

Martian Exploration Portable Life Support System Schematic Study

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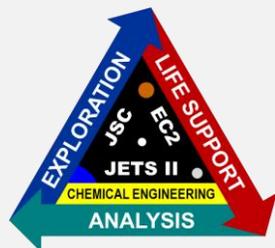
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Portable Life Support System (PLSS)



- **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
- 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
- It provides schematic recommendations for the Martian Exploration PLSS (mxPLSS)

The Martian Environment/Mission Characteristics

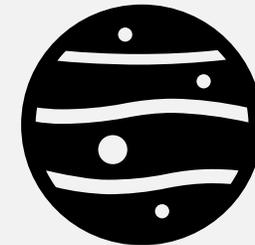


- **Low pressure atmosphere – not at vacuum conditions**

- Martian atmosphere is 95% CO₂ at ~0.15 psia
- Precludes use of venting technologies (SWME and RCA) 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

- **Seasonal changes/weather patterns or conditions**

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

- **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

Technology Identification & Guideline Development



- **Researched & compiled a list of technologies that have been or could be used in a PLSS to satisfy the major functions of a PLSS on Mars**

- A wide net was cast - hundreds of old reports and literature sources including space and terrestrial applications
- 89 technologies identified
- *Many technologies overlap, accomplishing more than one function

- **Consulted experts to identify promising options to further investigate – eliminated those with obvious safety concerns or low/no TRL**

- Lower TRL technologies could become viable in the future
- 32 technologies eliminated at this stage

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

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

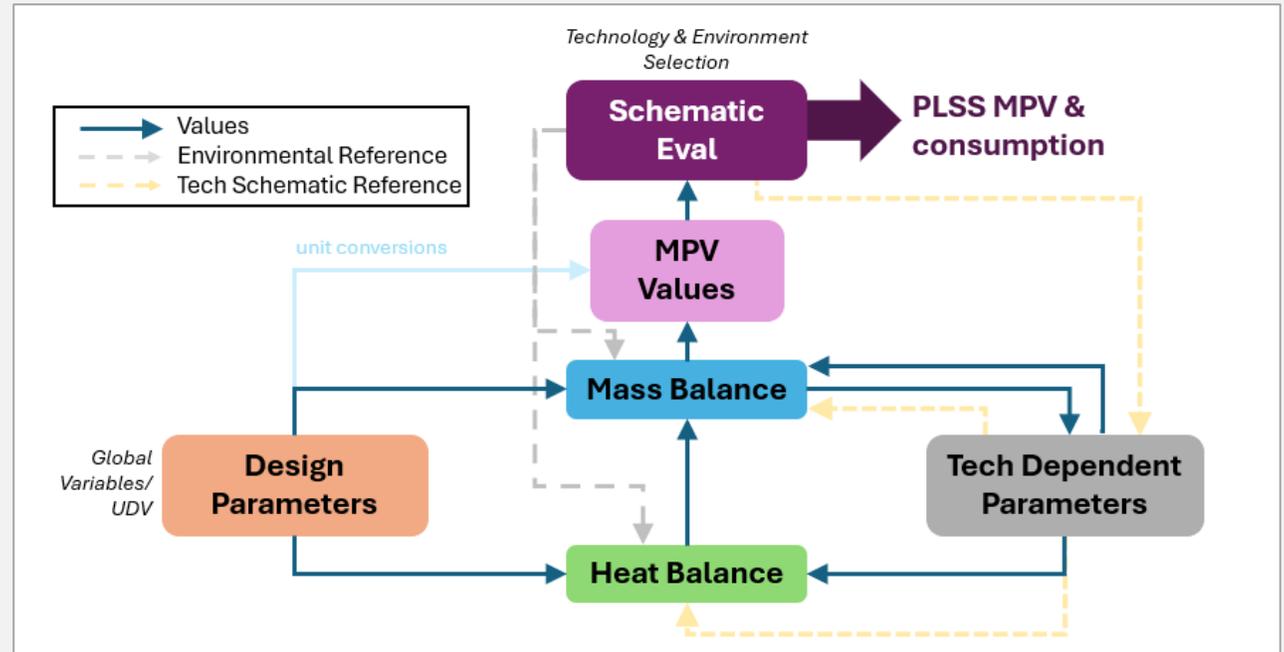
Function	# of Technologies Considered
Oxygen storage and supply	8
Ventilation network	2
Flow drive	6
Carbon dioxide removal*	22
Humidity removal*	25
Thermal control*	18
Trace contaminant control*	8
Power and energy storage	19
Total independent technologies	89
Eliminated	(32)
Technologies remaining	57

Development of Guided Utility Sizer (GUS)



- **A 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 23 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, martian, and deep space environments, with refined calculations for evaluating convective heat transfer contributions on Mars



- **Technologies were further narrowed down using an equivalent system mass (ESM) analysis – comparing technologies within each function**
 - ESM converts disparate sizing characteristics into a unified, quantifiable metric (mass) to easily compare technologies
 - Typically used in life support applications to assess vehicle-level impacts
 - xPLSS is used as a baseline for the system mass (M_S), system volume (V_S), and system power (P_S)
 - The subsystem being evaluated is changed while all other functions are satisfied by technologies in the xPLSS and the total system mass, volume, and power is calculated in GUS
 - The mass of oxygen (M_{O_2}) and mass of water (M_{H_2O}) consumed by the technology of interest is also included, if applicable, to account for an increase in the subsequent tank

$$ESM = M_S + \gamma_{O_2}M_{O_2} + \gamma_{H_2O}M_{H_2O} + \gamma_VV_S + \gamma_PP_S$$

- Equivalency factors (γ_x) come from xPLSS data
- **Largest ESM technologies in each major function were eliminated**
 - Any additional technologies that were deemed incompatible with the martian environment upon further assessment were also eliminated at this stage
- **44 final technologies were considered for schematic evaluations**

Schematic Identification & Selection Process



- **All possible schematic combinations were computed from the 44 down-selected technologies**
 - A few constraints were applied to restrict technology pairings when appropriate (e.g., cryogenic scrubbers must be paired with liquid oxygen (LOX))
- **Schematic combinations were reviewed and manually filtered based on technology compatibility, total system mass, and uniqueness**
 - Lowest system mass schematics were selected for further evaluation
 - In most cases, if schematics were identical in all but one function, only the lowest mass option was considered
 - The combined ESM of the individual technologies that made up each combination was used as a first pass guess for total system mass
- **Seven schematics were identified and selected for further assessment**
- **A complete schematic consisted of technologies satisfying the 8 major functions, packaging, & baseline emergency backup functions which did not vary across schematics but were used for estimating total PLSS mass**

Selected Schematics & Primary Technologies



Subsystem	Schematic 1	Schematic 2	Schematic 3	Schematic 4	Schematic 5	Schematic 6	Schematic 7
O₂ supply	LOX	LOX	GOX	GOX	GOX	GOX	GOX
Ventilation	LCVG	LCVG	LCVG	LCVG	ECVG	LCVG	LCVG
Flow Drive	Ejector + pump	Ejector + pump	Fan + pump	Fan + pump	Fan + pump	Fan + pump	Fan + pump
CO₂ removal	Dual cryo scrubber	Cryo scrubber	RCA + sweep gas	RCA + sweep gas	RCA + sweep gas	MTSA	MetOX
H₂O removal	Dual cryo scrubber	CHXR	RCA + sweep gas	RCA + sweep gas	RCA + sweep gas	MTSA	CHXR
Thermal control	SWME	SWME	SWME	VE EC radiator + SWME	LCAR + PCM	MTSA	Sub-cooled PCM
TCC	Activated charcoal	Activated charcoal	Nanoporous silica	Nanoporous silica	Nanoporous silica	Activated charcoal	MetOX
Power	Battery – solid state						

*Schematic 3 closely resembles that of the xPLSS, but modified for operation on Mars

*Schematic 7 closely resembles that of the EMU PLSS, but modified for operation on Mars

Schematic Evaluations in GUS



- **Total mass, volume, power consumption & consumables (O₂ & H₂O) were computed for each schematic for an 8-hr EVA in the Mars nominal environment using GUS**
 - Those technologies expected to operate during pre/post EVA were sized with an equipment duration of 10 hrs
- **Schematics were ranked by total mass**
 - Includes packaging and backup functions
- **Three schematic groupings were identified based on the vehicle architecture they require**
 - LOX schematics (1 & 2)
 - GOX schematics (3 & 4)
 - Low consumables schematics (5, 6 & 7)

Schematic	Mass (kg)	Volume (m ³)	Power consumption (W-hr)	Consumables	
				O ₂ (kg)	H ₂ O (kg)
1	87	0.047	266	8.6	3.5
2	88	0.046	266	8.6	2.9
3	98	0.046	419	1.7	3.7
4	98	0.044	422	1.7	3.2
6	106	0.064	363	0.7	0.5
5	114	0.087	419	1.7	2.5
7	150	0.088	363	0.7	-

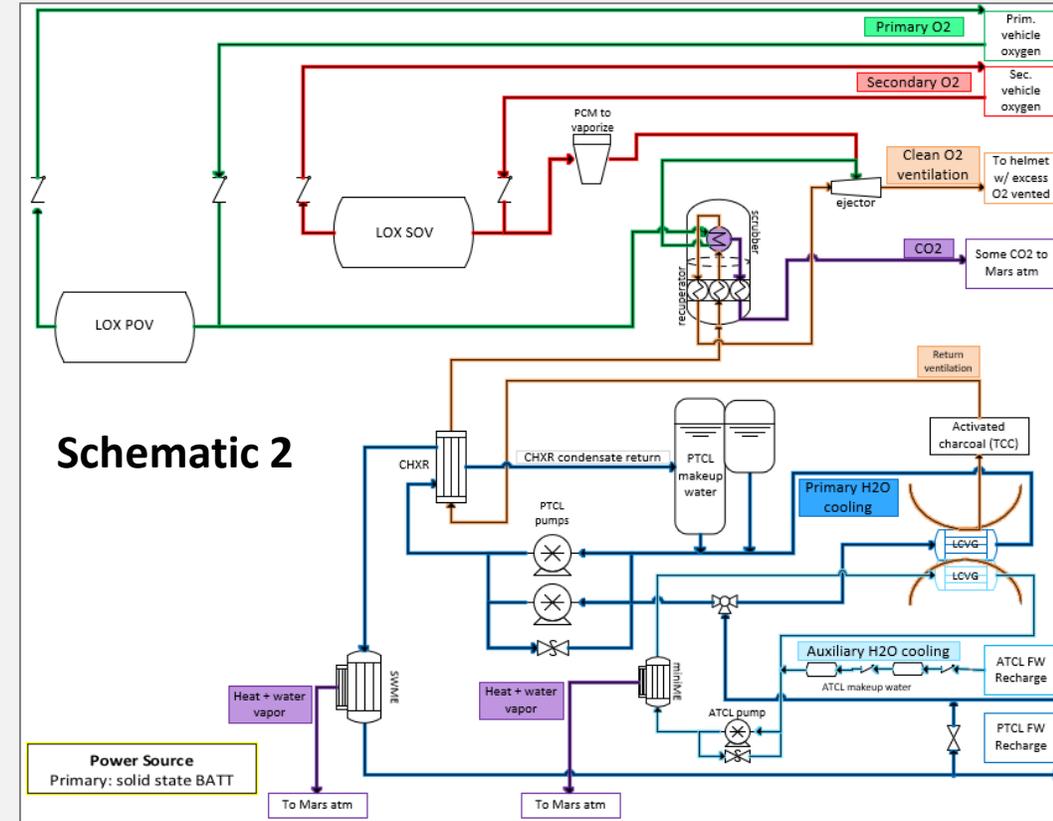
Global Variables

- Avg Metabolic Rate : 350 W (1194 BTU/hr)
- Max Metabolic Rate : 530 W (1810 BTU/hr)
- Suit Pressure : 4.3 psia
- Inner Suit Temp : 294.3 K
- EVA Time : 8 hours
- Equipment Duration : 10 hours
- Mass Package Factor : 2.2

LOX Schematics 1 & 2



- **LOX schematics have low mass and power but consume large amounts of O₂ & some H₂O**
 - Dual cryogenic scrubber has low mass compared to other CO₂/H₂O removal technologies
 - Ejector requires no power
 - Both require a high consumption of O₂ due to flowrate requirements
 - H₂O is consumed via the upsized SWME
- **H₂O removal technologies distinguish the two schematics**
 - Schematic 1 uses the dual cryogenic scrubber for both CO₂ and H₂O removal – metabolic water is lost
 - Schematic 2 adds a condensing heat exchanger (CHXR) – metabolic water is directed to the SWME
 - Reduces water lost to the environment compared to the dual cryo scrubber
 - Mass in water saved offsets more than half the mass of the CHXR – making mass differences minimal
- **Schematic 2 is chosen due to H₂O savings**

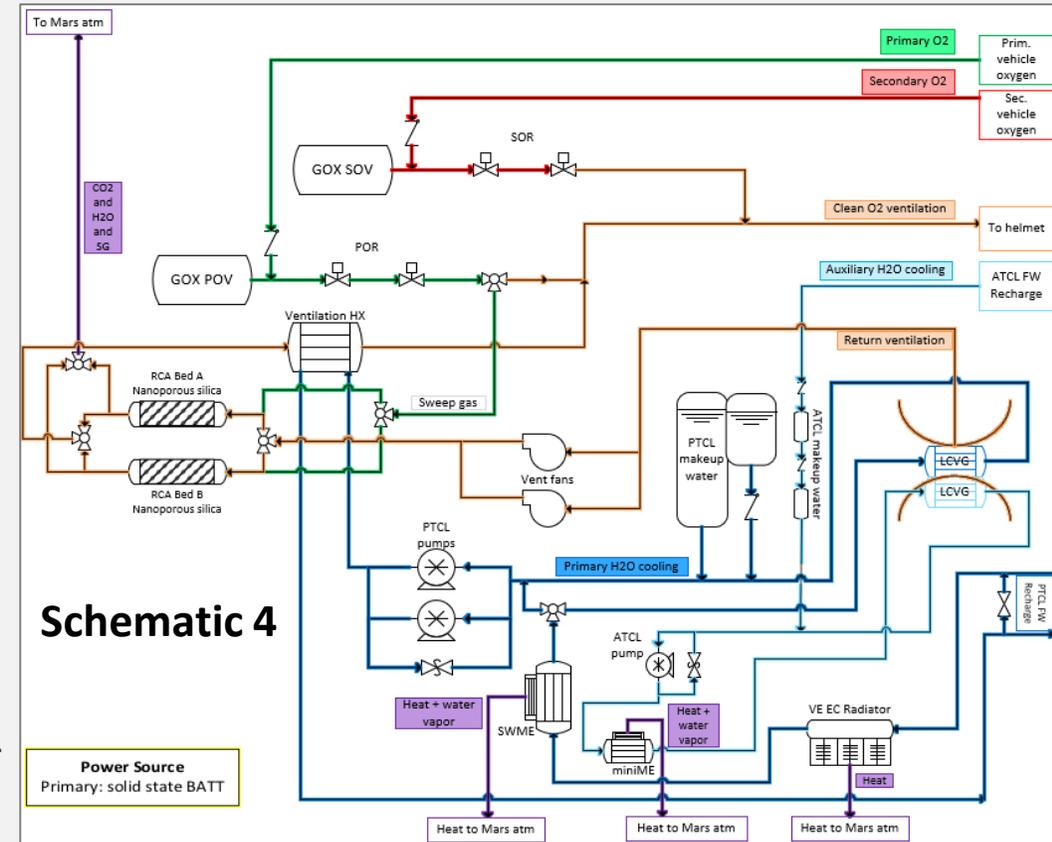


Environment	Mass (kg)	
	Schematic 1	Schematic 2
Mars Cold	85	86
Mars Nominal	87	88
Mars Hot	92	93

GOX Schematics 3 & 4



- **GOX schematics have greater mass and consume more power than the LOX schematics but consume less O₂**
 - Fan and RCA + sweep gas (SG) require significantly more power but consume far less O₂ than equivalent technologies in schematics 1 and 2
- **Thermal control technologies distinguish the two schematics**
 - Schematic 3 uses an upsized SWME – water is consumed
 - Schematic 4 has a variable emissivity electrochromic (VE EC) radiator and a SWME for backup – no water lost
 - Heat rejected is proportional to surface area of VE EC radiator
 - Set to 0.855 m² (~75% of the PLSS)
 - Requires SWME to meet max cooling requirements and whether average cooling requirements are met depends on environment
 - Increasing the VE EC radiator heat transfer surface area improves its emitted radiation in all environments
- **Schematic 4 is chosen due to H₂O savings**

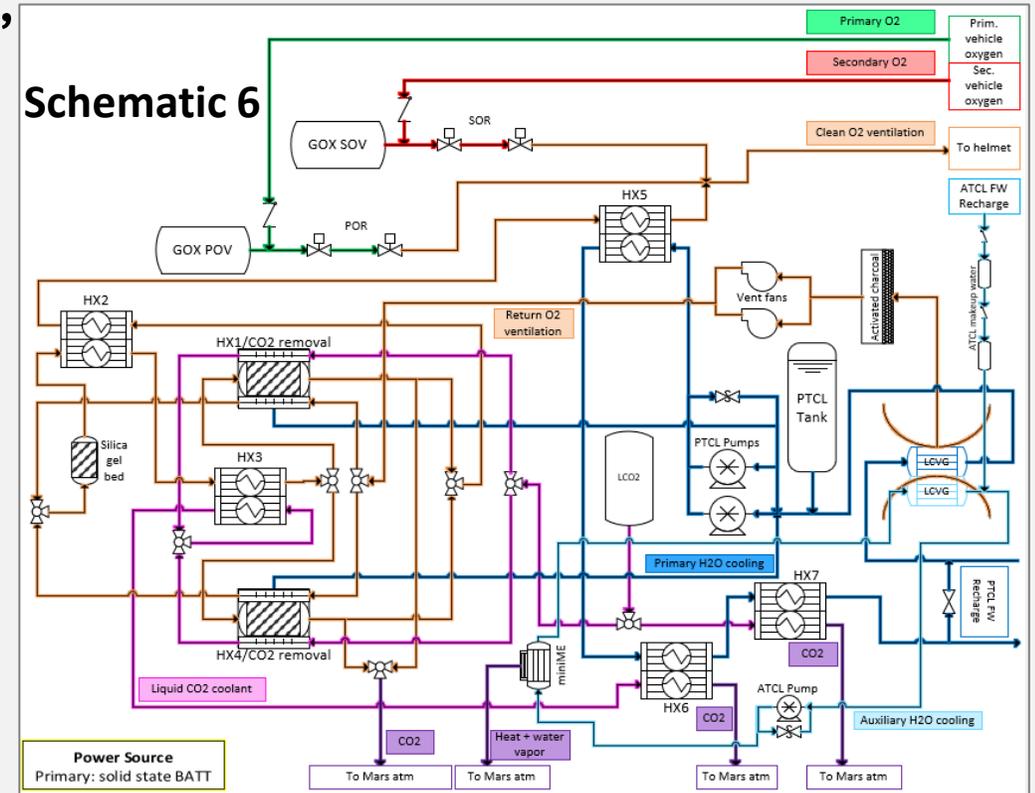


Environment	Mass (kg)	
	Schematic 3	Schematic 4
Mars Cold	93	93
Mars Nominal	98	98
Mars Hot	105	106

Schematics with Low Consumables 5, 6, & 7



- **Schematics 5, 6, & 7 have the greatest mass and volume, consume high power but consume the least amount of O₂ & H₂O**
- **Schematic 5 is similar to 3 & 4 but has an ECVG paired with the LCAR for thermal control**
 - O₂ and H₂O losses are due to the RCA + SG
 - Requires a phase change material (PCM) topping unit to meet thermal control requirements in warmer environments
- **Schematic 6 has one technology for CO₂ removal, H₂O removal, and thermal control**
 - Metabolic heat regenerated Temperature Swing Adsorption (MTSA)
 - Metabolic heat is the driving force to swing CO₂ removal beds
 - Consumes Liquid CO₂ (14.5 kg in Mars Nominal) –potential for ISRU
- **Schematic 7 closely resembles the EMU PLSS**
 - Metal Oxide (MetOx) for CO₂ removal & sub-cooled PCM for thermal control contribute to its high mass
- **Schematic 6 is chosen due to lowest mass and ISRU potential to harvest CO₂ on Mars**



Environment	Mass (kg)		
	Schematic 5	Schematic 6	Schematic 7
Mars Cold	106	103	146
Mars Nominal	114	106	150
Mars Hot	139	112	156

Final Recommendations & Conclusion



Functions	LOX Option: Schematic 2	GOX Option: Schematic 4	GOX & Reduced Consumables Option: Schematic 6
Oxygen storage and supply	LOX	GOX	GOX
Ventilation network	LCVG	LCVG	LCVG
Flow drive (ventilation & thermal loop)	Ejector + Pump	Fan + pump	Fan + pump
Carbon dioxide removal	Cryogenic scrubber	RCA + sweep gas	MTSA
Humidity removal	CHXR	RCA + sweep gas	MTSA
Thermal control	SWME	VE EC radiator + SWME	MTSA
Trace contaminant control	Activated charcoal	Nanoporous silica (RCA pair)	Activated charcoal
Power supply	Battery-solid state	Battery – solid state	Battery – solid state

- **Assuming EVAs do not drive vehicle design, the PLSS architecture depends on what the vehicle can supply**

- The LOX option is the lowest mass purely from a PLSS standpoint
- The GOX option is a lower consumable version of the xPLSS (VE EC radiator in place of SWME) and modified for Mars
- The GOX with reduced consumables is the highest in mass of all three options but is advantageous when O₂ and H₂O losses must be reduced

- **Vehicle-level impacts were assessed qualitatively**

Looking forward:

- Increasing the sophistication of the sizing tool GUS, including vehicle-level impacts and a mass-based combinatorial scheme, would provide more detailed insight on the optimal mxPLSS design
- Continued research efforts into low/no TRL technologies and restrictions on on-back mass would also better guide future recommendations



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Thank you!

Questions?