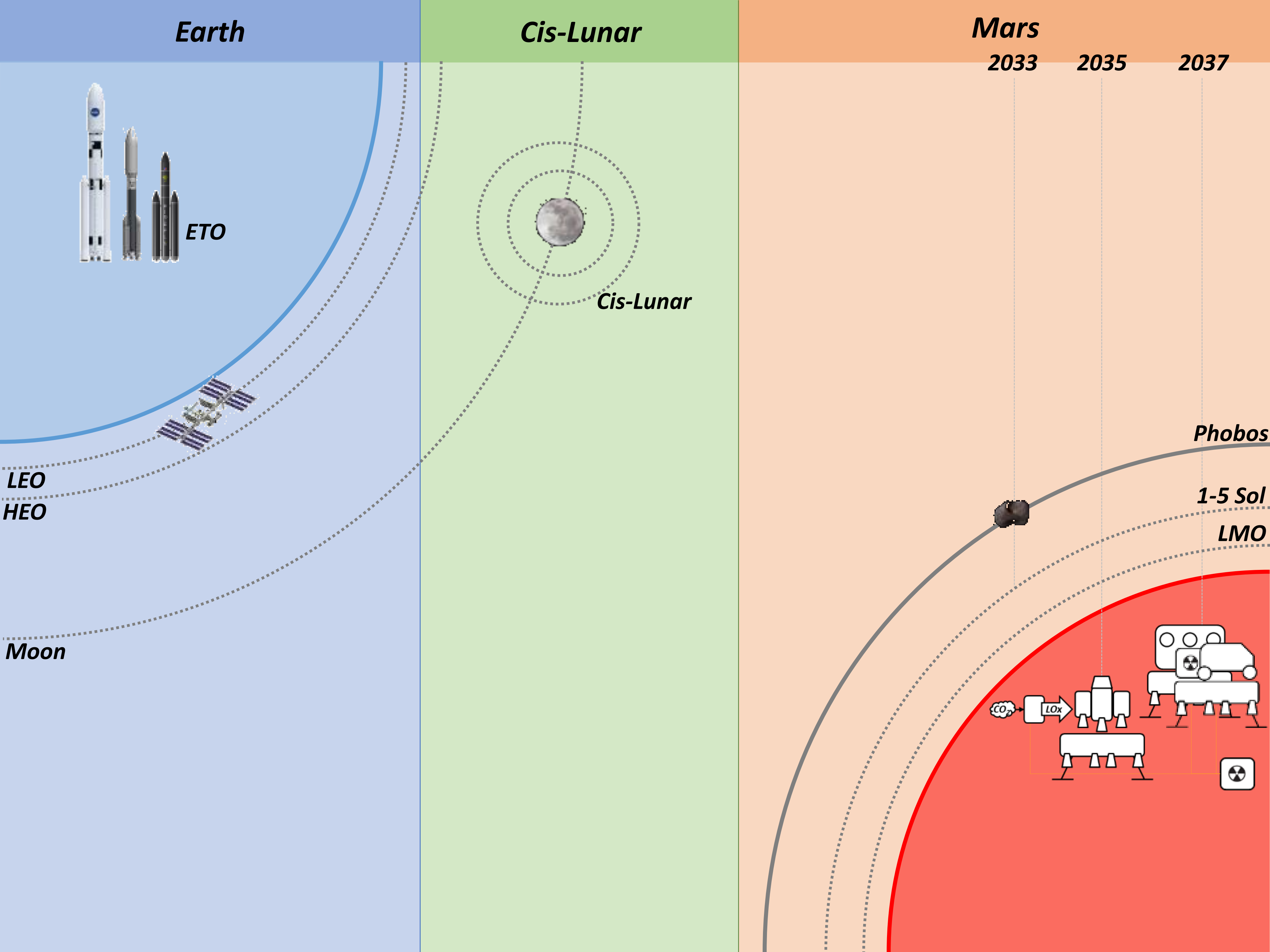
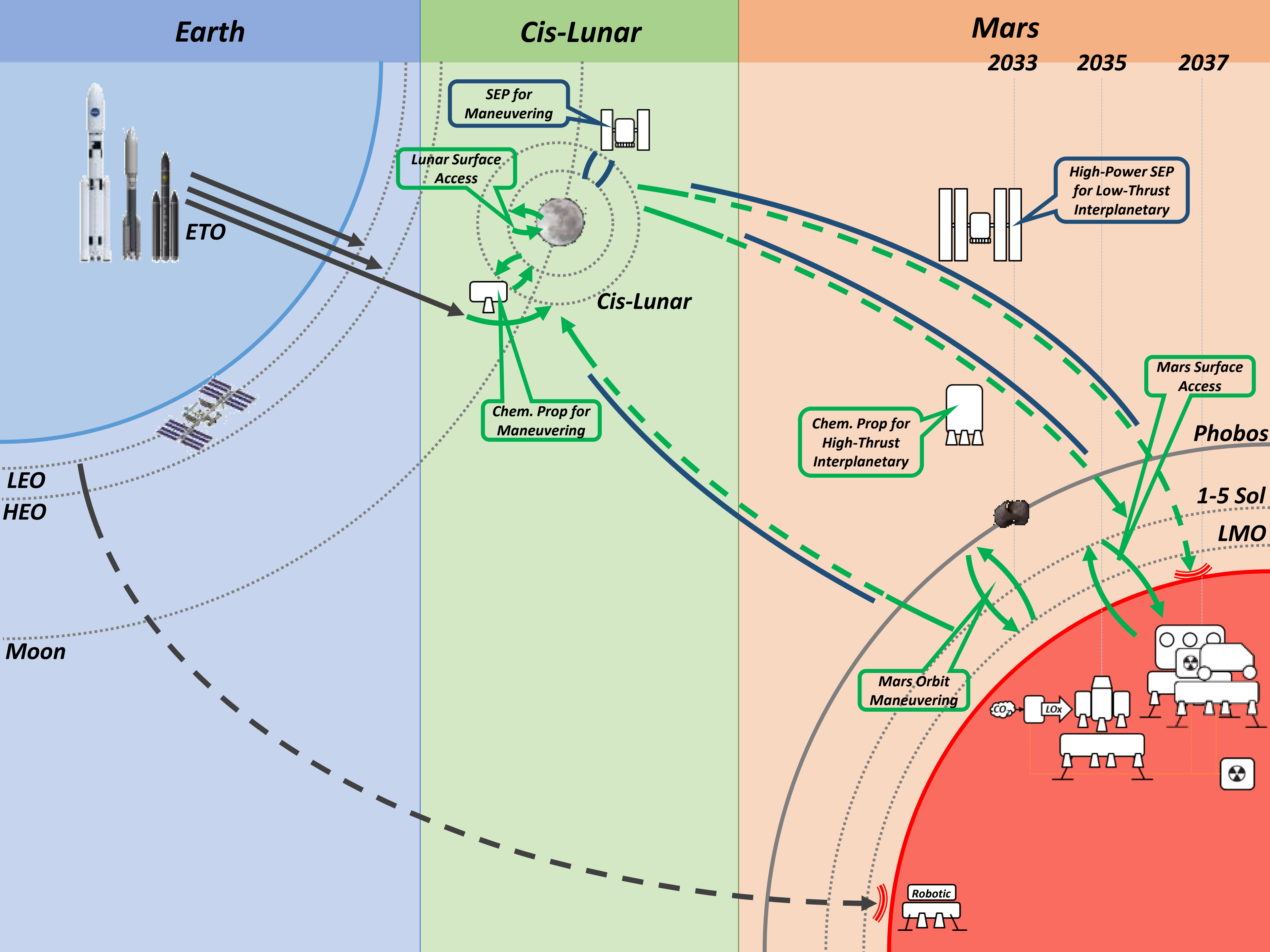
Introduction



- **Human exploration beyond LEO relies on a suite of propulsive elements to:**
  - Launch elements into space
  - Transport crew and cargo to and from various destinations
  - Provide access to the surface of Mars
  - Launch crew from the surface of Mars
- **Oxygen/Methane propulsion systems meet the unique requirements of Mars surface access**
- **A common Oxygen/Methane propulsion system is being considered to reduce development costs and support a wide range of primary & alternative applications**



Earth
Cis-Lunar
Mars
2033
2035
2037
ETO
Cis-Lunar
LEO
HEO
Moon
Phobos
1-5 Sol
LMO
CO2
LOx


Earth
Cis-Lunar
Mars
2033
2035
2037
SEP for Maneuvering
Lunar Surface Access
ETO
Cis-Lunar
High-Power SEP for Low-Thrust Interplanetary
Chem. Prop for Maneuvering
Chem. Prop for High-Thrust Interplanetary
Mars Surface Access
Phobos
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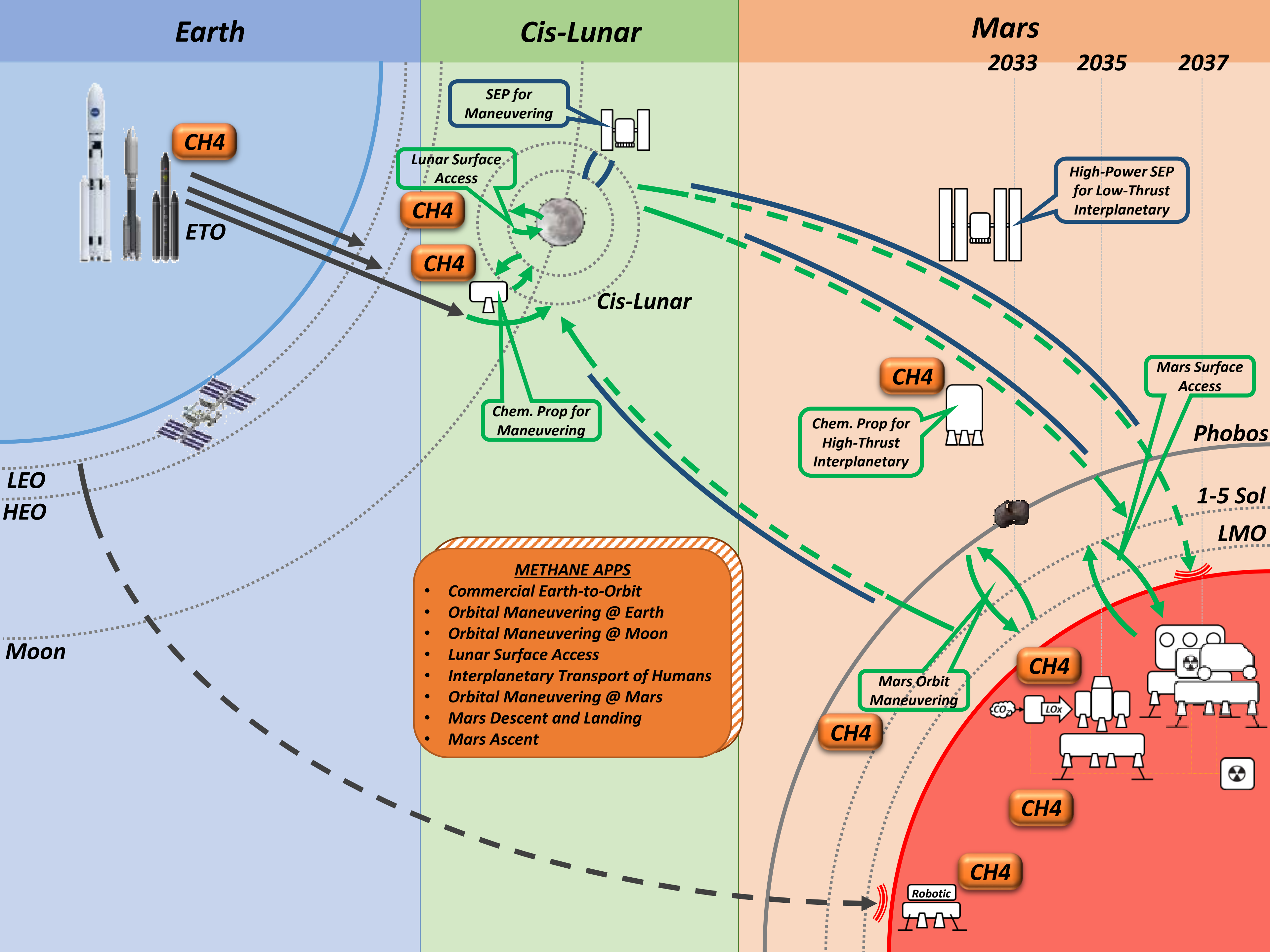
LMO
LEO
HEO
Moon
Mars Orbit Maneuvering
LOx
Robotic



Earth
Cis-Lunar
Mars
2033
2035
2037
CH4
ETO
SEP for Maneuvering
Lunar Surface Access
CH4
CH4
Cis-Lunar
Chem. Prop for Maneuvering
High-Power SEP for Low-Thrust Interplanetary
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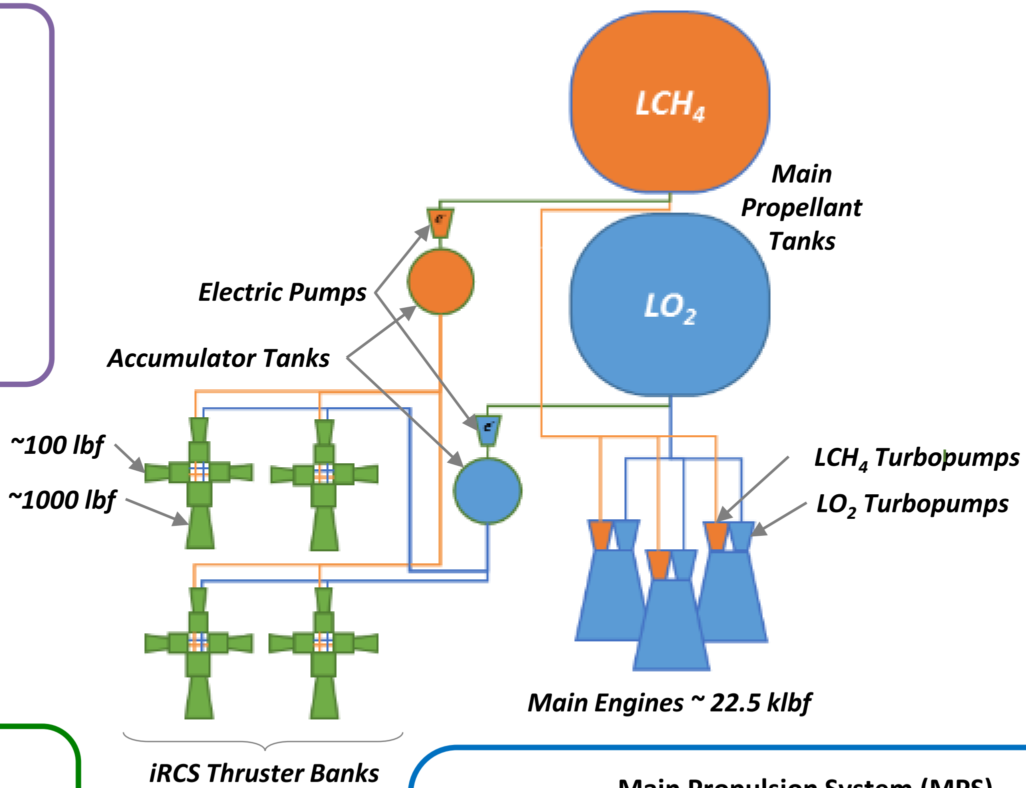
Moon
METHANE APPS
Commercial Earth-to-Orbit
Orbital Maneuvering @ Earth
Orbital Maneuvering @ Moon
Lunar Surface Access
Interplanetary Transport of Humans
Orbital Maneuvering @ Mars
Mars Descent and Landing
Mars Ascent
Mars Orbit Maneuvering
CH4
CH4
CO2
LOx
CH4
CH4
Robotic

Methane Propulsion System Definition

Cryogenic Fluid Management (CFM)

- **Benefits:**
  - Propellant Enabler: Enables use of Lox/LCH_4 propulsion systems
- **CFM Requirements & Assumptions**
  - Eliminate boil-off under steady-state conditions
  - Support ISRU liquid oxygen production on Martian surface (including liquefaction)
  - 90 K, 100 W cryo-cooler (~10 W/W)



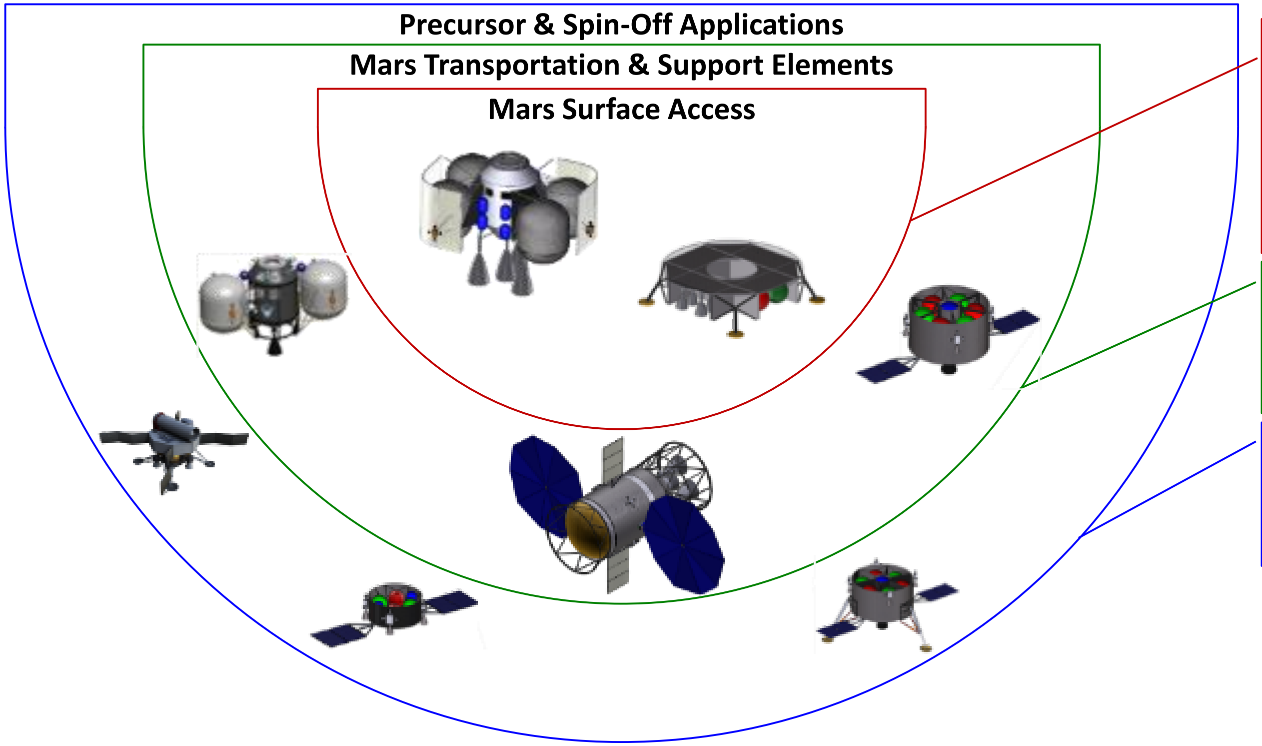
Integrated Reaction Control System (iRCS)

- **Benefits:**
  - Packaging: Limited real estate for MAV systems
  - Specific Impulse: Reduction in total RCS propellant load
  - Thermal: Centralized propellant storage
- **RCS Requirements & Assumptions**
  - Support steady-state and pulsed mode operations
    - Attitude control, AR&D, small steady-state burns
    - For In-Space Transportation, on average the RCS propellant budget is ~30% of the total stage prop budget (can be as high as 55%)
  - Provide attitude control for Mars descent & ascent
  - Need both 100 lbf-class and 1000 lbf-class thrusters

Main Propulsion System (MPS)

- **Benefits:**
  - ISRU: Production of LOX from Martian atmosphere reduces MAV landed mass by 25t
  - Density-I_{sp}: Balance of performance, packaging & storage
- **MPS Requirements & Assumptions**
  - Engine Thrust ~ 22,500 klbf
  - Engine Isp ~ 360 s
  - Throttle Range ~ 5:1
  - In-space / Martian Surface Dormancy periods > 5 years
  - Minimal propellant loss (~0.15 kg/day)

Methane Commonality: Driving Requirements to Family of Elements



Mars Surface Access Drives Methane Propulsion Requirements

- MAV packaging constraints lead to iRCS
- Methane propellant selection leverages ISRU to reduce landed mass of MAV
- Main Engine Thrust & I_{sp} set for MAV performance
- Main Engine throttling required for MDM

Common Propulsion Leads to Inheritance of Performance & Design

- In-space elements add engine restart requirement
- Different performance benefits ID'd & leveraged

Spin-Off Applications Leverage Investment

- Early application can provide demo opportunities
- Alternative applications not in Mars critical path but available before and during Mars campaign

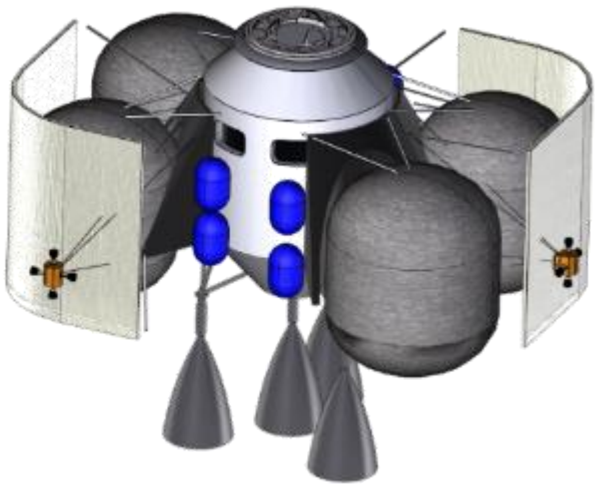
Delivery of First In-Space Transportation Element Drives Development Schedule

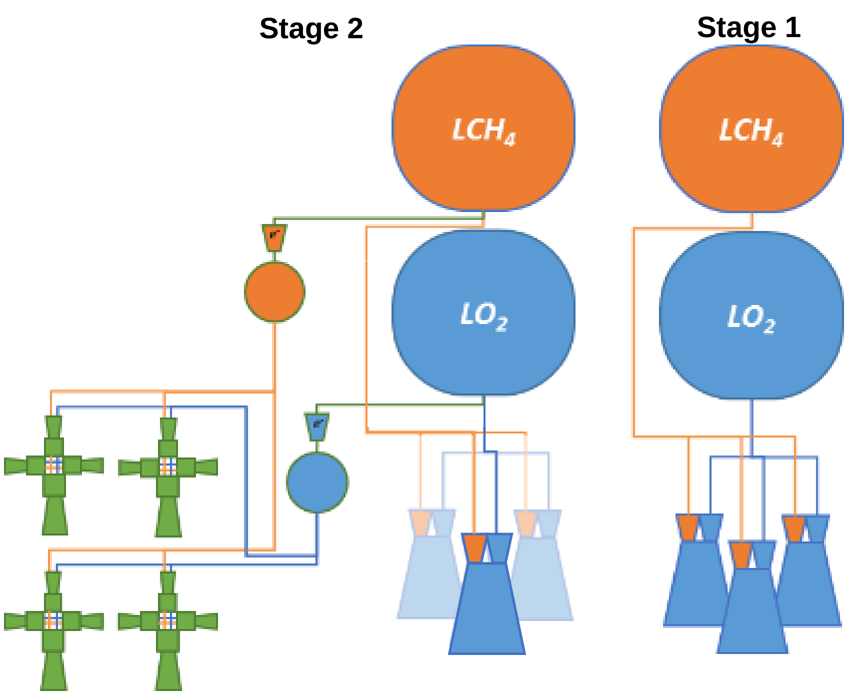
- Precursor & spin-off availability tied to, but do not drive, development schedule
- Precursor applications provide system demo opportunity

Phase 1 & 2 | *Phase 3 & 4*

2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035

Methane Element: Mars Ascent Vehicle



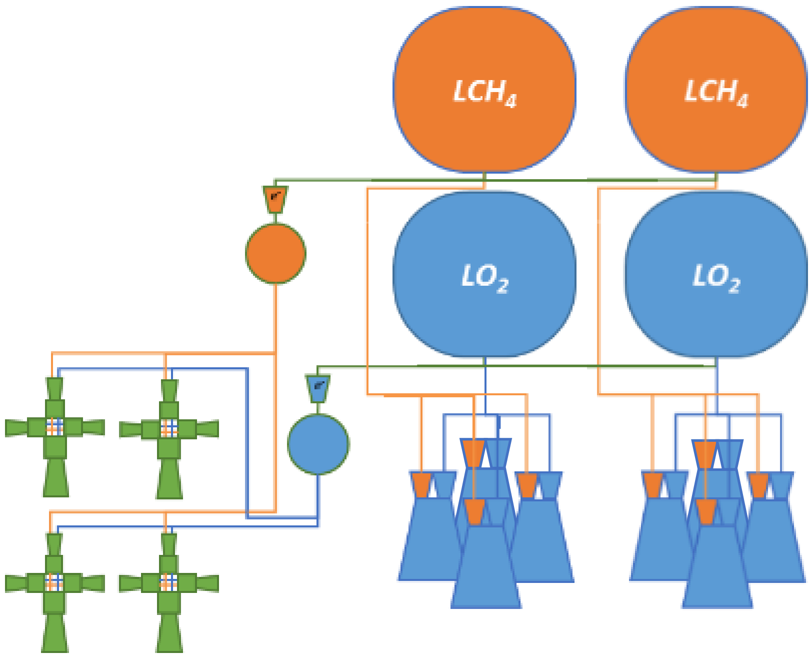


- **This Mars Ascent Vehicle (MAV) carries 4 crew members and science cargo off the surface of Mars to rendezvous with an Earth Return Vehicle waiting in a 1 Sol Mars orbit.**

- **General Design Specs**
  - Operational Life = 2 days
  - Total Service Life ~ 3058 days
  - Crew Capacity = 4
  - 4 engines (3 on 1st Stage, 1 on 2nd stage)

- **General Design Notes**
  - 2 Stage to Orbit
  - Nested propellant tanks
  - ISRU Oxygen Production

Methane Element: Mars Descent Module

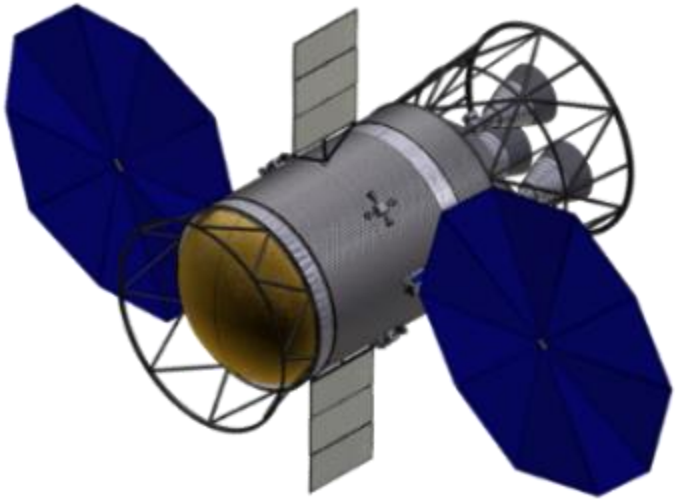


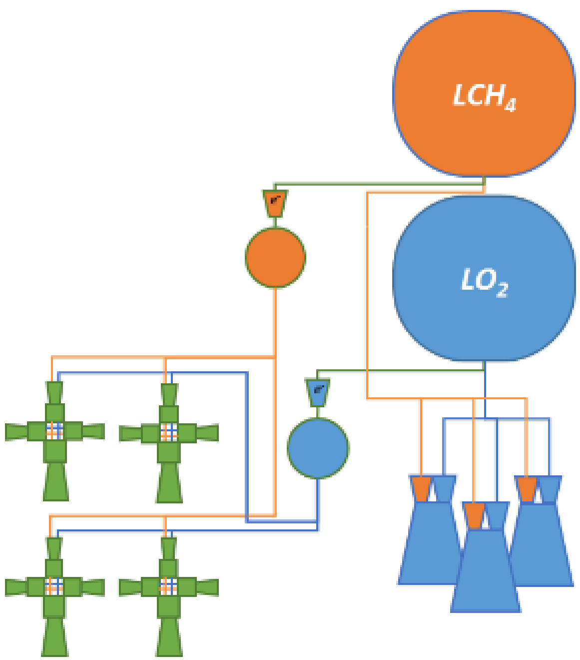
- **The Mars Descent Module (MDM) is sized to carry all mission manifests to the Martian surface. Uses a combination of inflatable aerodynamic decelerator and super-sonic retro-propulsion to perform controlled entry, descent, & landing.**

- **General Design Specs**
  - Total Service Life may be > 5 years
  - Cargo Capacity = 20t
  - 8 engines (throttle to 20%)

- **General Design Notes**
  - Use of HIAD (other decelerator approached being traded)
  - Supports aerocapture and EDL
  - Provides power & support to payloads during Earth-Mars transit
  - Supports MAV during Mars surface stay (structurally & thermally)

Methane Element: Mars Cryo Propulsion Stage



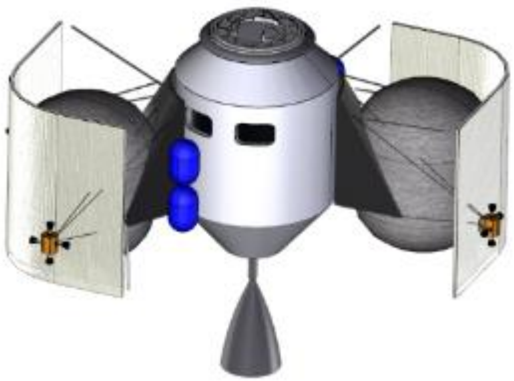


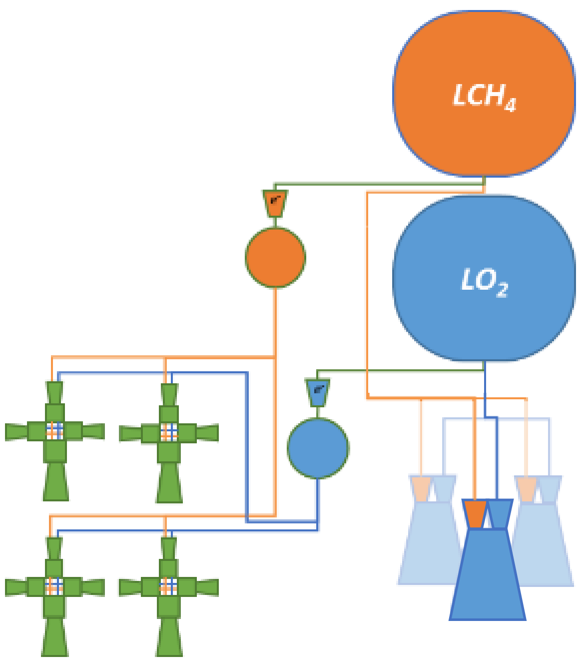
- **The Mars Cryo Propulsion Stage (MCPS) is one of several options currently being traded for Earth-Mars transportation.**

- **General Design Specs**
  - Total Service Life may be > 5 years
  - Total Prop Capacity ~43t
  - 3 main engines
  - 4 RCS pods with 1000 lbf rear-axial pointing thrusters for small translational maneuvers

- **General Design Notes**
  - Stages used for Earth return from Mars are pre-deployed and spend extended dormancy periods in orbit around Mars
  - RCS maneuvers make up a significant portion of total propellant load
  - Multiple main engine restarts required

Methane Element: Crew Taxi



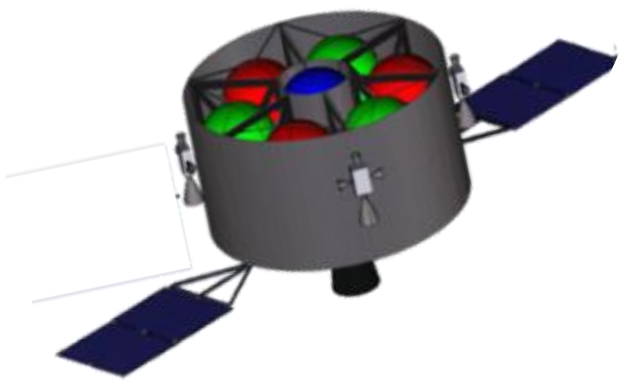


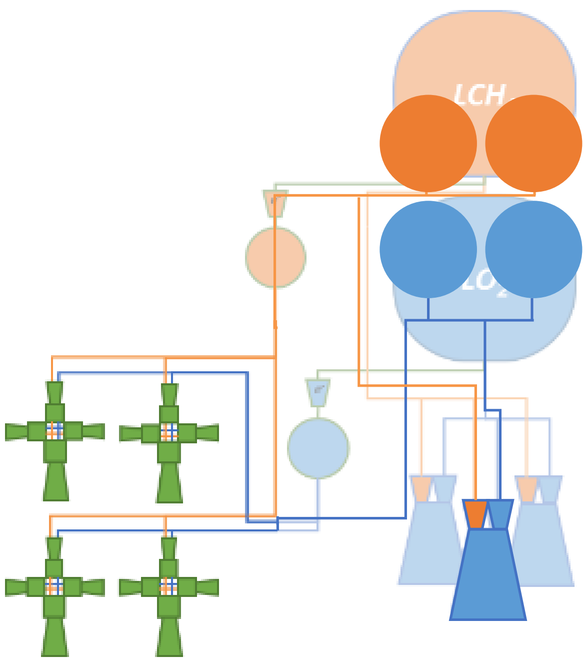
- **Some Mars mission concepts under consideration have a functional requirement to transfer crew between different parking orbits at Mars. A vehicle based on the MAV 2nd stage is one concept being considered for use as the crew taxi.**

- **General Design Specs**
  - Operational Life = 2 days w/ long periods of dormancy
  - Crew Capacity = 4
  - 1 main engine
  - ΔV capacity ~ 2 km/s

- **General Design Notes**
  - Potentially common design with MAV
  - Requires multiple restarts
  - Extended dormancy period before and between operations

Methane Element: cis-Lunar Propulsion Module



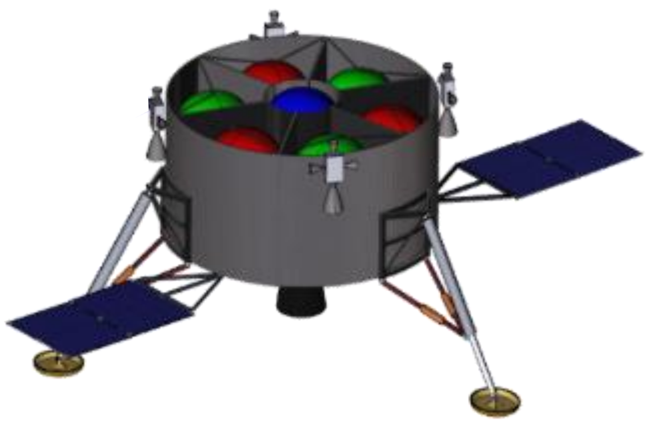


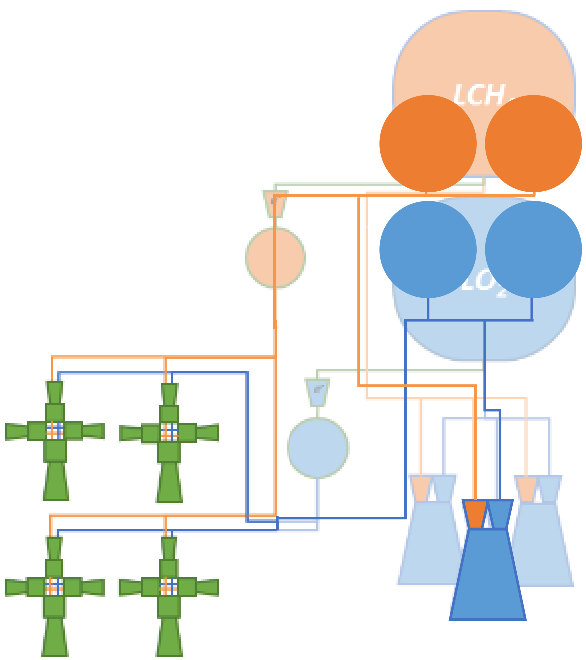
- **Methane propulsion could be applied to cis-Lunar propulsion functions for element maneuvering, aggregation, and repositioning. The concept shown here is designed to leverage propulsion systems required for Mars.**

- **General Design Specs**
  - Long-duration active CFM for prop storage
  - Total Prop Capacity ~15t
  - 1 main engine

- **General Design Notes**
  - Designed to be co-manifested with large cargo elements on an SLS Cargo vehicle
  - Avionics and navigations system enable free-flyer operations
  - Potential to provide significant mass savings to Mars missions by performing “tug” functions during aggregation periods

Methane Element: Lunar Surface Access/Robotic



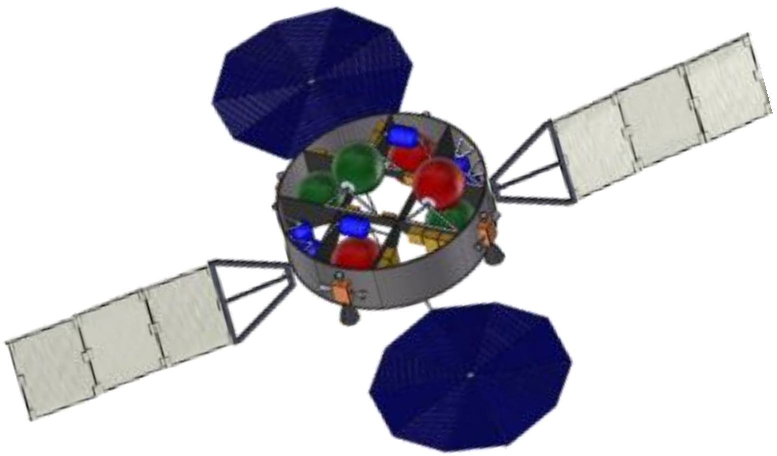


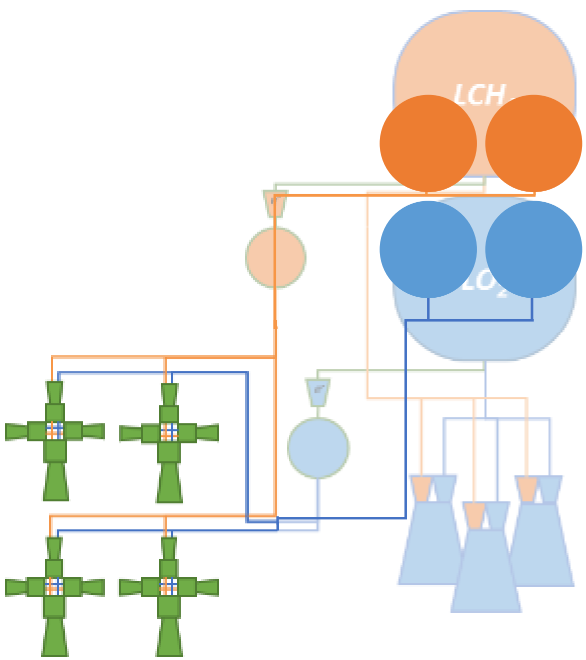
- **This is a conceptual vehicle design based on the cis-Lunar Propulsion Module which could provide Lunar surface access by leveraging the throttling capability of the Methane main engine.**

- **General Design Specs**
  - Long-duration active CFM for prop storage
  - Total Prop Capacity ~15t
  - 1 main engine (throttleable to 20%)

- **General Design Notes**
  - Designed to be co-manifested with large cargo elements on an SLS Cargo vehicle
  - Avionics and navigations system enable free-flyer operations
  - Could be adapted for landing at other destinations.

Methane Element: Co-Manifested Prop Module





- **This is a conceptual vehicle specifically designed to serve as a propulsion module for payload that are co-manifested on SLS Crew launches. It leverages the components of the iRCS for Mars.**

- **General Design Specs**
  - Passive and active CFM variants have been designed
  - Total Prop Capacity ~2t
  - 4 x 1000 lbf RCS thrusters as main propulsion
  - 3-6t of payload delivered to LDRO

- **General Design Notes**
  - Designed to be co-manifested on SLS Crew vehicle with or without a payload element
  - Avionics and navigations system enable free-flyer operations
  - Variant shown on this chart supports a CFM Demonstration mission

Other Applications and Future Investigations

- **Early applications of the Methane Propulsion System components can be designed to maximize mission flexibility**
  - Key is to use only systems with direct ties to Mars elements (no new or unique developments)
  - Use of precursor elements builds flight time on crew-critical propulsion systems during the early phases of the program

- **New elements and application still to be investigated**
  - Some work has been completed looking at Lunar surface access with Mars lander elements
  - MSC will be looking at a variant of the Hybrid spacecraft with Methane propulsion

- **Iterative design with technologist feedback is key**
  - Preliminary designs assume levels of performance, reliability, and feasibility
  - Engagement with propulsion and CFM technologists will ensure that early lessons learned (including findings from relevant test programs) are incorporated into design refinements


Questions?
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