



Mars Exploration Portable Life Support System Schematic Study: Architecture Down-Selection

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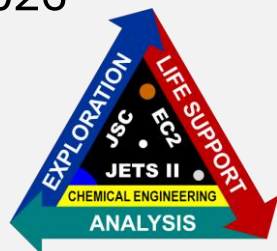
Madeleine Oliver, Emma Quick, Dana Masangkay, Isabella LeJeune-Bolivar, Lawrence Barrett, & Bruce Conger

Amentum, Houston, TX

Cinda Chullen, Colin Campbell, & Ryan Ogilvie

NASA, Houston, TX

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Portable Life Support System (PLSS)



- **The PLSS supports extravehicular activities (EVAs) through 8 major functions**

- Oxygen storage and supply : Gaseous oxygen (GOX)
- Ventilation : Liquid cooling ventilation garment (LCVG)
- Flow drive : Centrifugal fans (vent loop) & pumps (water loop)
- Carbon dioxide removal : Rapid cycle amine (RCA)
- Humidity removal : Rapid cycle amine (RCA)
- Thermal control : Spacesuit water membrane evaporator (SWME)
- Trace contaminant control : Activated charcoal beds
- Power and energy storage : Lithium-ion batteries



- **PLSS schematic studies have guided PLSS technology development and PLSS designs since the Apollo program, identifying the best path forward each time**

- In the early 2000s, the Constellation Space Suit Element PLSS schematic study was conducted, resulting in what is now the Exploration PLSS (xPLSS)

- **To achieve Mars surface exploration, modifications to the current xPLSS must be made**

- This schematic study investigates promising technologies for all major functions of the PLSS
- Providing schematic recommendations for the Mars exploration PLSS (MxPLSS)

The Martian Environment

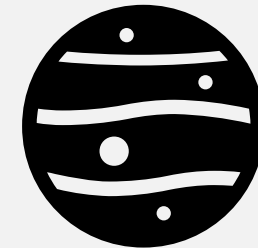


- **There is an atmosphere with low pressure – no longer at vacuum conditions**

- Martian atmosphere is 95% CO₂ at ~0.15 psia
- Precludes use of venting technologies (SWME and RCA) without modification and calls for adjustments to suit insulation (gaseous atmosphere adds significant thermal conductance)

- **Martian gravity is ~2.5x lunar gravity**

- Martian gravity is 0.38g compared to Lunar gravity at 0.16g
- On-back weight limits will be much more restrictive



- **Large travel distance and long mission duration**

- High reliability and regenerable elements to reduce weight and volume are necessary

- **Mars has seasonal changes/weather patterns or conditions**

- Materials used must withstand radiation received from planet and varying environmental conditions

- **Conditions such as dust, lighting, and visibility**

- Atmosphere introduces dust as a major hazard which could enter the space suit and expose CM to toxic particles – less abrasive than lunar soil but more reactive

- **Blank-sheet approach was taken to compile a list of promising technologies that could satisfy the eight major functions of the PLSS**

- Initial list of 89 independent technologies which was reduced to 57 after Subject Matter Expert (SME) consultation

- **Developed mxPLSS specifications/requirements & assessment criteria**

- Environmental conditions, metabolic profiles, figures of merit, operational concepts, etc.

- **Guided Utility Sizer (GUS) tool developed to assess technologies and identify favorable schematics**

- Performs mass and heat balances to determine sizing and performance parameters for selected schematic combinations based on user defined inputs

- **Schematic down-selection conducted via Equivalent System Mass (ESM) analysis**

- Resulted in 7 PLSS schematic recommendations

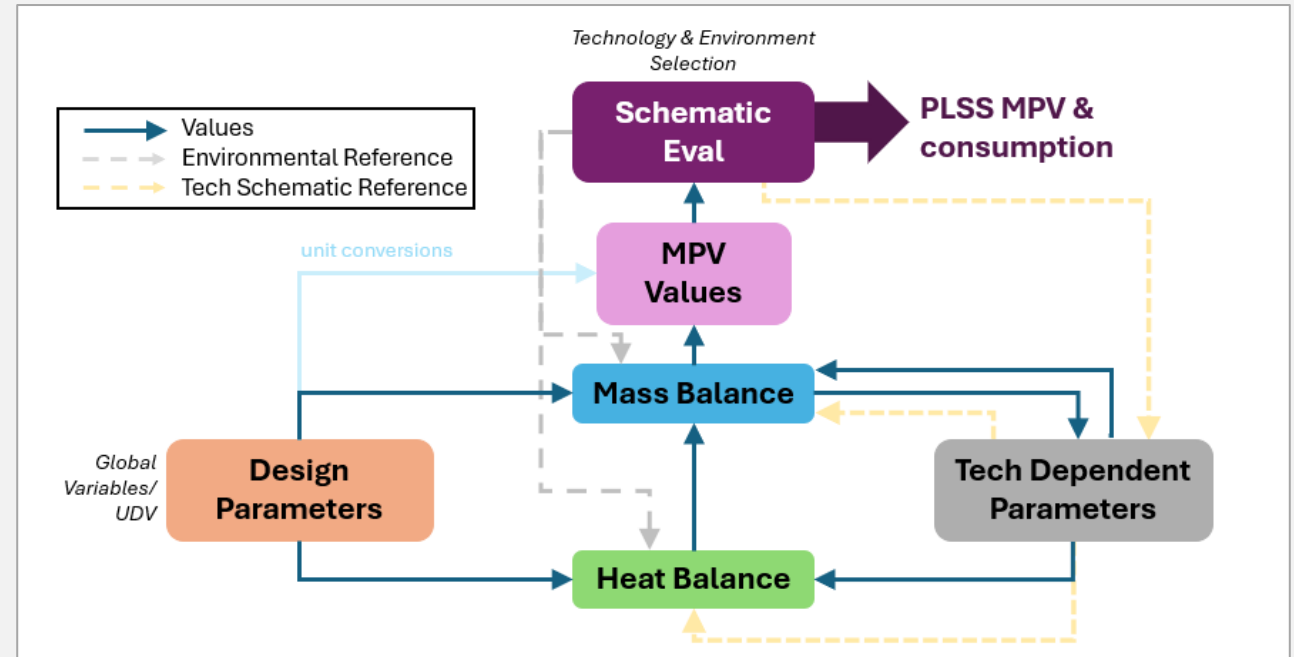
Function	# of Technologies Considered
Oxygen storage and supply	8
Ventilation network	2
Flow drive	6
Carbon dioxide removal*	22
Humidity removal*	25
Thermal control*	18
Trace contaminant control*	8
Power and energy storage	19
Total independent technologies	89
Eliminated	-32
Technologies remaining	57

Guided Utility Sizer (GUS) Tool



- A simplified, user-friendly sizing tool that performs mass and heat balances for user-selected PLSS schematics under a user-defined environment

- Programmed within Microsoft Excel 2024
- Computes mass, power, volume and consumables requirements for selected technologies & associated PLSS



- Includes sizing of relevant technologies modeled previously, as well as 24 new technology options never sized before
 - Mass balances for new technologies use experimental sizing data in literature & are correlated to PLSS operational requirements when necessary
- Programmed to allow schematic sizing under a variety of operating conditions including Lunar and Mars environments, with refined calculations for evaluating convective heat transfer contributions on Mars

- **The following upgrades were incorporated into GUS in FY25 to improve upon initial simplifications:**
 - Addition and modification of previously existing technologies to maintain relevancy to the state of the art
 - Addition of **secondary subsystem sizing** as well as open & closed loop schematic configurations
 - Habitat/lander mass and architecture penalties for **system-level assessment of schematics**, including pre- and post- EVA consumables calculations
 - Enablement of **transient heat balance analyses** for selected PLSS schematics to increase fidelity of EVA evaluations in various environments
 - Improved tailoring to Mars missions via addition of location-specific Martian environments
- **With these upgrades, a higher-fidelity schematic analysis was performed that incorporates:**
 - Primary and secondary subsystem contributions
 - System-level assessments of technology impacts on the vehicle level
 - Different system architectures investigated at different EVA times

- **Improved upon the fidelity of the previous schematic down selection process by using GUS to evaluate every possible schematic combination**
- **Combinatorial process achieved using Mission Analysis and Integration Tool (MAIT)**
 - Given a list of input and output variables, MAIT opened the GUS tool, plugged in technology options for each PLSS major function, and extracted calculated sizing and performance parameters for thousands of architectures at varying EVA times
 - Constraints and assumptions were implemented to reduce processing time by skipping incompatible or redundant schematic pairings
 - Results were sorted and postprocessed to determine lowest PLSS mass and vehicle mass options
- **PLSS options optimized for open loop, semi-open loop, and closed loop primary subsystem configurations at 2-, 4-, 6-, and 8-hour EVA durations**
 - Secondary subsystem configuration always treated as open loop and is sized to operate for a duration of 0.5 hours with a 2-hour EVA and 1 hour with 4-, 6-, and 8-hour EVAs
- **For each case, the lowest mass options using both gaseous (GOX) and liquid (LOX) oxygen were recommended**
 - A mass packaging factor of 2.32 and a volume packaging factor of 2.62 were applied to all schematics to get total PLSS mass and volume
 - A handful of architectures that optimize vehicle ESM were also considered

Operational & Environmental Parameters



- **Primary Avg Met Rate** : 350 W (1194 BTU/hr)
- **Primary Max Met Rate** : 530 W (1810 BTU/hr)
- **Secondary Avg Met Rate** : 295 W (1007 BTU/hr)
- **Secondary Max Met Rate** : 350 W (1194 BTU/hr)
- **Suit Pressure** : 4.3 psia
- **Inner Suit Temp** : 294.3 K (70 F)
- **Primary EVA Time** : 2, 4, 6, & 8 hours
- **Secondary EVA Time** : 0.5, 1, 1, & 1 hour
- **Pre/post EVA duration** : 2 hours
- **Mission Duration** : 180 days
- **EVAs Scheduled** : 100
- **EVAs Contingency** : 1
- **Recharge Duration** : 34 hours
- **EVA Crew** : 2

Habitat	Volume (kg/m ³)	Power (kg/kW)	Cooling (kg/kW)
Mars Surface	170	87	146
Mars Transit	79.3	162	96

Environment	Surface Temp (K)	Sky Temp (K)	Atm. Press (psia)	Wind Speed (m/s)	Solar Flux (W/m ²)
Mars Hot	299.8	139.8	0.145	20.12	173.5
Mars Nominal	212.0	139.8	0.124	10.05	110.4
Mars Cold	162.6	139.8	0.087	4.88	59.94

- Every schematic was evaluated under **Mars nominal conditions** with a **Mars surface habitat** selected for vehicle analysis
- Schematics were **modeled in steady-state operation** assuming a **fixed metabolic rate** for the entire EVA duration

- **LOX schematics**

- Primary subsystem – LOX is modeled with a ventilation heat exchanger and heater for vaporization (depending on schematic)
- Secondary subsystem – LOX is modeled in conjunction with a super ice phase change material (PCM) as a vaporizer

- **GOX schematics**

- Modeled with a regulator in both primary and secondary subsystems

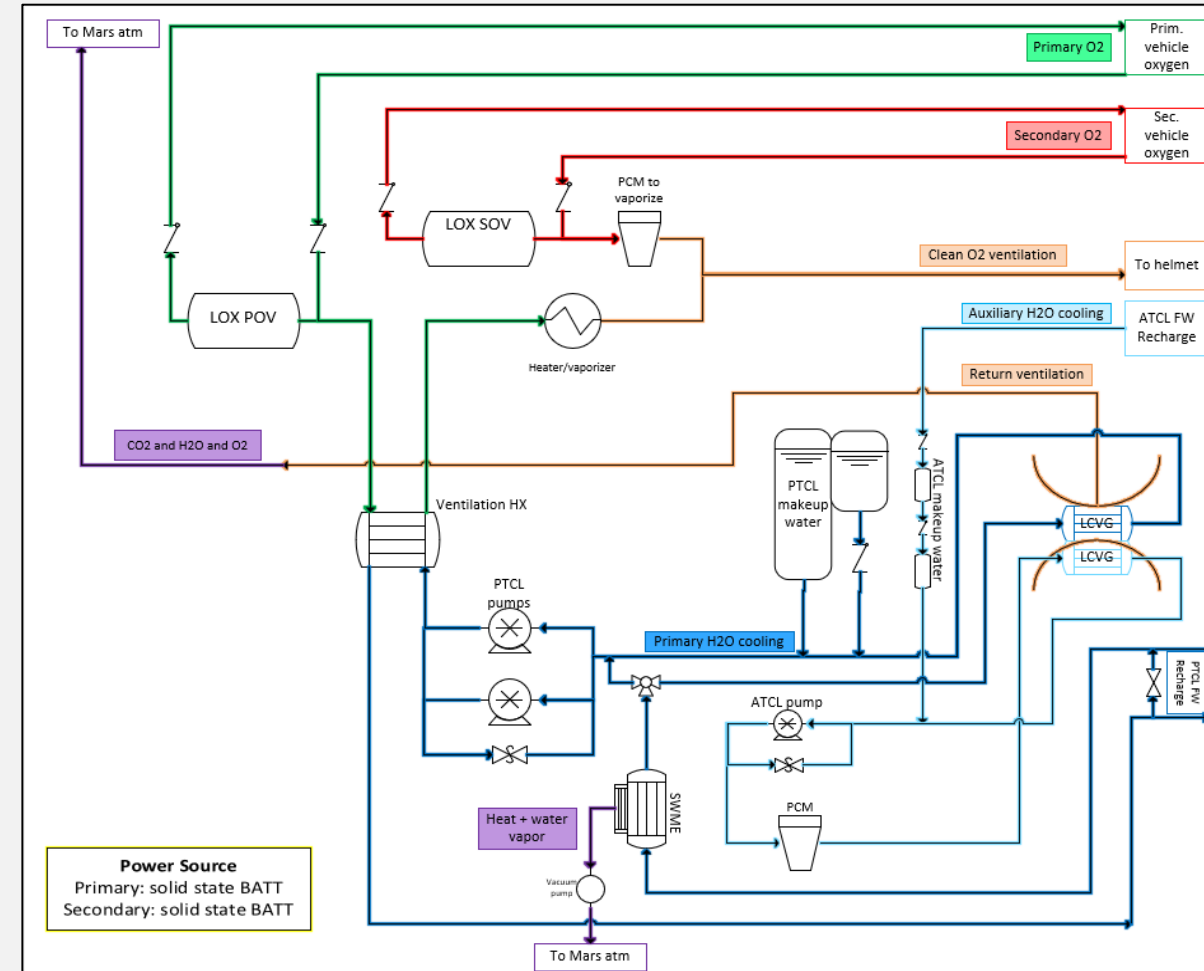
- **All recommended schematics**

- LCVG for ventilation network
- Fan or ejector for ventilation flow drive
- Pump for primary and secondary thermal loop flow drive
- Sub-cooled PCM or radiator for secondary thermal control
- Solid-state battery for primary and secondary power supply

Open Loop Schematic Options



Primary Subsystems		
Oxygen storage and supply	LOX + vent HX + heater/GOX + regulator	
Ventilation network	LCVG	
Flow drive (vent & thermal loop)	Pump	
Carbon dioxide removal	N/A	
Humidity removal	N/A	
Thermal control	SWME + vacuum pump/Upsized SWME	
Topping thermal control	N/A	
Trace contaminant control	N/A	
Power supply	Solid state battery	
Secondary Subsystems		
Oxygen storage and supply	LOX + PCM vaporizer/GOX + regulator	
Flow drive (thermal loop)	Pump	
Thermal control	Sub-cooled PCM	
Power supply	Solid state Battery	
Total PLSS Mass (kg)	2-hr LOX / GOX	8-hr LOX / GOX
	50.1 / 70.1	93.0 / 152.6
Vehicle ESM (kg)	1181 / 2103	3698 / 6931

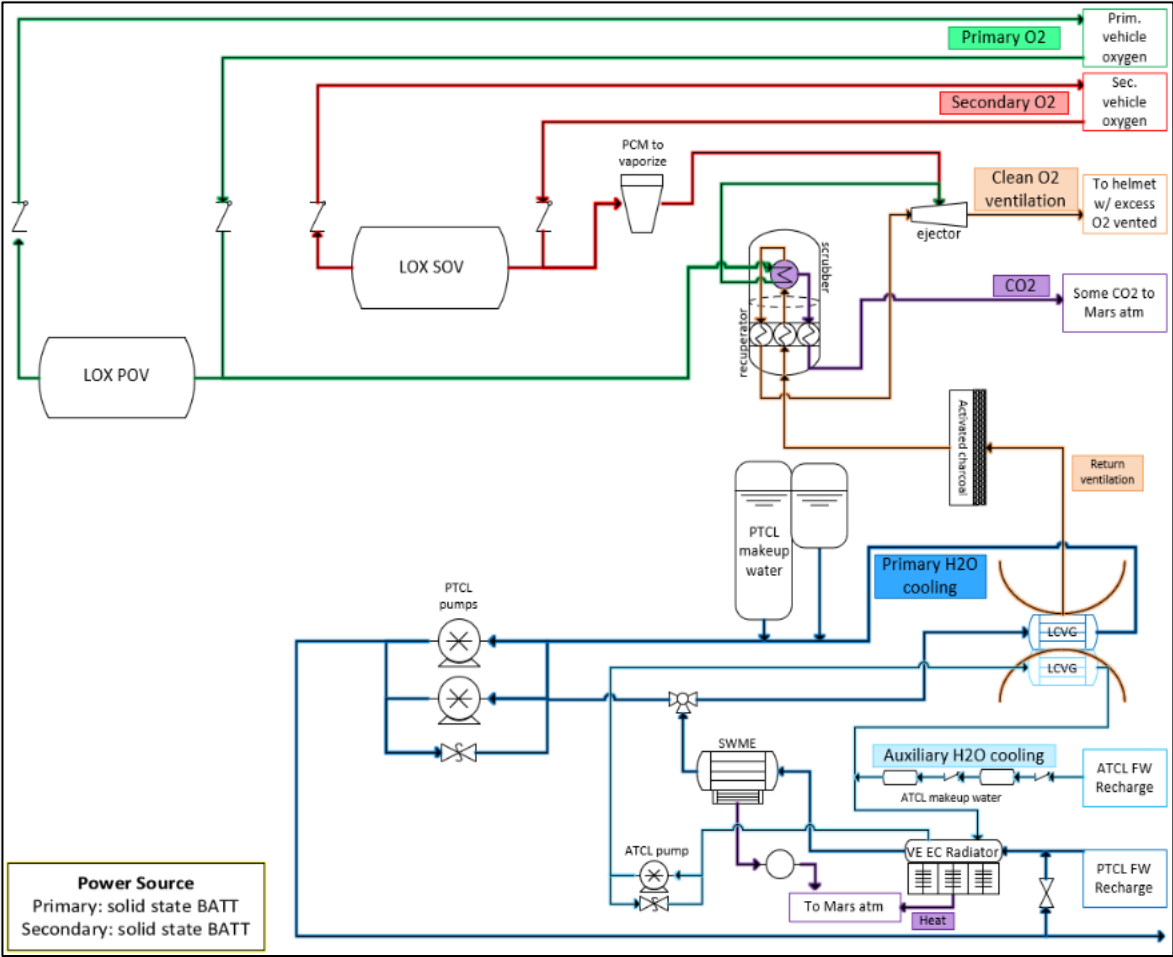


Open loop 2-, 4-hr EVA LOX schematic

Semi-Open Loop LOX Schematic Options



Primary Subsystems		
Oxygen storage and supply	LOX	
Ventilation network	LCVG	
Flow drive (vent & thermal loop)	Ejector + pump	
Carbon dioxide removal	Dual cryogenic scrubber	
Humidity removal		
Thermal control	SWME + vacuum pump/Variable emissivity electrochromic radiator	
Topping thermal control	N/A/SWME attachment	
Trace contaminant control	Activated charcoal	
Power supply	Solid state battery	
Secondary Subsystems		
Oxygen storage and supply	LOX + PCM vaporizer	
Flow drive (thermal loop)	Pump	
Thermal control	Sub-cooled PCM/Variable emissivity electrochromic radiator	
Power supply	Solid state Battery	
Total PLSS Mass (kg)	2-hr LOX	8-hr LOX
	47.9	87.4
Vehicle ESM (kg)	1657	3970

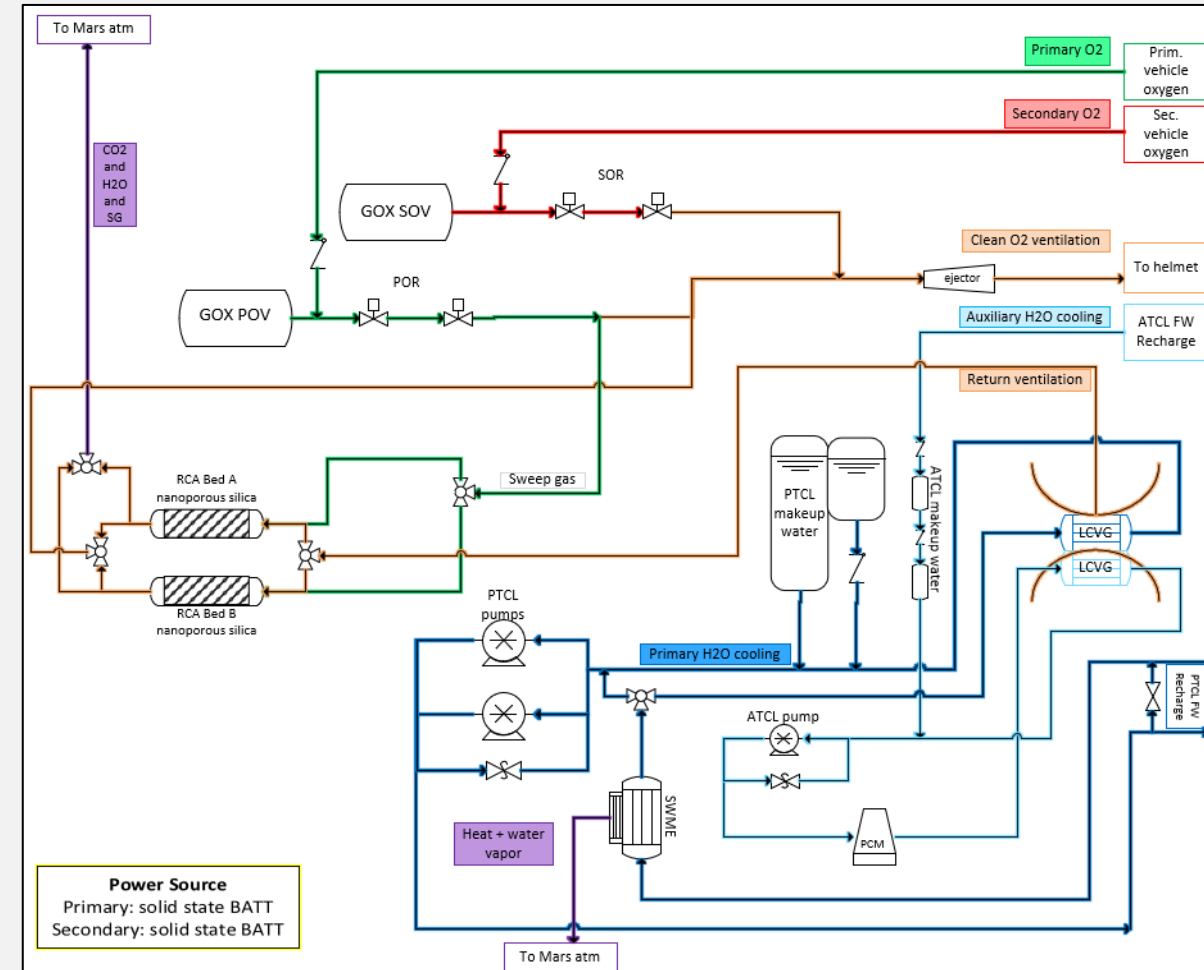


Semi-open loop 4-, 6-, 8-hr EVA LOX schematic

Semi-Open Loop GOX Schematic Options



Primary Subsystems		
Oxygen storage and supply	GOX + regulator	
Ventilation network	LCVG	
Flow drive (vent & thermal loop)	Ejector + pump	
Carbon dioxide removal	RCA + boost compressor/RCA + sweep gas	
Humidity removal		
Thermal control	SWME + vacuum pump/Upsized SWME	
Topping thermal control	N/A	
Trace contaminant control	Nanoporous silica	
Power supply	Solid state battery	
Secondary Subsystems		
Oxygen storage and supply	GOX + regulator	
Flow drive (thermal loop)	Pump	
Thermal control	Sub-cooled PCM	
Power supply	Solid state Battery	
Total PLSS Mass (kg)	2-hr GOX	8-hr GOX
	73.2	110.8
Vehicle ESM (kg)	1505	3264

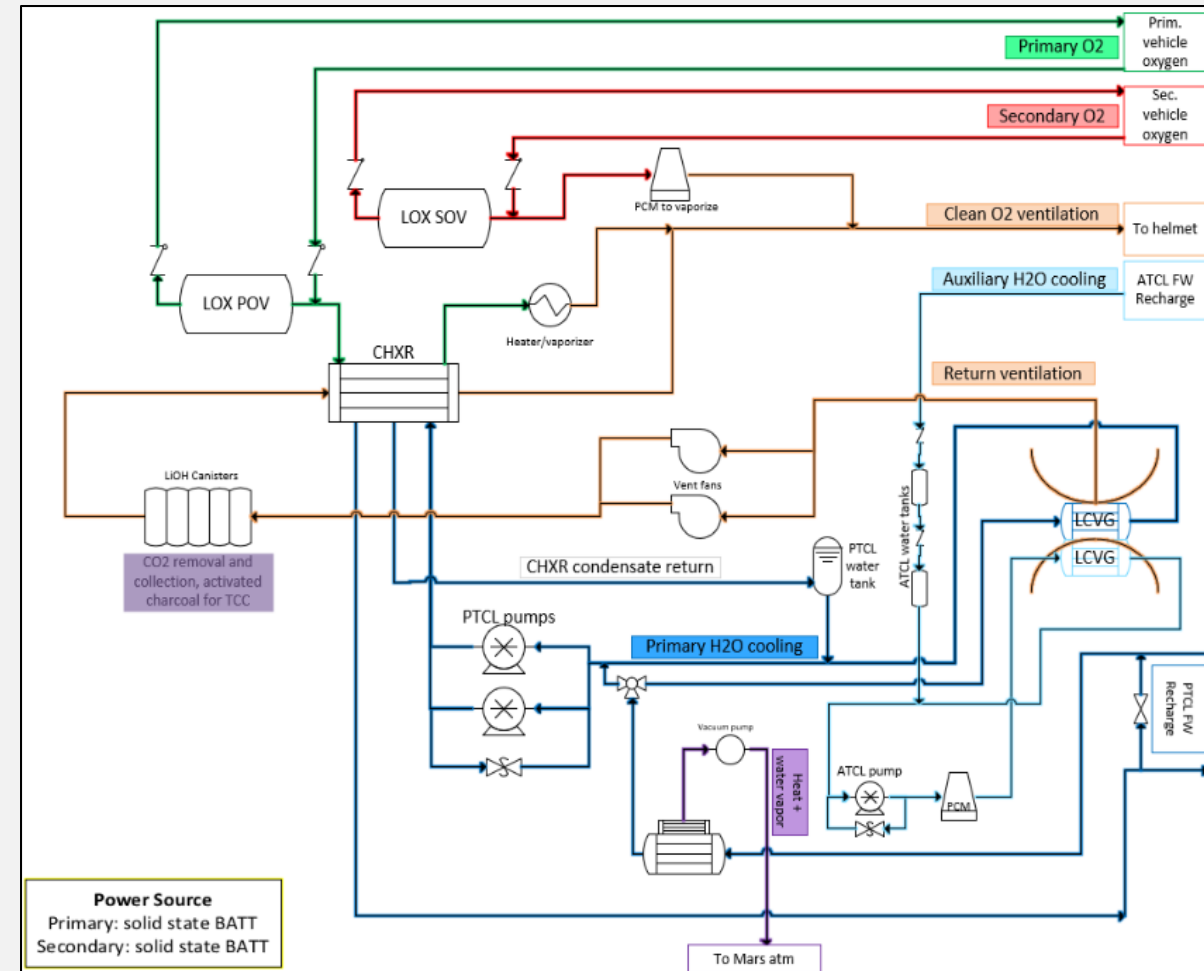


Semi-open loop 6-, 8-hr EVA GOX schematic

Closed Loop Schematic Options



Primary Subsystems		
Oxygen storage and supply	LOX + heater/GOX + regulator	
Ventilation network	LCVG	
Flow drive (vent & thermal loop)	Fan + pump	
Carbon dioxide removal	LiOH	
Humidity removal	CHXR	
Thermal control	SWME + vacuum pump/Upsized SWME	
Topping thermal control	N/A	
Trace contaminant control	Activated charcoal (integrated with LiOH)	
Power supply	Solid state battery	
Secondary Subsystems		
Oxygen storage and supply	LOX + PCM vaporizer/GOX + regulator	
Flow drive (thermal loop)	Pump	
Thermal control	Sub-cooled PCM	
Power supply	Solid state Battery	
Total PLSS Mass (kg)	2-hr LOX / GOX	8-hr LOX / GOX
	50.2 / 65.7	74.6 / 98.6
Vehicle ESM (kg)	1067 / 1477	2441 / 3374



Closed loop 2-, 4-hr EVA LOX schematic

Low Vehicle ESM Schematics



Primary Subsystems	Closed Loop		Open Loop		Semi-Open Loop	
Oxygen storage and supply	LOX + heater		LOX + vent HX + heater		LOX + heater	
Ventilation network	LCVG		LCVG		LCVG	
Flow drive (vent & thermal loop)	Fan + vent HX + pump		Pump		Fan + vent HX + pump	
Carbon dioxide removal	Hollow fiber membrane		N/A		RCA + boost compressor	
Humidity removal						
Thermal control	Radiator + heat pump		Radiator + heat pump		Radiator + heat pump	
Topping thermal control	N/A		N/A		N/A	
Trace contaminant control	Activated charcoal		N/A		Nanoporous silica	
Power supply	Solid state battery		Solid state battery		Solid state battery	
Secondary Subsystems	Closed Loop		Open Loop		Semi-Open Loop	
Oxygen storage and supply	LOX + PCM vaporizer		LOX + PCM vaporizer		LOX + PCM vaporizer	
Flow drive (thermal loop)	Pump		Pump		Pump	
Thermal control	Sub-cooled PCM		Sub-cooled PCM		Sub-cooled PCM	
Power supply	Solid state Battery		Solid state Battery		Solid state Battery	
Total PLSS Mass (kg)	2-hr EVA	8-hr EVA	2-hr EVA	8-hr EVA	2-hr EVA	8-hr EVA
	73.7	90.5	62.9	95.6	71.0	86.4
Vehicle ESM (kg)	372	498	723	2222	323	466

Conclusions



- **Lowest mass options vary based on EVA time**
 - Shorter EVA times (2 & 4 hours): semi-open loop LOX, cryogenic scrubber, SWME + VP or VE EC radiator/SWME attachment
 - Longer EVA times (6 & 8 hours): closed loop LOX, LiOH/CHXR, upsized SWME
- **Some schematics that are not the lowest mass option within their own configuration category (closed, open, or semi-open loop) trade better than options in other categories**
 - 8-hour EVA schematics optimized for vehicle ESM in the semi-open and closed loop configurations trade better than the option optimized for PLSS mass in the open loop configuration
 - Additional low mass options in each configuration category are being investigated in forward work

Schematic		Primary Subsystems	Mass (kg)	Vehicle ESM (kg)
1	Closed	LOX + heater, fan + pump, LiOH, CHXR, SWME, activated charcoal	74.6	2441
2*	Semi-Open	LOX + heater, fan + vent HX + pump, RCA + BC, radiator + HP, nanoporous silica	86.4	466
3	Semi-Open	LOX, ejector + pump, dual cryogenic scrubber, VE EC radiator, SWME topping unit, activated charcoal	87.4	3970
4*	Closed	LOX + heater, fan + vent HX + pump, HFM, radiator + HP, activated charcoal	90.5	498
5	Open	LOX + vent HX + heater, pump, SWME	93.0	3698
6*	Open	LOX + vent HX + heater, pump, radiator + HP	95.6	2222
7	Closed	GOX + regulator, fan + pump, LiOH, CHXR, SWME, activated charcoal	98.6	3374
8	Semi-Open	GOX + regulator, ejector + pump, RCA + SG, SWME, nanoporous silica	110.8	3264
9	Open	GOX + regulator, pump, SWME + VP	152.6	6931

*Low vehicle ESM option



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Thank you!

Questions?



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