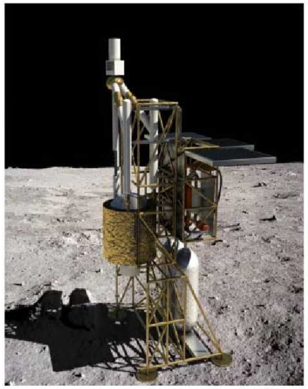
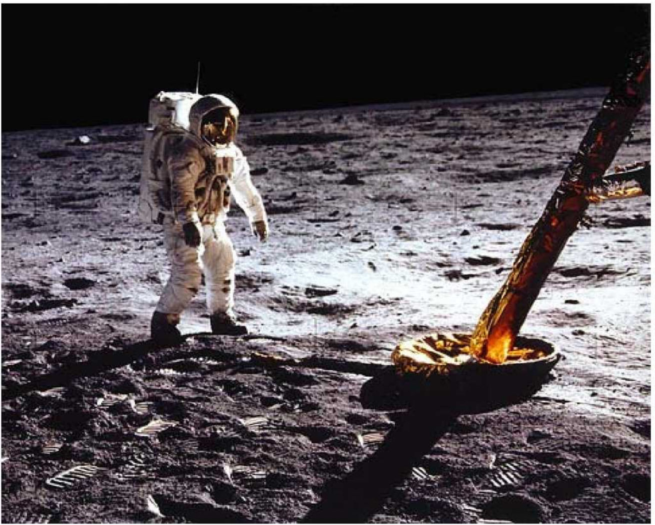
Providing Oxygen for the Crew of a Lunar Outpost



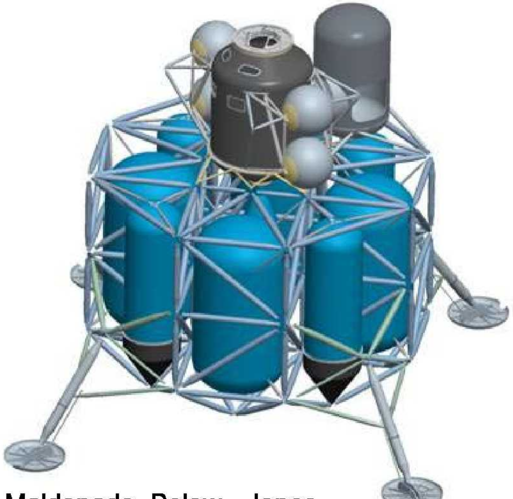
Frank F. Jeng and Bruce Conger
Engineering and Science Contract Group

Molly S. Anderson and Michael K. Ewert
NASA Johnson Space Center



Space 2009

Pasadena, California
September 2009

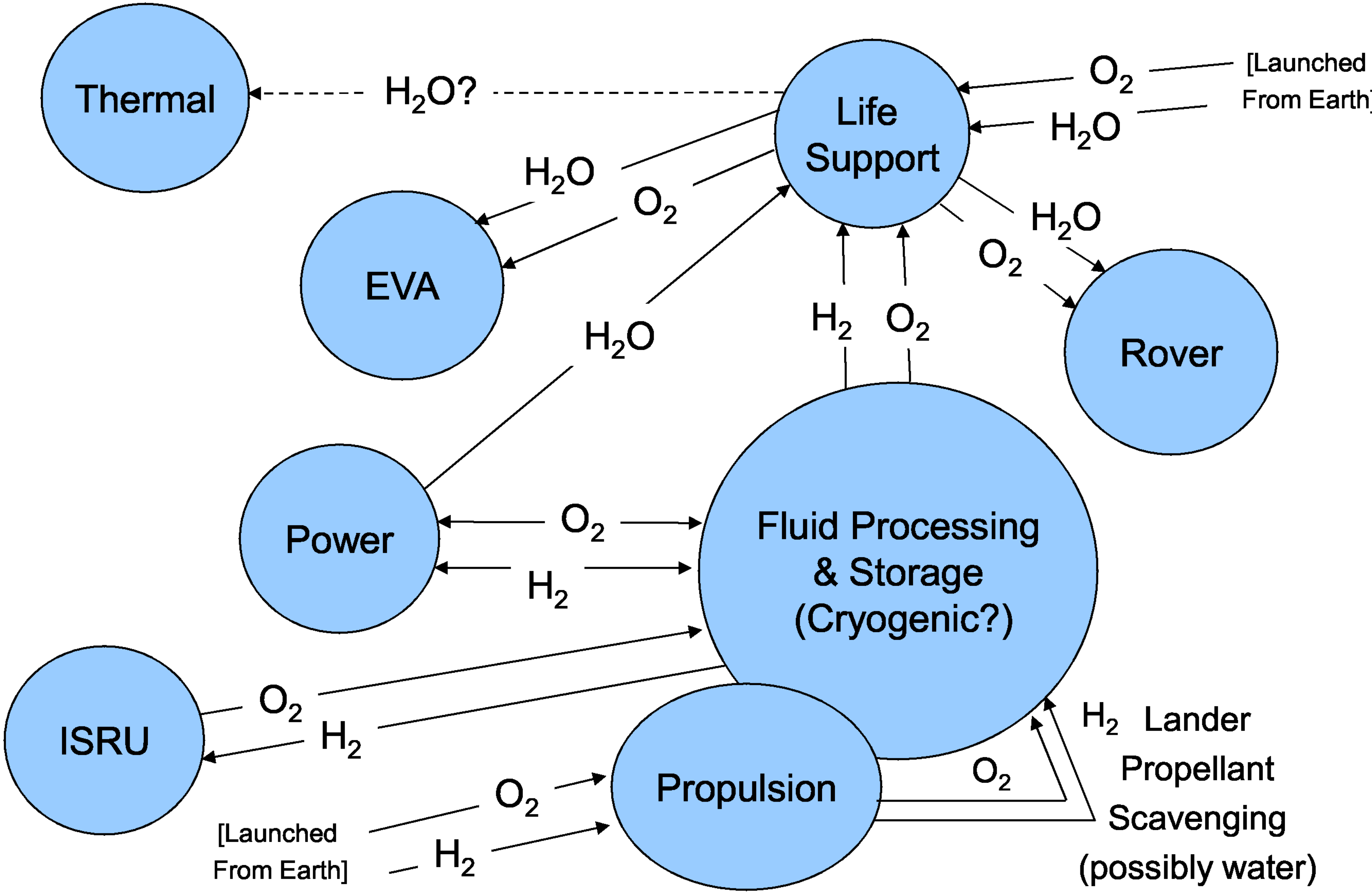


Photo/CAD image credits: Left – NASA, Above – Santiago-Maldonado, Below - Jones

Overview

- ***Part of a Lunar Surface Integrated Fluid Systems Analysis, which is a collaborative effort between the following Exploration Technology Development Projects:***
  - ***Exploration Life Support (ELS, a.k.a ECLSS), Extravehicular activity (EVA), In-situ resource utilization (ISRU), Propulsion and cryogenic advanced development (PCAD), Cryogenic fluid management (CFM)***
  - ***Goal: Starting with non-integrated fluid systems as a baseline, develop an optimized integrated concept and identify technology needs***
- ***This study evaluates technologies for provision of oxygen (O_2) to the crew of a Lunar Outpost***
  - ***Especially high-pressure O_2 for EVA life support system recharge***
  - ***By calculating equivalent system mass (ESM) of the options***
- ***3 Cases are presented:***
  - ***7 day Lunar Lander sortie mission***
  - ***180 Lunar Outpost***
  - ***10 years of successive 180 missions to the Outpost***
  - ***(Updates are included from previously reported studies)***

LUNAR OUTPOST COMMON FLUIDS



Driving Requirement: High Pressure Oxygen for EVA Recharge

Lunar exploration plan is to fill primary & secondary oxygen bottles with one pressure at 3000 psia

Concepts for providing high pressure EVA O_2 refill include:

- *Store GOX in 5000 psia tanks and transfer via pressure equalization*
- *Low pressure electrolysis followed by mechanical compression*
- *Store LOX in space suit to provide for breathing, CO_2 washout & thermal control (results shown in previous paper)*
- *Convert LOX into high pressure oxygen by:*
  - *direct heating and expansion for EVA and ECLSS applications (a.k.a. "vaporizer")*
  - *Or by using a Temperature Swing Adsorption Compressor (TSAC)*
  - *Use left over LOX in propellant tanks if available; otherwise, bring it along*
- *High pressure electrolysis*
  - *May be able to share the electrolyzer of the regenerative fuel cell at an Outpost*
- *Compress and store GOX from ISRU*

4 person crew

- *2 crew per EVA (if 4 crew per EVA is required, double these results)*

Crew Requirements for Oxygen (180 day case)

Current Shuttle/ISS EMU O_2 bottle capacities are:

– Primary O_2, 850 psia	1.2 lb
– Secondary O_2, 6000 psia	2.6 lb

High pressure oxygen users in Lunar Outpost

– O_2 for EVA[3]

Primary O_2 bottle, 3000 psia	1.6 lb/CM[1]-EVA
Secondary O_2 bottle, 3000 psia (infrequent)	2.6 lb/CM-EVA
Suit purge, <20 psia	1.0 lb/CM-EVA

High pressure (3000 psia) O_2 resupply (primary tank only)	**1.6 lb/CM-EVA**
Low pressure metabolic O_2 consumption	**1.94 lb/day**

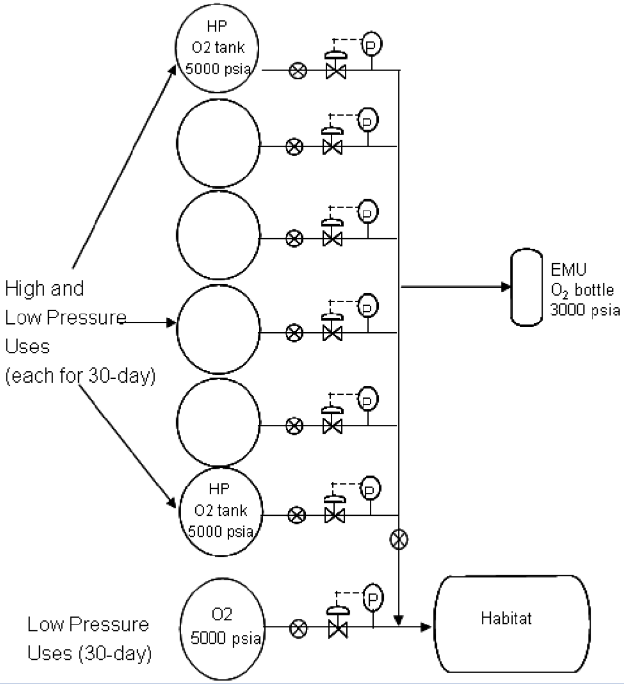
Number of Outpost EVA Sorties

– Nominal EVA-CM hours[2] (8 hours/CM-EVA)	2400 hours
– 300 CM-EVA's in 180-day Outpost mission	

Total O_2 requirements (high and low pressures)	**1745 lb**
Total high pressure O_2 required (180 days)	**480 lb**
– Mission average delivery rate	2.7 lb/day
– Design O_2 daily delivery rate (consecutive day EVAs)	3.2 lb/day

- 1. CM: crew member
- 2. Exploration Life Support Reference Missions Document, ESCG-4470-07-TEAN-DOC-0204.
- 3. Conger, B., Falconi E., Greg Leavitt, and Chullen C.," PLSS Baseline Schematics and Internal Interfaces", Rev. A, JSC–65563/CTSD-CX-5117

Baseline Technology – High Pressure Oxygen Tanks



Simple and reliable

Tanks made of Inconel® liner over-wrapped with carbon-fiber are relatively light weight.

For oxygen gas storage, 5000 psia is a reasonable limit.

- ***Material compatibility and safety issues increase with higher pressures***

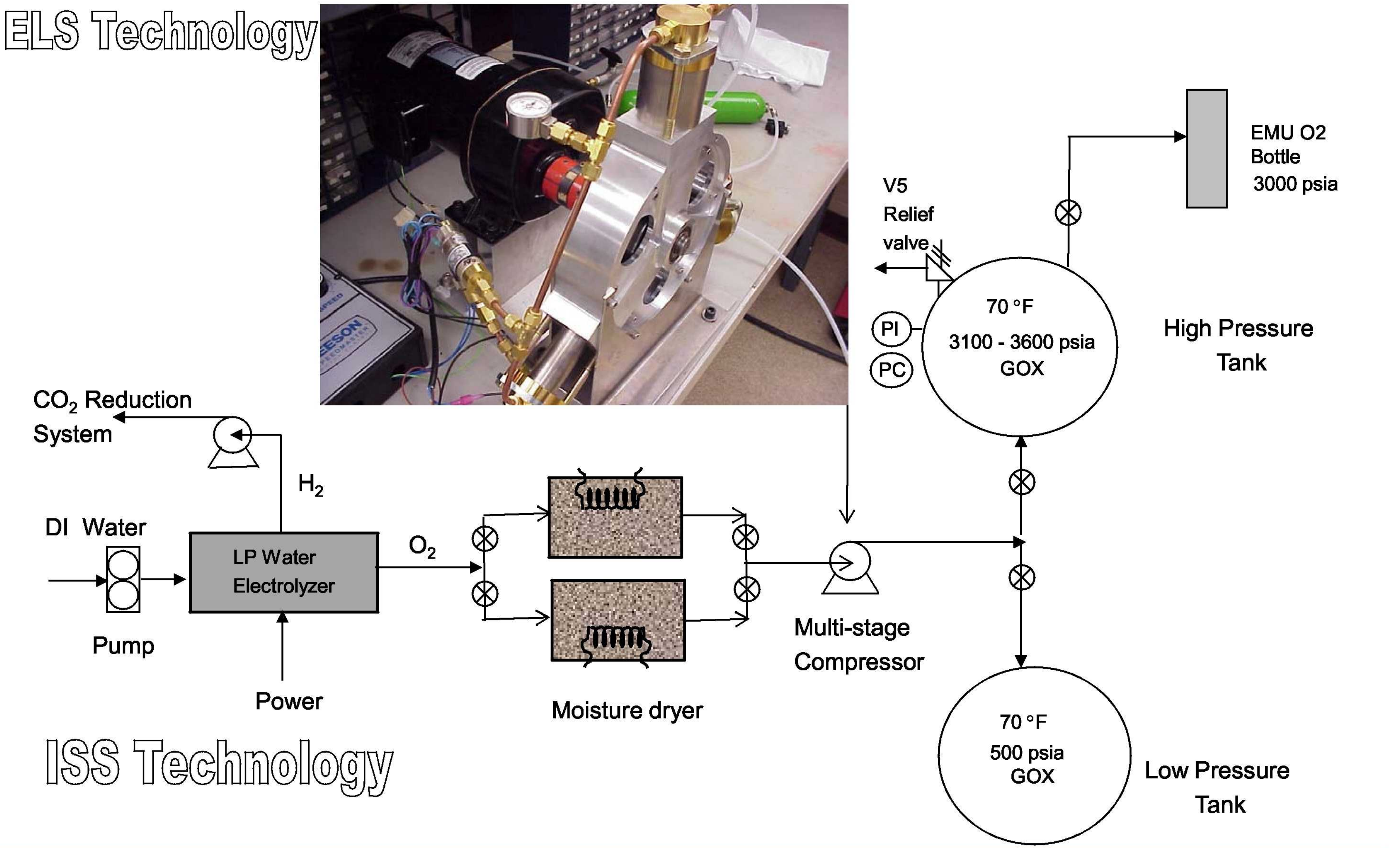
While 3100 – 3600 psia is the range for charging EVA oxygen bottles, left-over oxygen is enough for medium/low pressure applications, such as:

Crew breathing

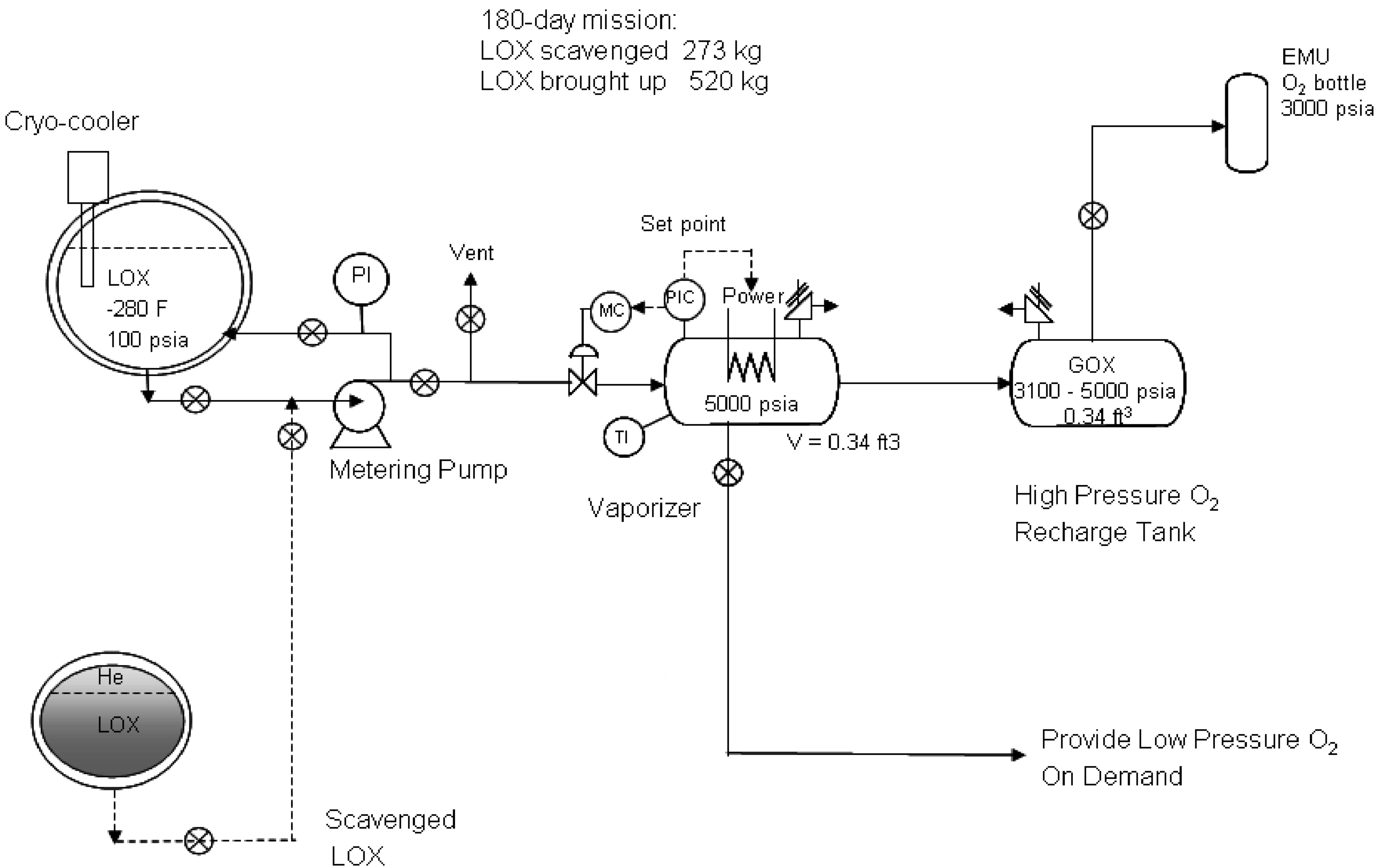
EMU purging

Other ECLSS use

Low Pressure Water Electrolyzer, Dryers and Multi-Stage Piston Compressor

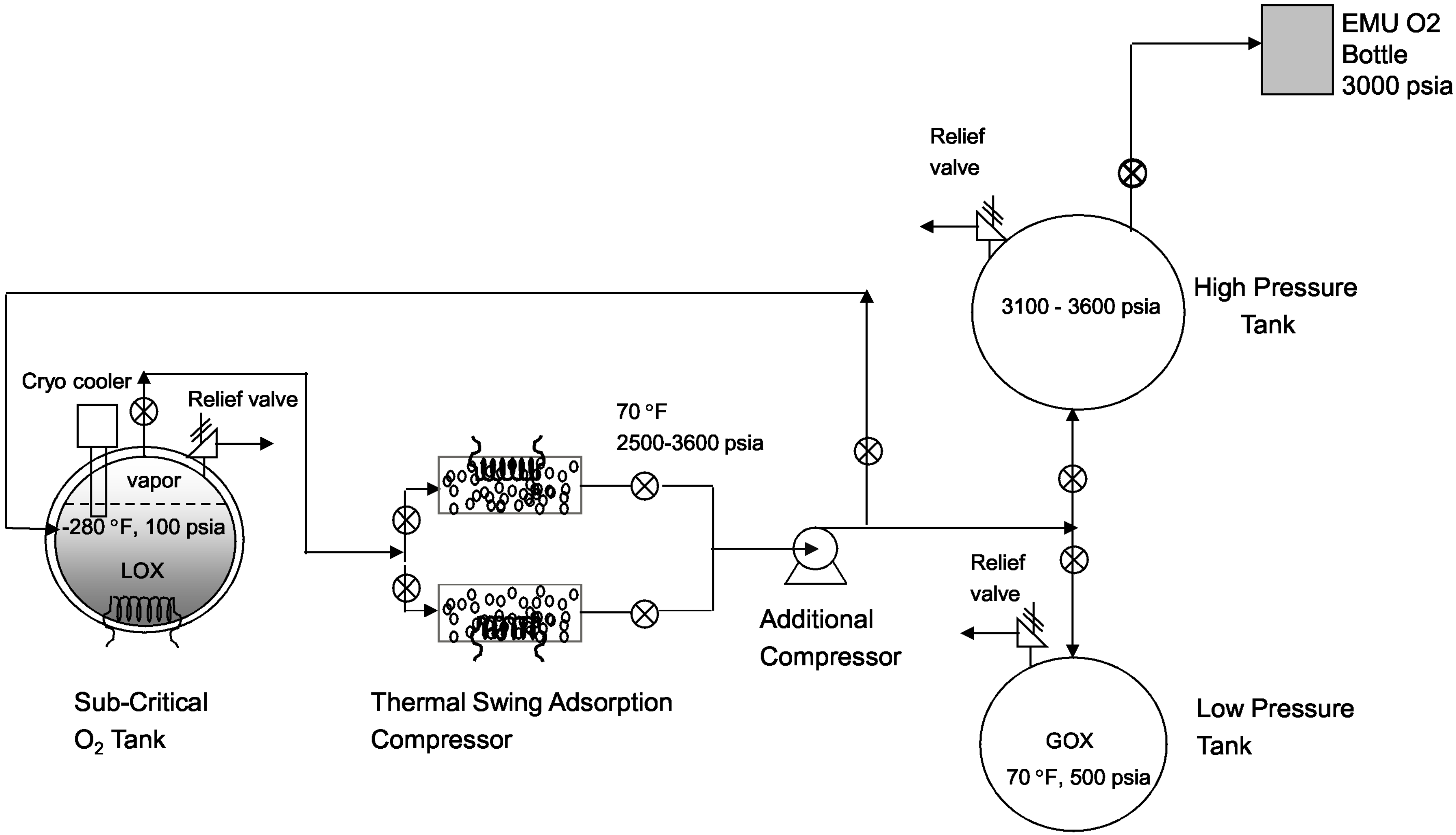


Deliver LOX to HP Tank and Vaporize to High Pressure
(Supply from Dedicated Tanks or Propellant Scavenging)



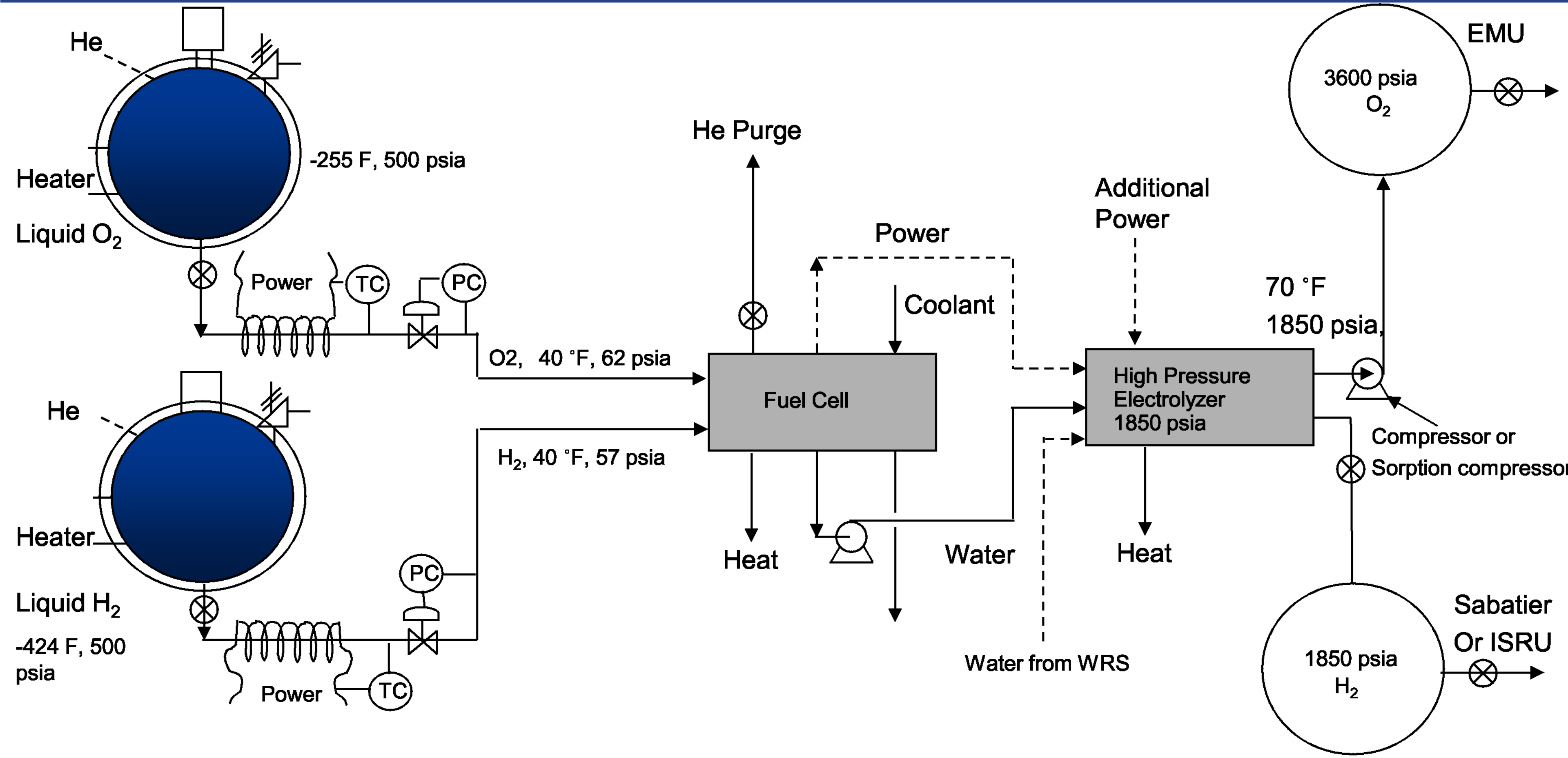
Thermal energy on lunar surface is used to generate high pressure GOX, heater is for back-up.

Cryo Tank, Thermal Swing Adsorption Compressor and Additional Compressor



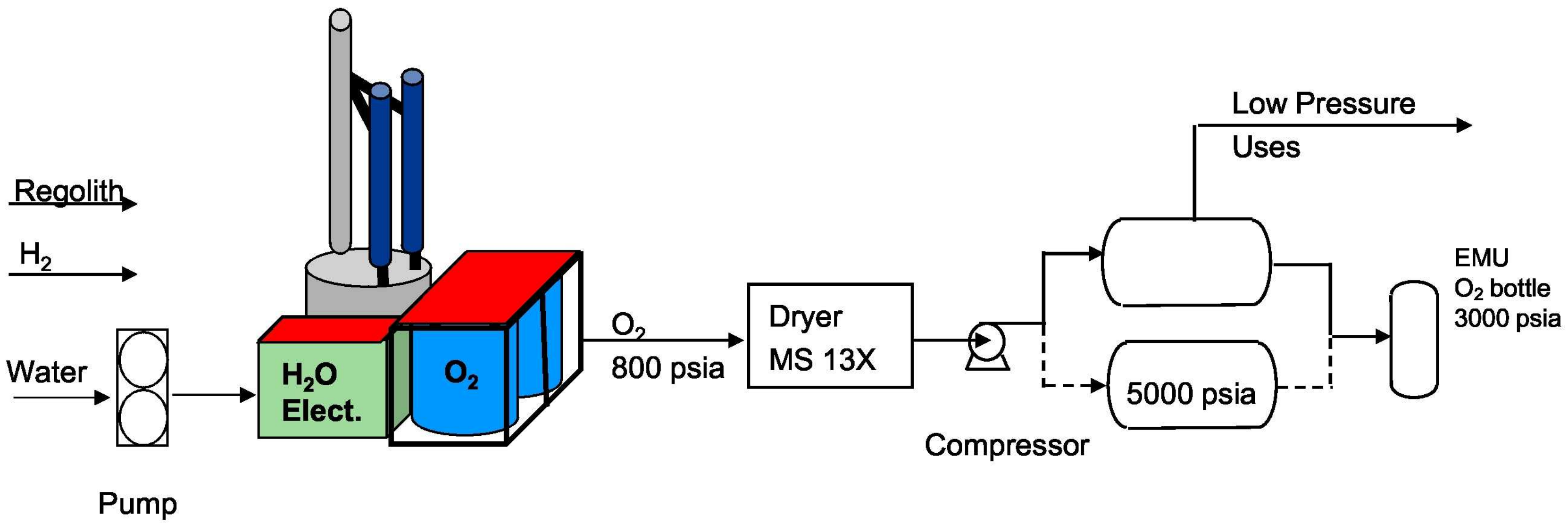
The TSAC is solid-state technology; its operation life should be longer than a mechanical compressor; but lower TRL

Generating High Pressure O_2 Using Fuel Cell and High Pressure Electrolyzer

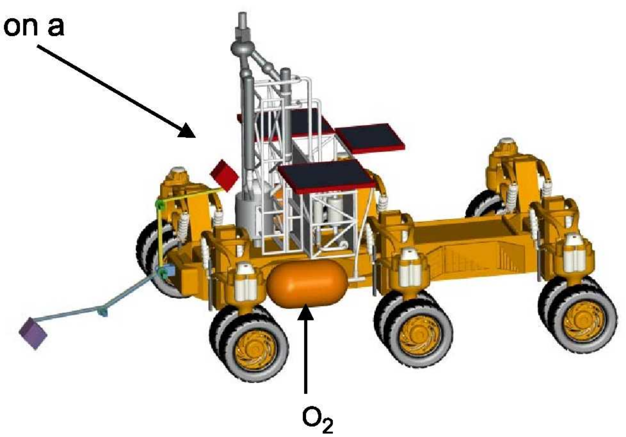


- ***Solid Polymer Electrolysis (SPE®) water electrolysis technology has been used in UK and US submarines for approximately 20 years***
  - ***Hamilton Sundstrand has accumulated 50,000+ hours in testing a <u>single cell water electrolysis unit operated at 1850 psia</u>***
- ***Lunar Surface Power System and ECLSS could share the high pressure water electrolyzer***
- ***Two options for generating O_2 at 3600 psia:***
  - ***Use an electrolyzer operating at 3600 psia***
  - ***Use a mechanical compressor to boost O_2 pressure from 1850 psia to 3600 psia (assumed here)***

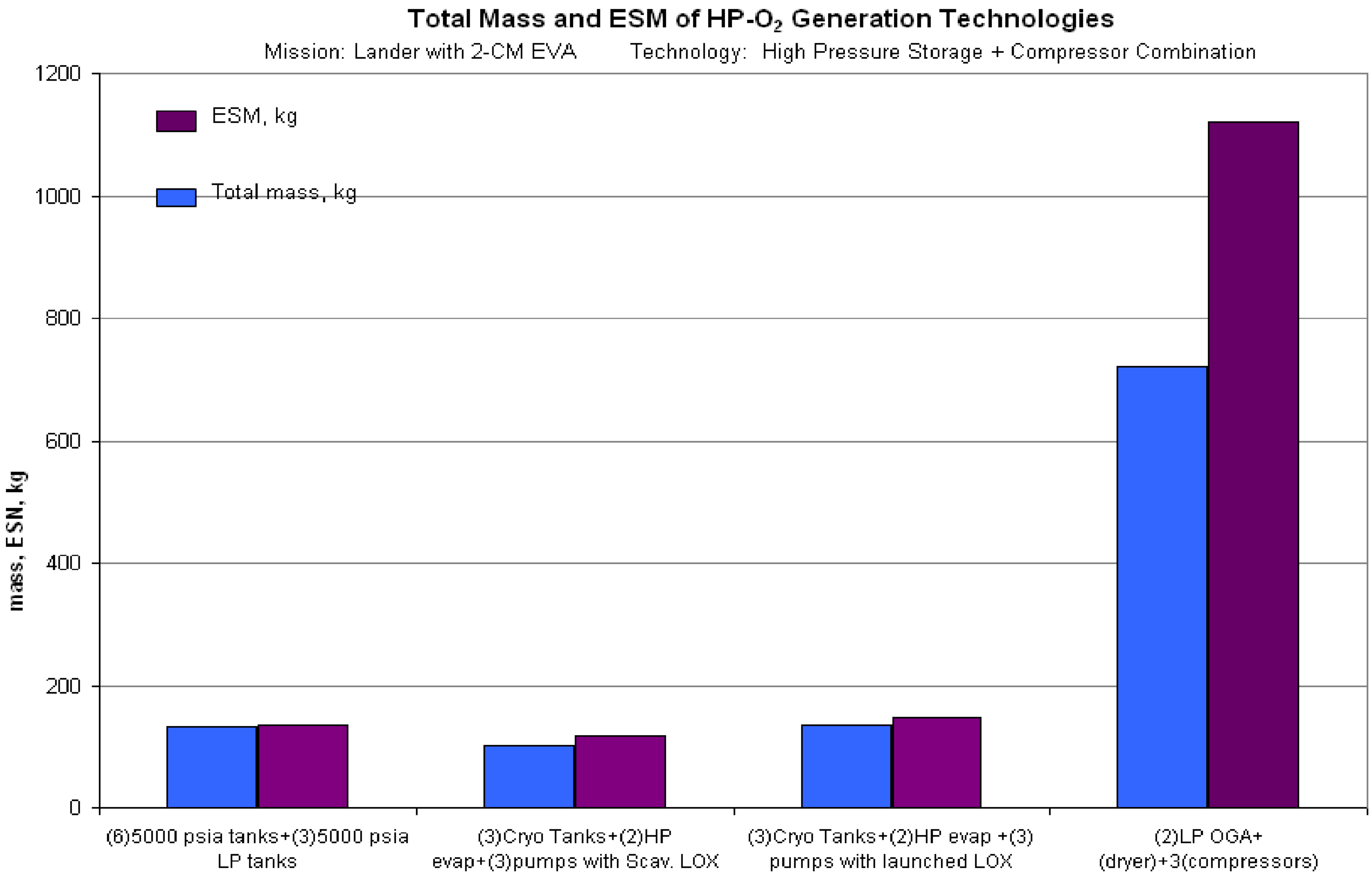
Import Moderate Pressure O2 from ISRU and Compress to Desired EVA O_2 Pressure



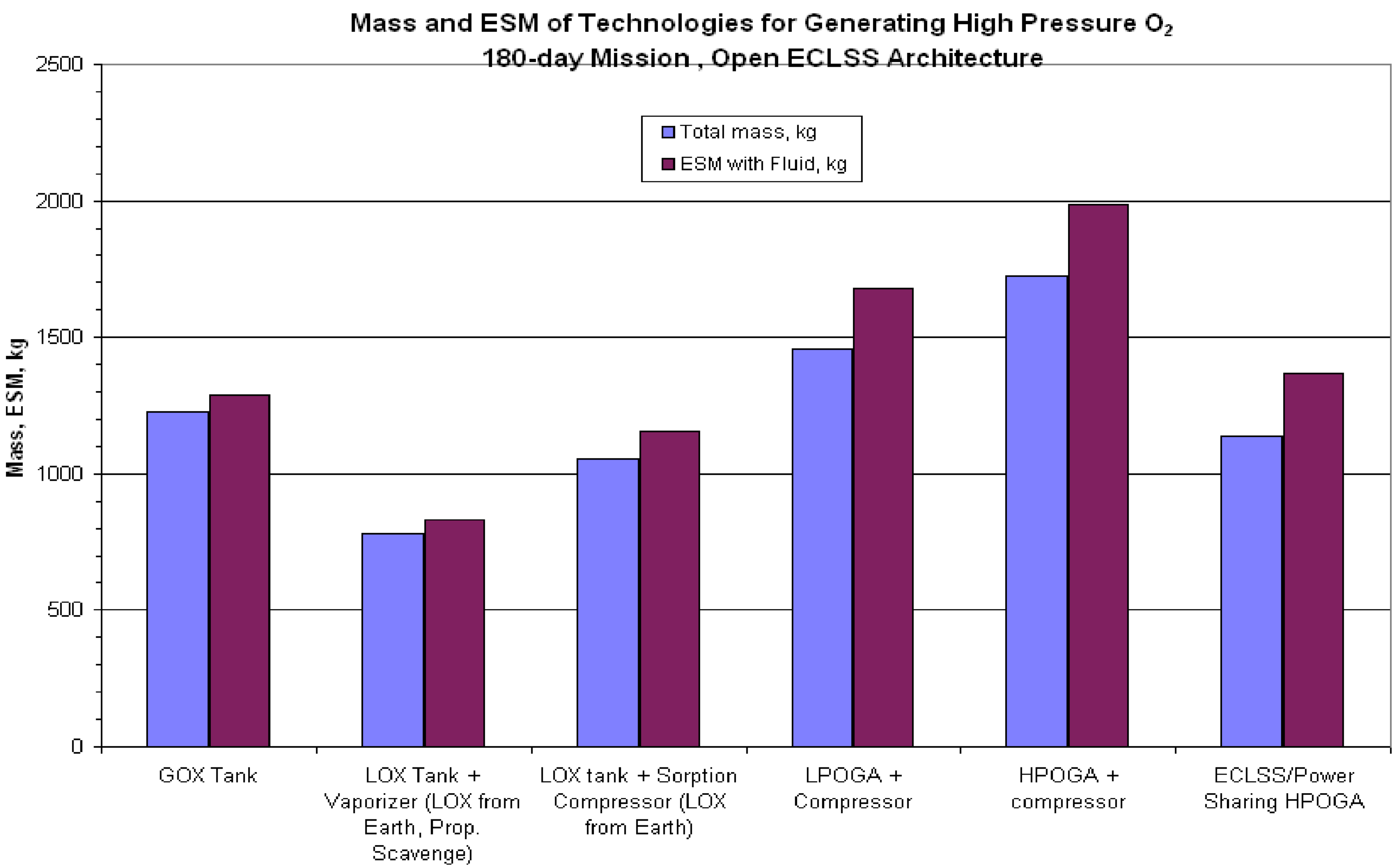
A Concept of Generating And Delivering O_2 on a Surface Vehicle



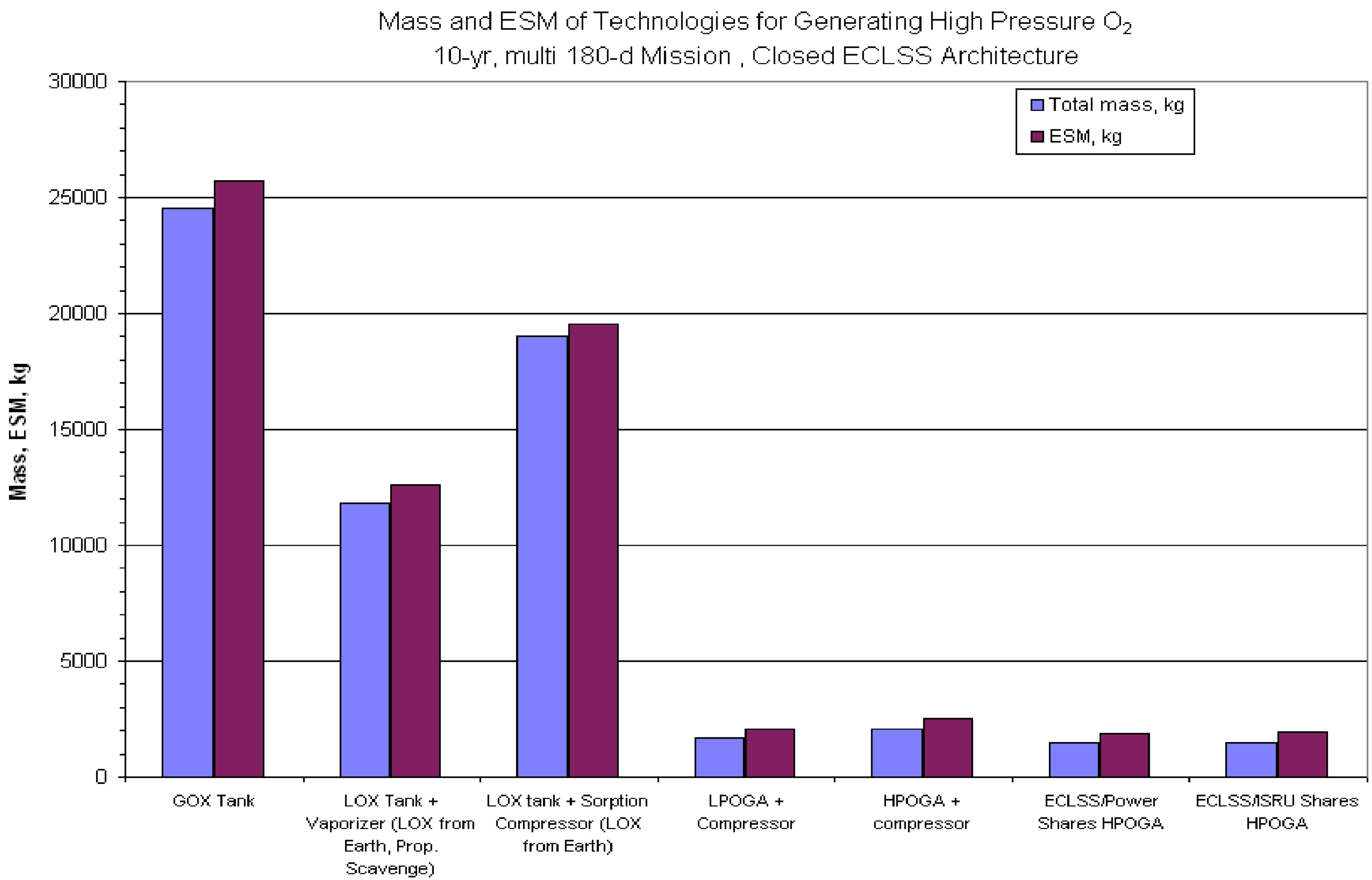
Mass and ESM of O_2 Generation Options (Open architecture) - Lunar Lander 7-day Sortie Mission



Mass and ESM of O_2 Generation Options (Open architecture) – 180-day Mission



Mass and ESM of O_2 Generation Options (Closed architecture) - 10-year Outpost Mission



Conclusions and Recommendations

For Sortie missions (open ECLSS architecture)

- Scavenging LOX & vaporizing it to meet high/low pressure O_2 needs has lowest ESM, followed closely by launching 5000 psia GOX tanks

For a180-day Outpost mission (open ECLSS architecture)

- Scavenging LOX & vaporizing it into high/low pressure GOX has lowest ESM, followed by LOX plus sorption compressor

For 10-yr multi 180-day missions (closed ECLSS architecture)

- Sharing high pressure oxygen generation assembly (HPOGA) between Power and ECLSS has the lowest total mass and ESM
- But the ISRU option & low pressure electrolysis with compressor are within 10% of HPOGA

Development of the following technologies recommended:

- Multi-stage O_2 piston compressor
- Vaporization and compression of a LOX/GOX mixture to 3600 psia
  - A thermal compression technology with few rotating components
- High pressure cryogenic O_2 pump
  - An essential component in the above LOX vaporizing technology
- HPOGA for generating O_2 up to 3600 psia and H_2 to a moderate pressure.
  - A technology shared among Power, ECLSS and ISRU Elements.

Further Study recommended on:

- Risks, including micrometeoroids and high pressure oxygen safety in the various options
- Optimization of exact O_2 tank pressure and geometry
- The propellant scavenging concept, including launching extra O_2 for delivery of LOX or H_2O
- Mission water balance
- Mission scenarios involving pressurized rovers

References

Jeng, Frank, et al., "High Pressure Oxygen Generation for Lunar Outpost EVA", SAE 2009-01-2534, SAE 39th International Conference on Environmental Systems, Savannah, GA, July 12-16, 2009

Jeng, Frank, "High-Pressure Oxygen Generation for Lander EVA Study", ESCG-4470-09-TEAN-DOC-0100, ESC Group, Houston, TX, July 30, 2009.

Jeng, Frank, "High-Pressure Oxygen Generation for Outpost EVA Study", ESCG-4470-08-TEAN-DOC-0358A, ESC Group, Houston, TX, November 24, 2008.

Jeng, Frank, "Status of Integrated Lunar Fluid Systems Analysis", ESCG-4470-09-TEAN-DOC-0039", ESC Group, Houston, TX, March 31, 2009.

Jones, Brad. "Altair (Lunar Lander) Project Overview." Presentation to AIAA Space 2008 Conference & Exposition. San Diego, CA. September 10, 2008.

Linne, D.L., et al., "Feasibility of Scavenging Propellants from Lander Decent Stage to Supply Fuel Cells and Life Support", AIAA-2009-6511, AIAA Space 2009, Pasadena CA, September 14-17, 2009.

Polsgrove, Tara, et al. "Altair Lunar Lander Consumables Management", AIAA-2009-6589, AIAA Space 2009, Pasadena, CA, September 14-17, 2009.

Backup Material

Mass, Volume, Power & ESM for O_2 Provision (Sortie Mission) – 7-d Sortie Mission

	Oxygen/ Water, kg	Mass[1], kg	Volume, m^3	Power, W	Cooling, W	ESM, kg
GOX Tanks (5000 psia)	34	132	0.106	0	0	136
Cryo Tanks + Evaporizers + Scavenged LOX	0	102	0.190	42	4	116
Cryo Tanks + Evaporizers + Launched LOX	32	134	0.190	42	4	149
LP OGA + Compressors	40	721	0.457	1,610	889	1,121

Notes:

1. Includes mass of oxygen/water and hardware.

Mass, Volume, Power & ESM for O_2 Provision (Open Architecture) – 180-d Mission

Technologies	Fluid, kg	Hardware Mass, kg	Volume, m^3	Power, W	Cooling, W	Total Mass, kg	ESM of Hardware and Fluid, kg
GOX Tank (5000 psia)	891[1]	337	2.314	0	0	1,228	1,288
LOX Tank + Vaporizer	520[2]	264	1.715	19	7	784	830
LOX Tank + Sorption Compressor	804[3]	373	1.844	444	432	1,052	1,155
LP OGA + Compressor	894[4]	560	1.285	1,703	982	1,454	1,682
HP OGA + Compressor	894[4]	832	1.596	1,999	1,006	1,726	1,985
ECLSS/Power Sharing HP OGA	894[4]	243	0.947	2,012	1,019	1,137	1,368

Notes:

1. Includes O_2 left over in the tank.
2. 520 kg LOX launched from Earth. No mass penalty for 273 kg scavenged from Lander propellant
3. All LOX from Earth.
4. Mass of water for electrolysis.

Mass, Volume, Power and Resupply Penalties of O_2 Generation Options (Closed Architecture) – 10-yr Outpost Mission

Technologies	Initial Mass[1], kg	Initial Volume, m^3	Power, W	Cooling, W	Resupply Mass, kg	Resupply Volume, M^3	Total Mass[1], kg	ESM, kg
GOX Tanks	1,227	2.314	0	0	23,319	43.966	24,546	25,740
LOX Tanks + Vaporizer	784	1.715	19	7	11,025	29.054	11,809	12,605
LOX Tank + Sorption Compressor	1,052	1.715	444	432	17,994	17.299	19,047	19,573
LP OGA + Compressor[2]	459	0.464	1,703	982	1,232	1.151	1,691	2,088
HP OGA + Compressor[2]	733	0.775	2,003	1,010	1,482	1.482	2,080	2,516
ECLSS/Power Sharing HP OGA[2]	137	0.126	2,012	1,019	1,347	1.482	1,484	1,905
ECLSS/ISRU Sharing HP OGA[2]	161	0.396	2,074	1,081	1,346	1.482	1,507	1,943

1. Total mass Includes fluid and hardware.
2. Includes 73 kg make-up water for each 180-day mission with a closed ECLSS architecture.

Generating 3600 psia O_2 from a LOX and GOX mixture in an Isochoric Process