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# A Combined Solar Electric and Storable Chemical Propulsion Vehicle for Piloted Mars Missions

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# A Combined Solar Electric and Storable Chemical Propulsion Vehicle for Piloted Mars Missions –

A concept study by NASA Glenn Research Center's Collaborative Modeling for Parametric Assessment of Space Systems (COMPASS) team

**OVERVIEW**

Study Objective
Study Assumptions
Study Figures of Merit

Summary of prior studies

Mission Trades

Baseline Concept of Operations and Trajectory
Baseline Vehicle

Technology Trades

Summary

# Solar Electric Propulsion for Piloted Mars Mission

**Study Objective**

Determine the feasibility of using power-constrained solar electric propulsion (SEP) to transport crew and cargo according to the Design Reference Architecture 5.0 (DRA 5) mission.

**Study Assumptions:**

Per DRA 5.0: 2037 launch date; conjunction-class "long-stay" mission for six crew

**Study Figures of Merit:**

Total crew time of 1000 days or less

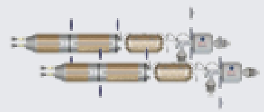
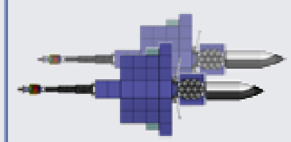
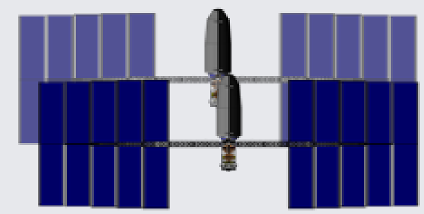
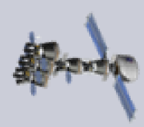
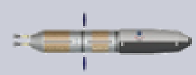
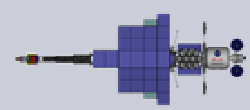
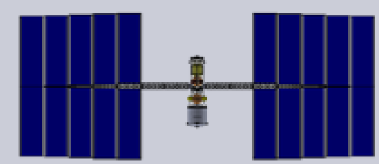
Mars stay time of 365 days or more

Mass and volume

- Minimize initial mass of the spacecraft in LEO to reduce the required number of Space Launch System (SLS) launches to 2
  - SLS net launch capability of 113.8 t delivery to LEO (–92.5 km by 407 km), with an 8.5- by 25-m shroud

No more than 1 MW of electric power to the electric propulsion system at beginning of life

# Summary of prior studies for Mars transportation systems

| | | | | |
|---|---|---|---|---|
| **Cargo Missions** |  |  |  |  |
| **Crew Mission** |  |  |  |  |
| **2037 Conjunction Class "long stay" mission** | **Chemical Propulsion** | **Nuclear Thermal** | **Nuclear Electric** | **Solar/Chem** |
| **Electric Propulsion Power level** | n/a | n/a | 2.5MW crew/ 1MW cargo | 800kW Solar |
| **Total Mass (t)** | ~1,250 | ~890 | ~770 | ~780 |
| **# Heavy Lift (SLS) Launches** | ~12 | 9 (7) | ~7 | ~7 |
| **SLS Delivery to LEO (t)** | 105 & 130 | 105 (130) | 105 & 130 | 105 & 130 |
| **SLS Shroud Dia. /Barrel Length** | 10 / 22 | 10 / 25 | 10 / 25 | 10 / 15 |
| **Trip Duration (days to Mars, On Mars, back home)** | 180 / 500 / 200<br>880 days total trip | 174 / 539 / 201<br>914 days total trip | 309 / 400 / 224<br>980 days total trip | 439 / 300 / 326<br>1065 days total trip |
| **Comments** | Requires propellant depot | Number of launches reduced to 7 with 130mt SLS | | 1-2 ATV launches required to provide consumables to L2 |

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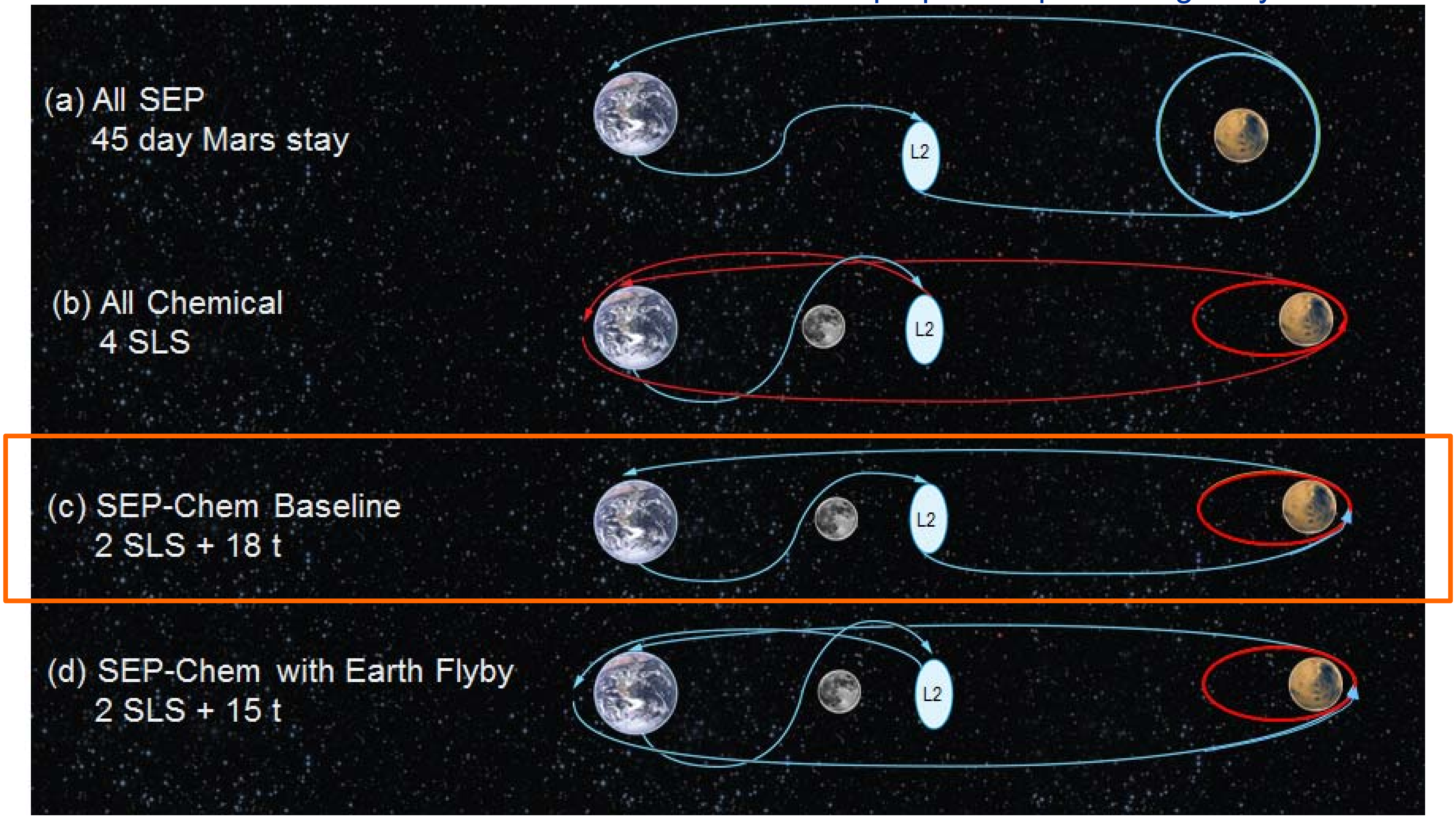
# Mission trades

**All-SEP** – SEP provides all change in velocity (ΔV) from L2 to Mars and back

**All-Chemical** – Chemical propulsion provides all ΔV from L2 to Mars and back

**SEP-Chem** – SEP provides interplanetary ΔVs; chemical propulsion provides gravity well ΔVs



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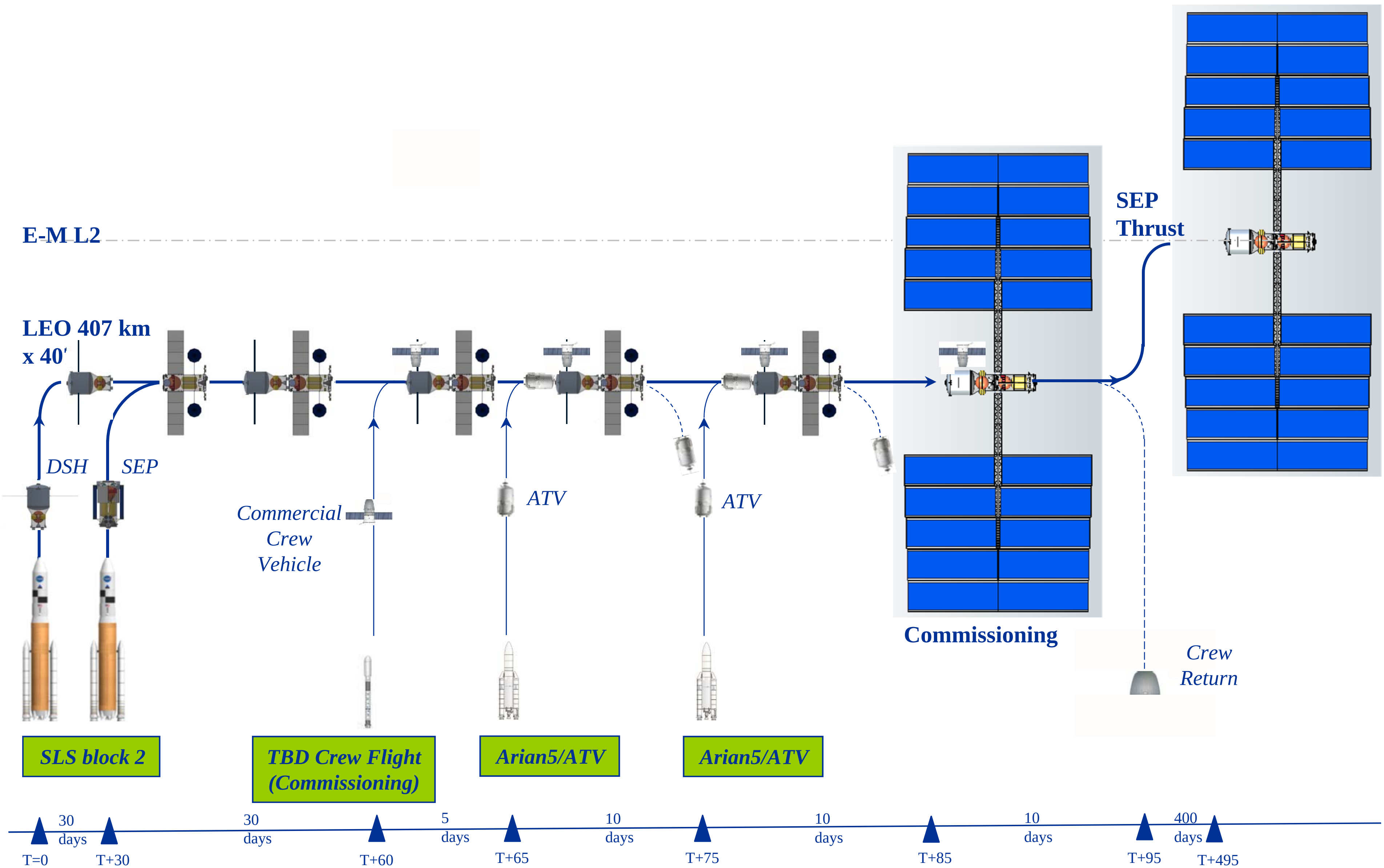
# Concept of Operations to Earth-Moon L2



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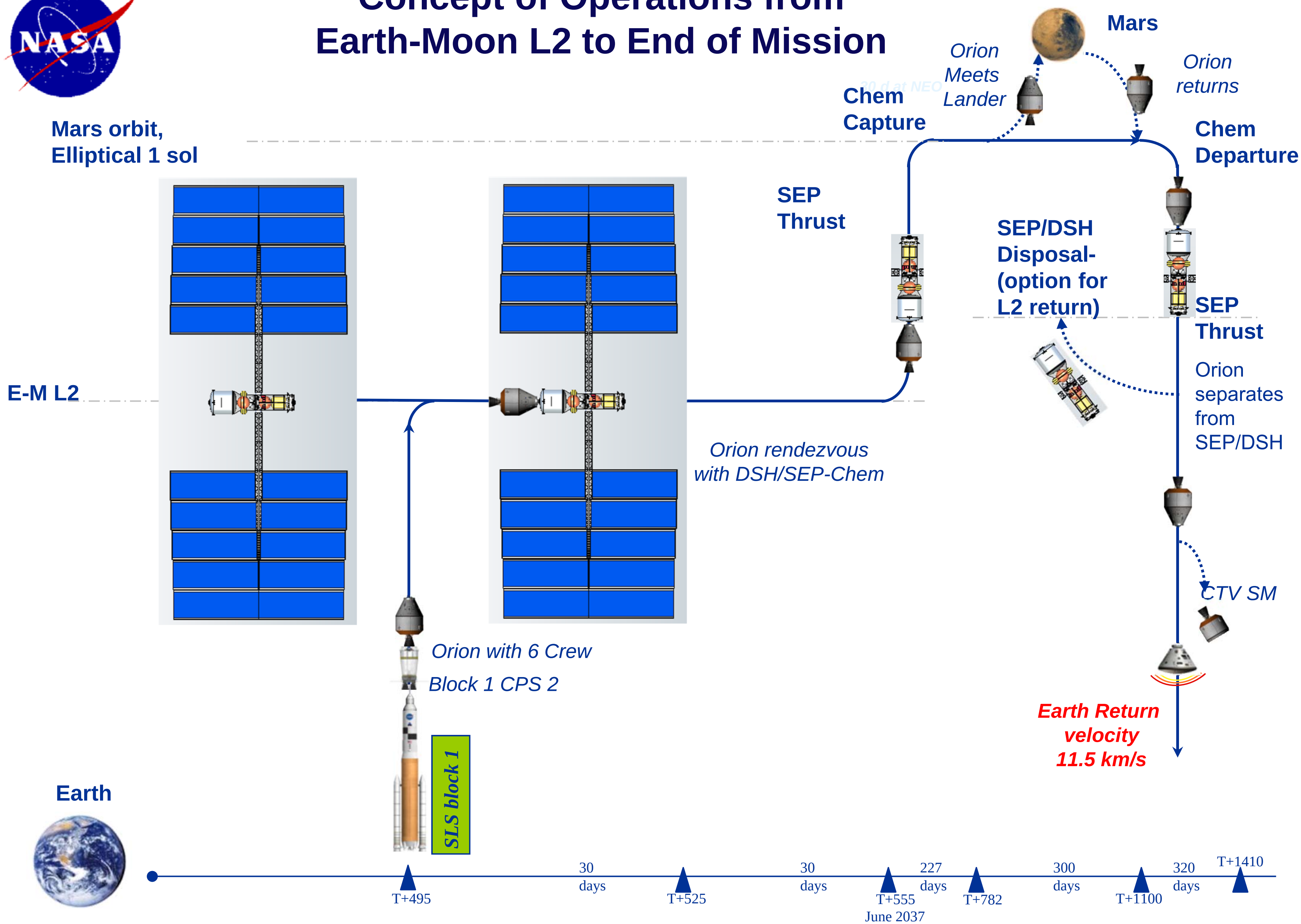
# Concept of Operations from Earth-Moon L2 to End of Mission



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# Baseline Trajectory (No Earth Flyby, Direct Drive)

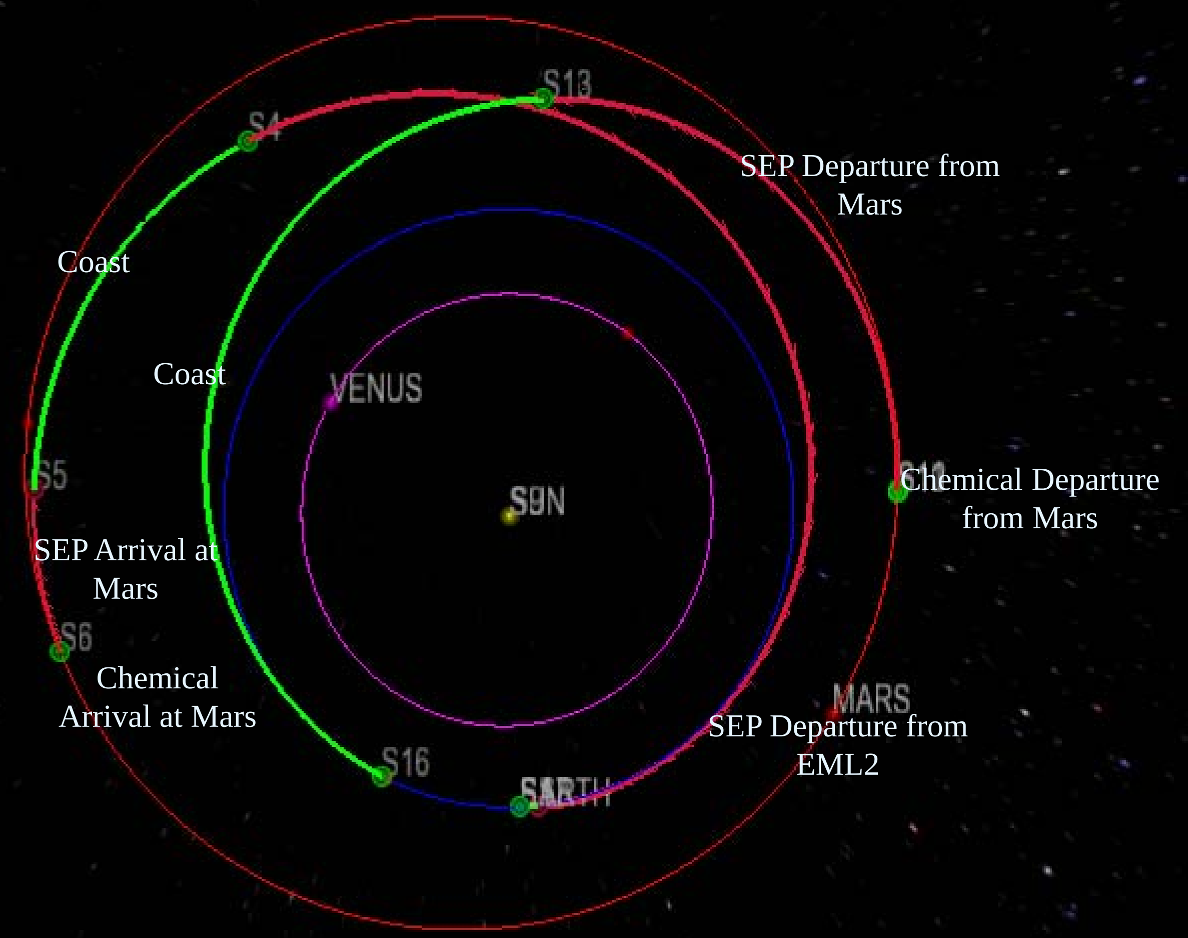
**SEP Delta-Vs:**
- EML2 Departure: 4204 m/s
- Mars Arrival: 391 m/s
- Mars Departure: 2203 m/s

**Chemical Delta-Vs:**
- Mars Arrival: 345 m/s
- Mars Departure: 226 m/s

**Earth Departure Date:** June 17, 2037
**Mars Arrival Date:** August 30, 2038
**Mars Departure Date:** June 26, 2039
**Earth Arrival Date:** May 17, 2040

**Mars Stay Time:** 300 days
**Total TOF:** 1066 days

*Optimized for inert mass of 122mt



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# Baseline SEP-Chem System

SEP: 800 kW, 2400 sec Isp

Chemical: Orion-derived storable, 327 sec Isp

2 SLS-launched SEP-Chem vehicles to deliver 6 crew from EM-L2 to elliptical 1 sol Mars orbit and back to Earth

Spiral from LEO 400km to EM-L2 unpiloted;
Rendezvous with MPCV launched to EM-L2 on separate vehicle.

SEP-Chem Element

**SEP:**

(2) 500-kW solar arrays beginning-of-life (BOL)
400 kW end-of-life at 1 AU (EOL)

500V power bus voltage

(8) 125-kW nested Hall thrusters at 2400 s Isp with direct drive
6 operational; 2 as spares

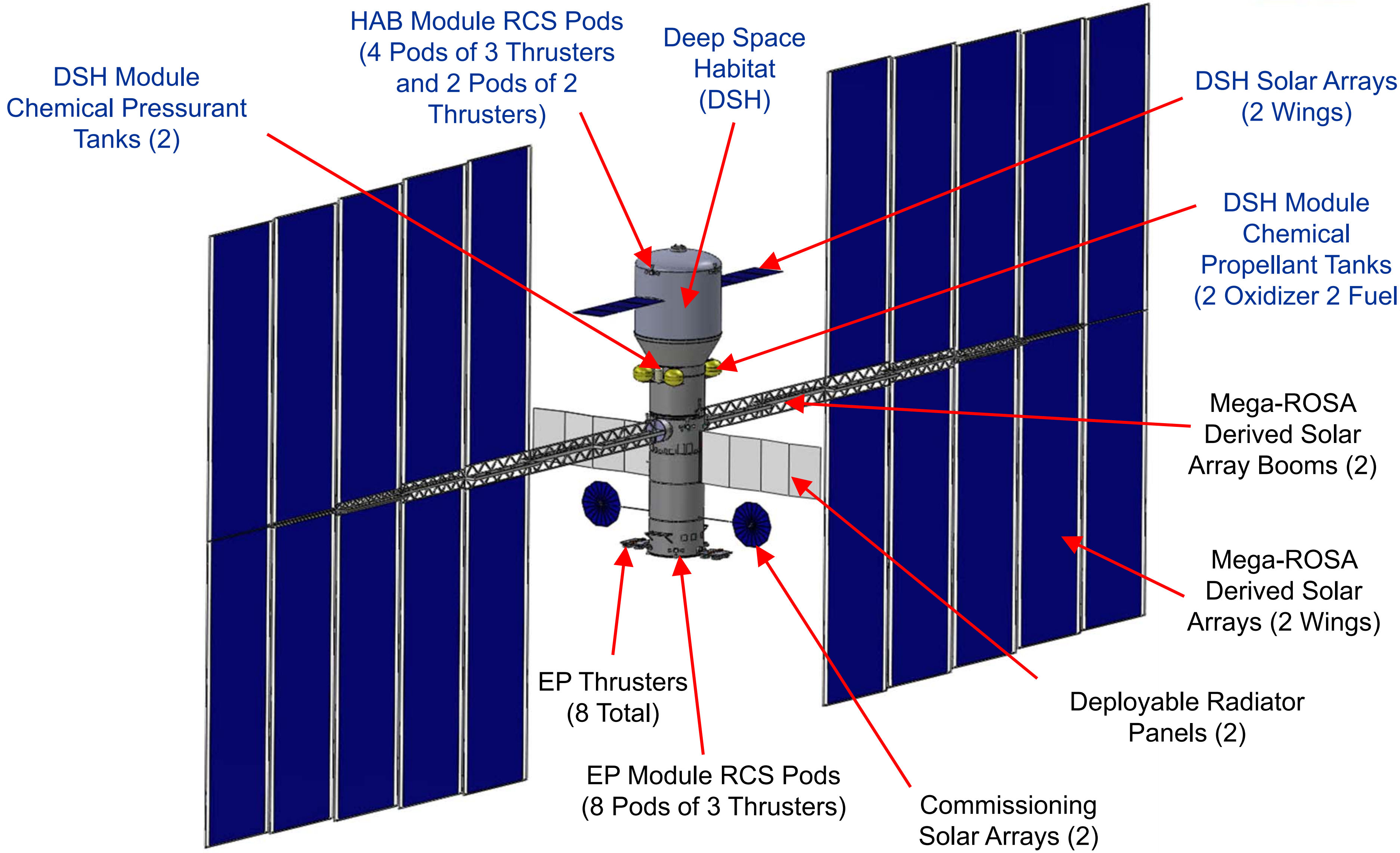
(2) 3.9-m-diameter COPV Xe tanks (109 t)

Hab Element

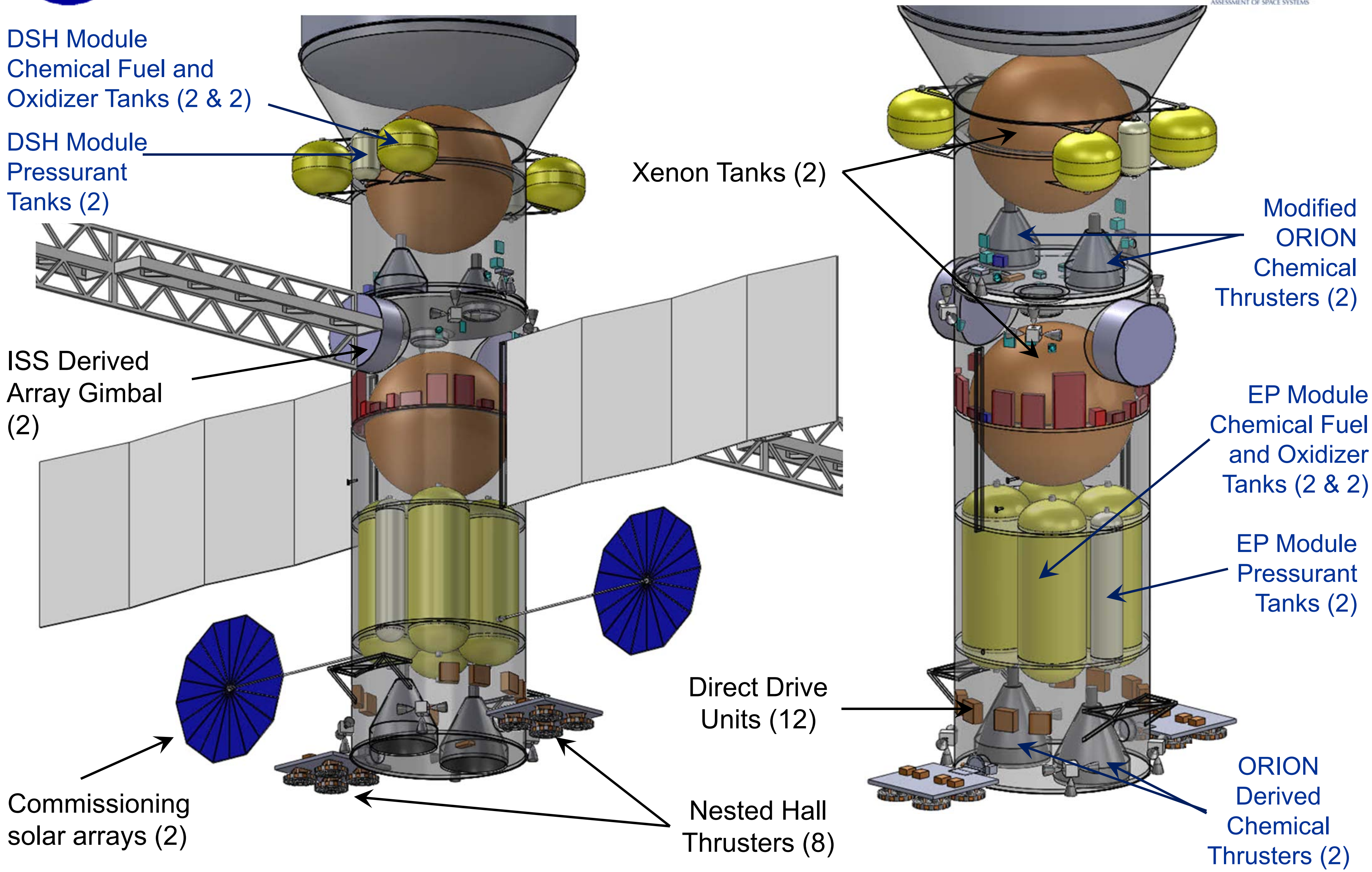
**Chemical**:

(2) Orion-derived storable bi-propellant chemical thrusters (7000 lbf)

# SEP-Chem Baseline: Major External Components



# SEP-Chem Baseline: Propulsion System Layout



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# Technology variants

**Specific impulse** (Isp): 2000 to 3000 s
**Power to thrusters**: 600 to 900 kW
**Bus voltage:** 300 to 500 V

**Thruster type:** Hall effect and nested Hall effect
**Power processor**: Direct drive (DDU) and conventional power processing unit (PPU)
**Chemical system:** Storable and cryogenic systems

| | | **SEP-Tug** | **SEP-Chem** | | **SEP-Chem** | | | | | **All SEP** | **SEP Cargo** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **all Chem** | **Earth Flyby** | | **Baseline** | | **LOx LCH4** | | **PPU** | **all SEP** | **SEP Cargo** |
| **Transport** | **LEO to L2** | SEP | SEP | | SEP | | | | | SEP | SEP Cargo |
| | **Earth/Moon Depart flyby** | chem | chem/SEP | | none - SEP from L2 | | | | | none - SEP from L2 | none - SEP from L2 |
| | **Interplanet propulsion** | **None - coast** | SEP | | SEP | | | | | SEP | SEP |
| | **Mars gravity well propuls** | chemical | chemical | **SEP** | chemical | | | | | **SEP** | none - cargo aerocapture |
| | **Mars parking orbit** | Elliptic 1 sol | Elliptic 1 sol | Circular 1 sol | Elliptic 1 sol | | | | | Circular 1 sol | none - SEP flys by Mars |
| | **Launch requirements** | ~4 SLS | 2 SLS + 3 ATV | | 2 SLS + 2 ATV | | | | | 2 SLS + 2 ATV | 2 SLS (1 SEP + 1 aeroshell cargo) |
| | **Outbound/Inbound transit time** | | 344 / 315 days | | 439 / 326 days | 416 / 321 days | 470 / 330 days | 439 / 326 days | 405 / 337 days | | |
| | **Mars stay time** | ~500 days | 367 days | | 300 days | 300 days | 270 days | 300 days | 300 days | 45 days | n/a |
| | **Total trip time** | | **1026 days** | | **1066 days** | **1037 days** | **1070 days** | **1066 days** | **1041 days** | | |
| **Propulsion** | **Power system** | 800 kW EOL/1AU, 500 V | | | 800 kW EOL/1AU, 500 V | | | | | 800 kW, 500V | 800 kW, **300 V** |
| | **Electric thruster type (Direct Drive unless noted)** | Nested Hall 8 @ 125 kW | | | Nested Hall 8 @ 125 kW | **Nested Hall 12 @ 75 kW** | Nested Hall 8 @ 125 kW | **Hall 20 @ 50kW** | **Nested Hall (PPU) 12 @ 75 kW** | | PPU |
| | **Electric thruster Isp** | 2400 sec | | | 2400 sec | **2000 sec** | | 2400 sec | **3000 sec / 2140 sec** | 2400 sec | **2870 sec** |
| | **Xenon mass** | | | | 109 t | | | | | | 74 t |
| | **Chemical propulsion** | Orion-derivative storable chemical propulsion (327 sec Isp) | | | 327 sec Orion-derived | | **349 sec $LOx/LCH_4$** | 327 sec Orion-derived | | n/a | n/a |

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# Technology Development

## Existing technology development may be extensible to these power levels –

- 20-kW-class Mega-ROSA and MegaFlex solar array structures being built with extensibilty to 250kW-class operation;
  Modular designs may be scalable to 1 MW

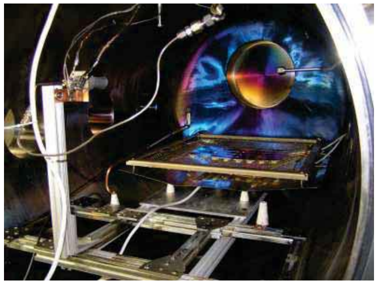
- 100-kW-class nested Hall thrusters are currently under development;
  50-kW to 125-kW thrusters could be used for very high power system

- Photovoltaic (PV) cells are being characterized for operation at high voltage and robust operation near electric thruster plumes

- Electronic parts are being characterized for robustness in the deep space radiation environment

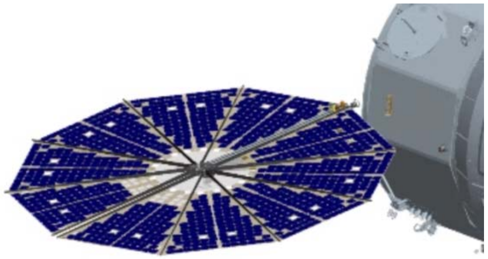
100-kW-class nested Hall thruster (University of Michigan)

High voltage electronic parts radiation testing (NASA GSFC)



PV plasma testing (NASA JPL)

Mega-ROSA solar array (DSS, Inc.)



MegaFlex solar array (ATK, Inc.)

# Summary

**Figures of Merit nominally met –**

Total crew time of 1000 days or less : Final design has 1065 day crew time

Mars stay time of 365 days or more: Final design is 300 days

Solar arrays sized for ≤1 MW at beginning of life:

Final design is 1 MW BOL, 800kW EOL

Reduce the required number of SLS launches to 2:

Final design required additional ~18 t of crew consumables on ELV to LEO

**Solar Electric Propulsion can be viable to transport both crew and cargo to Mars at reasonable power levels for reasonable trip times.**

**Existing technology development may be extensible to these power levels:**

Solar array structures, nested Hall thrusters, direct drive power processing.