Introduction to Space Life Support

- Lecture #16 - October 17, 2019
- Life support systems overview
- Major component systems
- Open-loop life support
- Physico-chemical life support
- Bioregenerative life support
- Case study: UMd Minimum Functional Lunar Habitat Element
Notes about the Mid-Term Exam

• Tuesday, Oct. 29
• On Systems Engineering materials from the course (lectures 1-10)
• All solution sets will be posted well before the exam and graded homework returned
• Sample mid-term exam (with solutions) has been posted for study purposes
• 1 8.5”x11” “cheat sheet”, both sides
• Bring a calculator - no cell phones or other internet- or wifi-enabled devices!
Second Team Design Problem

• X-Hab team will start on their minimum cabin design activities immediately
• The faculty will select the most competitive 8-10 of the 20 BIG Ideas topics developed during Team Project 1
• After projects selected, students will self-select final project teams
• Limit of ten people per team - team membership will be on a first come, first joined basis
• Teams must produce a full proposal and video for submission to NASA by the end of the term
Life Support Block Diagram

- Atmosphere Management
- Food Preparation
- Humans
- Water Management
- Waste Management
- Hygiene Facilities

Boxes: O2, CO2, Water, Nutrients, Waste, Stores

Arrows indicate flow of resources and systems interactions.
Life Support Block Diagram

- Plants & Animals
- Atmosphere Management
- Food Preparation
- Humans
- Water Management
- Hygiene Facilities
- Waste Management

Inputs: O2, CO2, Water, Nutrients, Waste, Stores
Essentials of Life Support

- Air
  - Constituent control
    - CO$_2$ scrubbing
    - Humidity control
    - Particulate scrubbing
    - O$_2$, N$_2$ makeup
  - Temperature control
- Water
- Food
- Waste Management
## Human Metabolic Inputs and Outputs

<table>
<thead>
<tr>
<th>Inputs</th>
<th>kg</th>
<th>Output</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>0.84</td>
<td>Carbon dioxide</td>
<td>1.00</td>
</tr>
<tr>
<td>Food solids</td>
<td>0.62</td>
<td>Respiration &amp; perspiration water</td>
<td>2.28</td>
</tr>
<tr>
<td>Water in food</td>
<td>1.15</td>
<td>Urine water</td>
<td>1.50</td>
</tr>
<tr>
<td>Food preparation water</td>
<td>0.76</td>
<td>Feces water</td>
<td>0.09</td>
</tr>
<tr>
<td>Drinking water</td>
<td>1.62</td>
<td>Sweat solids</td>
<td>0.02</td>
</tr>
<tr>
<td>(water subtotal)</td>
<td>3.53</td>
<td>(water subtotal)</td>
<td>3.87</td>
</tr>
<tr>
<td>Total mass</td>
<td>4.99</td>
<td></td>
<td>4.98</td>
</tr>
</tbody>
</table>

# Oxygen Requirements

<table>
<thead>
<tr>
<th>Category</th>
<th>Metabolic Load [kJ/(person•day)]</th>
<th>Oxygen Requirements: [kg/(person•day)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Activity Metabolic Load *</td>
<td>10,965</td>
<td>0.78</td>
</tr>
<tr>
<td>Nominal Activity Metabolic Load **</td>
<td>11,820</td>
<td>0.84</td>
</tr>
<tr>
<td>High Activity Metabolic Load *</td>
<td>13,498</td>
<td>0.96</td>
</tr>
<tr>
<td>5&lt;sup&gt;th&lt;/sup&gt; Percentile Nominal Female</td>
<td>7,590</td>
<td>0.52</td>
</tr>
<tr>
<td>95&lt;sup&gt;th&lt;/sup&gt; Percentile Nominal Male</td>
<td>15,570</td>
<td>1.11</td>
</tr>
</tbody>
</table>

- **Notes:**
  - * From Space Station Freedom Program via C. H. Lin (NASA/JSC), personal communication.
  - ** From the Baseline Values and Assumptions Document, JSC-47804.
  - The assumed conversion factor from liters of O<sub>2</sub> to calories is 4.8 cal/L here. A pressure of 101.325 kPa and a temperature of 0 °C are the standard conditions.

Water Requirements

- Potable water - 2 L/crew-day (2 kg/crew-day)
- Hygiene water
  - Nominal - 2.84-5.16 L/crew-day
  - Contingency - 2.84 L/crew-day
Metabolic Energy Requirements

- **Men** (W=mass in kg)
  - 18-30: $26W+1154$ kcal/day
  - 30-60: $19.7W+1494$ kcal/day

- **Women** (W=mass in kg)
  - 18-30: $23.5W+794$ kcal/day
  - 30-60: $13.9W+1326$ kcal/day

- Add 500 kcal/day for
  - EVA days
  - Moderate exercise days
  - End-of-mission countermeasure days
ECLSS Mass Balance

**Needs**
- Oxygen = 0.84 kg (1.84 lb)
- Food solids = 0.62 kg (1.36 lb)
- Water in Food = 1.15 kg (2.54 lb)
- Food Prep Water = 0.76 kg (1.67 lb)
- Drink = 1.62 kg (3.56 lb)
- Metabolized Water = 0.35 kg (0.76 lb)
- Hand/Face Wash Water = 4.09 kg (9.00 lb)
- Shower Water = 2.73 kg (6.00 lb)
- Urinal Flush = 0.49 kg (1.09 lb)
- Clothes Wash Water = 12.50 kg (27.50 lb)
- Dish Wash Water = 5.45 kg (12.00 lb)

**Total** = 30.60 kg (67.32 lb)

**Effluents**
- Carbon Dioxide = 1.00 kg (2.20 lb)
- Respiration & Perspiration Water = 2.28 kg (5.02 lb)
- Food Preparation, Latent Water = 0.036 kg (0.08 lb)
- Urine = 1.50 kg (3.31 lb)
- Urine Flush Water = 0.50 kg (1.09 lb)
- Feces Water = 0.091 kg (0.20 lb)
- Sweat Solids = 0.018 kg (0.04 lb)
- Urine Solids = 0.059 kg (0.13 lb)
- Feces Solids = 0.032 kg (0.07 lb)
- Hygiene Water = 12.58 kg (27.68 lb)
- Clothes Wash Water
  - Liquid = 11.90 kg (26.17 lb)
  - Latent = 0.60 kg (1.33 lb)

**Total** = 30.60 kg (67.32 lb)

**Note:** These values are based on an average metabolic rate of 136.7 W/person (11,200 Btu/person/day) and a respiration quotient of 0.87. The values will be higher when activity levels are greater and for larger than average people. The respiration quotient is the molar ratio of CO2 generated to O2 consumed.
## ISS Consumables Budget

<table>
<thead>
<tr>
<th>Consumable</th>
<th>Design Load (kg/person-day)</th>
</tr>
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<tbody>
<tr>
<td>Oxygen</td>
<td>0.85</td>
</tr>
<tr>
<td>Water (drinking)</td>
<td>1.6</td>
</tr>
<tr>
<td>Water (in food)</td>
<td>1.15</td>
</tr>
<tr>
<td>Water (clothes and dishes)</td>
<td>17.9</td>
</tr>
<tr>
<td>Water (sanitary)</td>
<td>7.3</td>
</tr>
<tr>
<td>Water (food prep)</td>
<td>0.75</td>
</tr>
<tr>
<td>Food solids</td>
<td>0.62</td>
</tr>
</tbody>
</table>
Resupply with Open Loop Life Support

Open-Loop Life Support System
Resupply Mass - 12,000 kg/person-year
(26,500 lbs/person-year)

- Water 89%
- Oxygen 2.5%
- Food (dry) 2.2%
  (Hydrated = 7%)
- Crew Supplies 2.1%
- Gases lost to space 2.1%
- Systems Maintenance 2.1%

Effect of Regenerative Life Support

- Open loop life support 100% resupply
- Waste water recycling 45%
- CO₂ absorbent recycling 30%
- O₂ regenerate from CO₂ 20%
- Food from wastes 10%
- Eliminate leakage 5%
Air Revitalization Processes

From Peter Eckart, Spaceflight Life Support and Biospheric, Kluwer Academic, 1996
Cabin Atmospheric Pressure

- Past choices driven by minimum mass
  - Mercury/Gemini: 100% O\textsubscript{2} @ 5 psi
  - Apollo: 100% O\textsubscript{2} @ 5 psi
  - Skylab: 80% O\textsubscript{2}/20% N\textsubscript{2} @ 5 psi
  - Shuttle/ISS: 21% O\textsubscript{2}/79% N\textsubscript{2} @ 14.7 psi

- Issues of compatibility for docking vehicles, denitrogenation for EVA

- Current practice driven by avionics, concern for research protocols
Oxygen Makeup Systems

- **Gaseous O\textsubscript{2}** storage (also N\textsubscript{2})
  - Typical pressures 200 atm (mass optimized) to 500-700 atm (volume optimized)
  - 2 kg tank/kg O\textsubscript{2}

- **Liquid O\textsubscript{2}** storage (also N\textsubscript{2})
  - Requires 210 kJ/kg for vaporization (~2W/person)
  - Supercritical storage $T=-118.8^\circ\text{C}$, $P=49.7$ atm
  - 0.3-0.7 kg tank/kg O\textsubscript{2}

- **Solid perchlorates** (“candles”)
  - $\text{LiClO}_4 \rightarrow \text{LiCl} + 2\text{O}_2 + Q @ 700^\circ\text{C}$
  - 2.75 kg LiClO\textsubscript{4}/kg O\textsubscript{2} (Typically 12.5 kg with packaging)
Superoxides and Ozonides

- **O2 generation**
  - \( \text{KO}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{KOH} + 3\text{O}_2 \)
  - \( \text{KO}_3 + 2\text{H}_2\text{O} \rightarrow 4\text{KOH} + 5\text{O}_2 \)

- **CO2 reduction**
  - \( 4\text{KOH} + 2\text{CO}_2 \rightarrow 2\text{K}_2\text{CO}_3 + 2\text{H}_2\text{O} \)
  - \( 2\text{K}_2\text{CO}_3 + 2\text{H}_2\text{O} + 2\text{CO}_2 \rightarrow 4\text{KHCO}_3 \)

- **KO2 removes 0.31 kg CO2/kg and generates 0.38 kg O2/kg**
## Nonregenerable O₂ Production

<table>
<thead>
<tr>
<th>Material</th>
<th>kg(material)/kg(O₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O₂</td>
<td>2.1</td>
</tr>
<tr>
<td>LiO₂</td>
<td>1.62</td>
</tr>
<tr>
<td>K₂O₂</td>
<td>2.96</td>
</tr>
<tr>
<td>MgO₄</td>
<td>1.84</td>
</tr>
<tr>
<td>CaO₄</td>
<td>2.08</td>
</tr>
<tr>
<td>LiClO₄</td>
<td>2.8</td>
</tr>
<tr>
<td>KClO₄</td>
<td>2.16</td>
</tr>
<tr>
<td>Mg(ClO₄)₂</td>
<td>1.74</td>
</tr>
</tbody>
</table>

- Allocate an additional 10 kg/kg O₂ for packaging, in addition to combustion receptacle (mass TBD)
Electrolytic Oxygen Generation

- Static Feed Water Electrolysis
- Solid Polymer Water Electrolysis
- Water Vapor Electrolysis
- CO2 Electrolysis
CO₂ Scrubbing Systems

- CO₂ production ~1 kg/person-day
- Lithium hydroxide (LiOH) absorption
  - Change out canisters as they reach saturation
  - 2.1 kg/kg CO₂ absorbed
  - Also works with Ca(OH)₂, Li₂O, KO₂, KO₃
- Molecular sieves (e.g., zeolites)
  - Porous on the molecular level
  - Voids sized to pass O₂, N₂; trap CO₂, H₂O
  - Heat to 350°-400°C to regenerate
  - 30 kg/kg-day of CO₂ removal; 200W
Nonregenerable CO2 Absorbers

<table>
<thead>
<tr>
<th>Material</th>
<th>kg(material)/kg(CO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiOH</td>
<td>1.09</td>
</tr>
<tr>
<td>Ca(OH)2</td>
<td>2.05</td>
</tr>
</tbody>
</table>

- Allocate an additional 1.0 kg/kg(CO2) for packaging
- Only works down to PPCO2 levels of ~0.5 kPa
CO₂ Regenerable Scrubbing Systems

- CO₂ production ~1 kg/person-day
- 4-Bed Molecular Sieves (4BMS)
  - Dual paths (one scrubbing, one regenerating)
  - Desiccant bed for moisture removal, 5 Å zeolite sieve for CO₂
  - Heat to 350°-400°C to regenerate
  - 30 kg; 0.11 m³; 170 W (all per kg-day of CO₂ removal)
- 2-Bed Molecular Sieves (2BMS)
  - Carbon molecular sieve for CO₂
  - 16 kg; 0.09 m³; 77 W (per kg/day CO₂)
CO2 Collection System Trade

![Graph showing CO2 Collection System Trade](image)

- **X-axis**: Duration (days)
- **Y-axis**: System Mass (kg)
- **Lines**:
  - Blue: CO2/LiOH
  - Red: CO2/2BMS

The graph illustrates the trade-off between system mass and duration for two CO2 collection systems: CO2/LiOH and CO2/2BMS.
CO₂ Regenerable Scrubbing Systems

• Solid Amine Water Desorption (SAWD)
  – Amine resin absorbs H₂O and CO₂; steam heat regenerates
    • Amine + H₂O --> Amine-H₂O (hydrated amine)
    • Amine-H₂O + CO₂ --> Amine-H₂CO₃ (bicarbonate)
    • Amine-H₂CO₃ + steam --> Amine + H₂O + CO₂
  – 17 kg; 0.07 m³; 150 W (all per kg-day of CO₂ removal)
CO₂ Regenerable Scrubbing Systems

- **Electrochemical Depolarization Concentration (EDC)**
  - Uses fuel-cell type reaction to concentrate CO₂ at the anode
  - \( \text{CO}_2 + \frac{1}{2}\text{O}_2 + \text{H}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{electricity} + \text{heat} \)
  - CO₂ and H₂ are collected at anode and directed to CO₂ recycling system (combustible mixture!)
  - 11 kg; 0.02 m³; 60 W (all per kg-day of CO₂ removal); does not include reactants for power output
CO2 Membrane Removal Systems

- Osmotic membranes
  - Poor gas selectivity
  - Returns CO2 to cabin air
- Electroactive carriers
  - Electroactive molecules act as CO2 “pump”
  - Very early in development
- Metal Oxides
  - AgO2 absorbs CO2 (0.12 kg O2/kg AgO2)
  - Regenerate at 140°C for 8 hrs (1 kW) - 50-60 cycles
  - Replacing LiOH in EMUs for ISS
CO₂ Reduction

- **Sabatier reaction**
  - CO₂ + 4H₂ --> CH₄ + 2H₂O
  - Lowest temperature (250°-300°C) with Ni catalyst
  - Electrolyze H₂O to get H₂, find use for CH₄
  - 91 kg; 3 m³; 260 W (all per kg-day of CO₂ removal)

- **Bosch reaction**
  - CO₂ + 2H₂ --> C + 2H₂O
  - 1030°C with Fe catalyst
  - C residue hard to deal with (contaminates catalyst)
  - 700 kg; 3.9 m³; 1650 W (all per kg-day of CO₂ removal)
CO₂ Reduction

- Advance Carbon-formation Reactor System (ACRS)
  - CH₄ → C + 2H₂
  - Lowest temperature (250°-300°C) with Ni catalyst
  - Electrolyze H₂O to get H₂, find use for CH₄
  - 60 kg; 0.1 m³; 130 W (all per kg-day of CO₂ removal)
O2 Recovery System Trade

![Graph showing O2 Recovery System tradeoff between system mass and duration for O2/Open Loop and O2/Sabatier systems.](image)

- System Mass (kg) on the y-axis.
- Duration (days) on the x-axis.
- Two lines represent:
  - Blue line: O2/Open Loop
  - Red line: O2/Sabatier
Nitrogen Makeup

- Nitrogen lost to airlock purges, leakage (can be >1%/day)
- Need to replenish N\textsubscript{2} to maintain total atmospheric pressure
- Choices:
  - High pressure (4500 psi) N\textsubscript{2} gas bottles
  - Cryogenic liquid nitrogen
  - Storable nitrogen-bearing compounds (NH\textsubscript{3}, N\textsubscript{2}O, N\textsubscript{2}H\textsubscript{4})
Trace Contaminant Control

- Particulate Filters (dusts and aerosols)
- Activated Charcoal (high molecular weight contaminants)
- Chemisorbant Beds (nitrogen and sulphur compounds, halogens and metal hybrids)
- Catalytic Burners (oxidize contaminants that can’t be absorbed)
- 100 kg; 0.3 m³; 150 W (all per person-day)
Types of Water

- Potable water
  - Drinking and food preparation
  - Organic solids < 500 \( \mu \text{g/liter} \)

- Hygiene water
  - Washing
  - Organic solids < 10,000 \( \mu \text{g/liter} \)

- Grey water (used hygiene water)

- Condensate water (from air system)

- Urine
Water Management

• Distillation Processes
  – Vapor Compression Distillation (VCD)
  – Thermoelectric Integrated Membrane Evaporation (TIMES)
  – Vapor Phase Catalytic Ammonia Removal (VAPCAR)
  – Air Evaporation

• Filtration Processes
  – Reverse Osmosis (RO)
  – Multifiltration (MF)
  – Electrodialysis
Water Distillation

- **Vapor Compression Distillation (VCD)**
  - 300 kg; 1.5 m³; 350 W (for 100 kg H2O processed per day)

- **VAPCAR**
  - 550 kg; 2.0 m³; 800 W (for 100 kg H2O processed per day)

- **TIMES**
  - 350 kg; 1.2 m³; 850 W (for 100 kg H2O processed per day)
Water Revitalization Processes

From Peter Eckart, Spaceflight Life Support and Biospherics, Kluwer Academic, 1996
Solid Waste Disposal Technologies

- Freeze Drying
- Thermal Drying
- Combustion Oxidation
- Wet Oxidation
- Supercritical Water Oxidation
Waste Management Processes

From Peter Eckart, Spaceflight Life Support and Biospherics, Kluwer Academic, 1996
Bioregenerative Life Support Schematic

From Peter Eckart, Spaceflight Life Support and Biospherics, Kluwer Academic, 1996
Life Support Systems Analysis

From Peter Eckart, Spaceflight Life Support and Biospherics, Kluwer Academic, 1996
## Impact of Closure on Duration

<table>
<thead>
<tr>
<th>% closure</th>
<th>Life support</th>
<th>Person days/1,000 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Open, all supplies from Earth</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Closed air, open water</td>
<td>32</td>
</tr>
<tr>
<td>42</td>
<td>Open air, 50% water recycle</td>
<td>55</td>
</tr>
<tr>
<td>62</td>
<td>Open air, 70% water recycle</td>
<td>80</td>
</tr>
<tr>
<td>87</td>
<td>Closed air, closed water</td>
<td>249</td>
</tr>
<tr>
<td>90</td>
<td>Dehydrated food</td>
<td>295</td>
</tr>
<tr>
<td>91</td>
<td>Minimum expendables</td>
<td>325</td>
</tr>
<tr>
<td>92</td>
<td>Increased recycling</td>
<td>385</td>
</tr>
<tr>
<td>93</td>
<td>Full human waste recycling</td>
<td>445</td>
</tr>
<tr>
<td>94</td>
<td>50% food grown</td>
<td>525</td>
</tr>
<tr>
<td>95</td>
<td>75% food grown</td>
<td>575</td>
</tr>
</tbody>
</table>

Impact of Closure on Duration

Impact of % closure on person-days per 1,000 kg supplies

UMd Final MFH Design

- 3.65 m diameter
- 5.5 m tall
- 4:1 ellipsoidal endcaps
- Three module berthing ports (Cx standard)
- Four suitports (two in berthing hatches)
- Inflatable airlock
- All 6063-T6 structure
MFHE Life Support Requirements

- 4 crew for nominal mission of 28 days
- Additional contingency mission of 30 days
- 8 crew in handoff mode for 48 hours
  - 4 95th percentile American males for 60 days
Lunar Habitat Water Recycling Trades

![Graph showing system mass (kg) vs. duration (days) for different water recycling methods: H2O/Open Loop, H2O/Condensate, and H2O/Cond+Urine. The graph illustrates how system mass increases over time for each method, with H2O/Open Loop having the highest mass requirement, followed by H2O/Condensate, and then H2O/Cond+Urine.]
Effect of Duration on Life Support

![Graph showing the effect of duration on life support system mass. The graph plots system mass (kg) against duration (days) for different durations: 7 Day Optimum, 28 Day Optimum, and 180 Day Optimum. The mass increases linearly with duration.]
MFHE Operational Assumptions

- Daily two-person EVAs during nominal operations
- One two-person airlock cycle per week and two two-person cycles in support of crew rotation for 12 suit transits/six airlock pressurize/depress cycles (all other EVAs performed using suitports)
- No appreciable atmosphere loss with a suitport cycle
- No EVAs during the contingency support period
- One four-person EVA at the end of the mission for the crew to return to the ascent vehicle
- 64 EVA suit operations during a nominal mission, based on the preceding assumptions
- Power supplied by a Constellation program Mobile Power Unit (MPU) and not charged against habitat mass
- Systems to be considered should have the maximum TRL of the possible candidates (proven systems should be used for simplicity and mission assurance)
EVA Support Requirements

- 64 suit operations in a nominal mission (no EVA during contingency phase)

- Suit CO₂ scrubbing options
  - LiOH canister (6.4 kg, expendable)
  - METOC canister (14.5 kg, reusable)

- METOX regeneration oven
  - Regenerates two canisters over 14 hours
  - 48 kg and 1000 W

- Each EVA uses 0.72 kg of O₂ and 2.1 kg of H₂O
  --> total 46.1 kg O₂ and 135 kg H₂O
Airlock Operating Requirements

- 6.5 m³ with 90% scavenging on depress
- Cabin atmosphere 8 psi (30% O₂)
- Atmospheric density 0.667 kg/m³
- 0.43 kg of atmosphere mix lost per airlock cycle
- 6 cycles/mission --> 6.93 kg (2.1 kg O₂, 4.9 kg N₂)
CO₂ Scrubbing Options

- LiOH canisters
- METOX canisters and regeneration
- Four bed molecular sieve (4BMS - preferred over 2BMS due to higher TRL and better recovery of atmospheric moisture)
CO₂ Scrubbing Analysis

- LiOH canisters
- METOX canisters and regeneration
- Four bed molecular sieve (4BMS - preferred over 2BMS due to higher TRL and better recovery of atmospheric moisture)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Mission Mass (kg)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiOH</td>
<td>420</td>
<td>—</td>
</tr>
<tr>
<td>METOX</td>
<td>106</td>
<td>1000</td>
</tr>
<tr>
<td>4BMS</td>
<td>120</td>
<td>680</td>
</tr>
</tbody>
</table>
Support of EVA CO₂ Systems

- Requires two METOX canisters and second oven (8 hour EVA with pre- and post-EVA prep, 14 hour regeneration cycle with cool-down)
- To stay below 50-55 cycle limits and relieve operational constraints, baseline 4 METOX canisters
- System with EVA support will double mass and power from habitat alone (212 kg, 2000 W)
- Alternative would require 410 kg of LiOH canisters
Support of Rover CO\textsubscript{2} System

- Multi-day pressurized rover (e.g., LEV/SEV)
- Designed to use same life support system as EVA portable life support system (PLSS)
- Required 3 METOX canisters/day (two EVAs and cabin at reduced activity levels)
- No capability for regeneration during sortie - 18 canisters returned to habitat following 6-day sortie
- Regeneration of canisters will require third oven and 5.25 days
- Total METOX canister mass (2x18) is 522 kg
Alternative Rover CO₂ Options

• LiOH canisters will mass 115 kg/sortie
• Four 6-day sorties over 28 day nominal mission --> 461 kg for LiOH canisters
• Compare to total METOX mass of 570 kg for two 18-canister sets and dedicated regeneration oven

• Optimal approach is to use METOX for habitat and local EVA, LiOH for rovers and remote EVA
References - Textbooks

• Peter Eckart, Spaceflight Life Support and Biospherics, Kluwer Academic, 1996
• A. E. Nicogossian, et. al., eds., Space Biology and Medicine - Volume II: Life Support and Habitability, American Institute of Aeronautics and Astronautics, 1994
References - NASA Design Documents

