Water Reclamation

- Fundamentals of water reclamation
- Water reclamation
  - Potable
  - Hygiene
  - Urine
- Solids disposal
### ISS Consumables Budget

<table>
<thead>
<tr>
<th>Consumable</th>
<th>Design Load (kg/person-day)</th>
</tr>
</thead>
<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
Effect of Regenerative Life Support

• Open loop life support          100% resupply
Effect of Regenerative Life Support

• Open loop life support 100% resupply
+ Waste water recycling 45%
Effect of Regenerative Life Support

- Open loop life support 100% resupply
+ Waste water recycling 45%
+ CO₂ absorbent recycling 30%
Effect of Regenerative Life Support

- Open loop life support 100% resupply
  + Waste water recycling 45%
  + CO$_2$ absorbent recycling 30%
  + O$_2$ regenerate from CO$_2$ 20%
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%
Effect of Regenerative Life Support

- Open loop life support 100% resupply
  + Waste water recycling 45%
  + CO$_2$ absorbent recycling 30%
  + O$_2$ regenerate from CO$_2$ 20%
  + Food from wastes 10%
  + Eliminate leakage 5%
Types of Water

- Potable water
  - Drinking and food preparation
  - Organic solids < 500µg/liter
- Hygiene water
  - Washing
  - Organic solids <10,000 µg/liter
- Grey water (used hygiene water)
- Condensate water (from air system)
- Urine
Potable Water Reclamation Technologies

- Multifiltration
- Reverse Osmosis
- Electrochemical Deionization
Potable Water Multifiltration Schematic
Potable Water Reverse Osmosis Schematic
Close-up of Reverse Osmosis Concept
Electrochemical Deionization Schematic
Hygiene Water Reclamation Technologies

- Multifiltration
- Reverse Osmosis
Hygiene Water Reverse Osmosis Schematic
Multifiltration for Hygiene Water
Urine Reclamation Technologies

- TIMES - Thermoelectric Integrated Membrane Evaporation System
- VCD - Vacuum Compression Distillation
- VPCAR - Vapor Phase Catalytic Ammonia Removal
- AIRE - Air Evaporation
TIMES Schematic

Thermoelectric Integrated Membrane Evaporation System

- Recycled Brine
- Hollow Fiber Membrane Evaporator
- Heat Exchanger
- Condenser
- Air Cooler
- Gas/Liquid Separator
- Product Water
Vacuum Compression Distillation Schematic
VCD Drum Distillation Schematic
Vapor Phase Catalytic Ammonia Removal

Diagram of VPCAR Schematic
VAPCAR Simplified Schematic

Diagram showing the process of water reclamation:

- Wastewater
- Heat Exchanger
- Wastewater Heat Exchanger
- Thermoelectric Elements
- Condenser
- Latent Heat
- Hollow Fiber Membranes
- Water Vapor
- Membrane Evaporator
- Waste water

Diagram details the flow of waste water through various components to produce purified water.
AES - Air Evaporation for Urine Treatment
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)
### Selected Design Parameters

Table B.1. ISS P/C ECLSS technologies.

<table>
<thead>
<tr>
<th>Function</th>
<th>technology</th>
<th>mass</th>
<th>volume</th>
<th>power</th>
<th>cooling</th>
<th>EM</th>
<th>logistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>units</td>
<td>kg/CM</td>
<td>m³/CM</td>
<td>kW/CM</td>
<td>kW/CM</td>
<td>kg/CM</td>
<td>kg/CM-y</td>
</tr>
<tr>
<td>O₂ generation</td>
<td>SPWE</td>
<td>28.3</td>
<td>0.04</td>
<td>0.37</td>
<td>0.37</td>
<td>173</td>
<td>3.2</td>
</tr>
<tr>
<td>CO₂ removal</td>
<td>4BMS</td>
<td>50.3</td>
<td>0.10</td>
<td>0.22</td>
<td>0.22</td>
<td>151</td>
<td>0.0</td>
</tr>
<tr>
<td>CO₂ reduction</td>
<td>Sabatier</td>
<td>4.5</td>
<td>0.19</td>
<td>0.01</td>
<td>0.07</td>
<td>58</td>
<td>0.0</td>
</tr>
<tr>
<td>Trace contaminant control</td>
<td>charcoal</td>
<td>19.6</td>
<td>0.07</td>
<td>0.04</td>
<td>0.04</td>
<td>51</td>
<td>40.8</td>
</tr>
<tr>
<td>Wastewater processing</td>
<td>multifiltration</td>
<td>119.0</td>
<td>0.56</td>
<td>0.08</td>
<td>0.08</td>
<td>268</td>
<td>119.5</td>
</tr>
<tr>
<td>Urine processing</td>
<td>VCD</td>
<td>32.0</td>
<td>0.09</td>
<td>0.02</td>
<td>0.02</td>
<td>60</td>
<td>43.8</td>
</tr>
<tr>
<td>N₂/O₂ storage</td>
<td>tank</td>
<td>272.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>272</td>
<td>136.0</td>
</tr>
<tr>
<td>Water storage</td>
<td>tank</td>
<td>26.5</td>
<td>0.13</td>
<td>0.00</td>
<td>0.00</td>
<td>54</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>totals mass equivalents</td>
<td>1</td>
<td>215.5</td>
<td>228</td>
<td>146</td>
<td>1,088</td>
<td>343.2</td>
</tr>
<tr>
<td></td>
<td>units mass equivalents</td>
<td>kg/kg</td>
<td>kg/m³</td>
<td>kg/kW</td>
<td>kg/kW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# Water System Design Parameters

<table>
<thead>
<tr>
<th>Function /technology</th>
<th>#crew</th>
<th>mass</th>
<th>volume</th>
<th>power</th>
<th>cooling</th>
<th>90-day resupply mass</th>
<th>TRL</th>
<th>EM (MTV, 400 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg</td>
<td>m³</td>
<td>kW</td>
<td>kW</td>
<td>kg</td>
<td>kg</td>
<td></td>
<td>kg</td>
</tr>
<tr>
<td>Condensate and hygiene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multifiltration</td>
<td>8</td>
<td>95</td>
<td>0.34</td>
<td>0.35</td>
<td>0.08</td>
<td>50.8</td>
<td>257</td>
<td></td>
</tr>
<tr>
<td>Reverse osmosis</td>
<td>8</td>
<td>88</td>
<td>0.50</td>
<td>0.26</td>
<td>0.09</td>
<td>34.5</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>Electrodeionization</td>
<td>8</td>
<td>59</td>
<td>0.31</td>
<td>0.36</td>
<td></td>
<td></td>
<td></td>
<td>121</td>
</tr>
<tr>
<td>Urine purification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VCD</td>
<td>8</td>
<td>150</td>
<td>0.38</td>
<td>0.18</td>
<td>0.26</td>
<td>421.8</td>
<td>1,090</td>
<td></td>
</tr>
<tr>
<td>TIMES</td>
<td>8</td>
<td>116</td>
<td>0.29</td>
<td>0.33</td>
<td>0.19</td>
<td>309.8</td>
<td>838</td>
<td></td>
</tr>
<tr>
<td>AES</td>
<td>3</td>
<td>91</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30.8  5.0  1,483</td>
</tr>
<tr>
<td>VPCAR</td>
<td>8</td>
<td>136</td>
<td>0.51</td>
<td>0.62</td>
<td>0.25</td>
<td>362.9</td>
<td>4.0</td>
<td>1,038</td>
</tr>
</tbody>
</table>

Solid Waste Disposal Technologies

- Freeze Drying
- Thermal Drying
- Combustion Oxidation
- Wet Oxidation
- Supercritical Water Oxidation
Freeze Drying Schematic

[Diagram showing the process of freeze drying with labeled parts: Vent Gases, Vacuum Pump, Refrigeration 1 (-26°F), Vacuum Evaporation, Refrgeration 2 (-50°F), Heater, Water, and Solids (60°F).]
Thermal Drying Schematic

Diagram showing the process:
- Feed (water & solids) enters the system.
- Enters the Regenerative Heater.
- HEATER processes the feed.
- VAPOR/SOLIDS separator removes solids.
- SOLIDS exit.
- VAPOR exits the separator.
- Enters the HEATER.
- Condenser condenses the vapor to condensate.
- COOLANT IN and OUT.
- POWER supplied.
- VENT GASES exit.
Combustion Oxidation Schematic
Wet Oxidation Schematic
Supercritical Water Oxidation Schematic
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
Lower Deck Layout

- CTB Stowage Racks
- Air Handling/CO₂ Scrubbing/Heat Exchanger
- Multipurpose Table
- Berthing Hatch
- Ladder to Upper Deck
- Water Recycling
Upper Deck Layout

Individual Crew Berths

Galley Wall - Food Preparation

Table and Seats
Opened for Meals; Stowed Otherwise

Bathroom

CTB Stowage Racks
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 over duration for different water recycling trades: H2O/Open Loop, H2O/Condensate, and H2O/Cond+Urine. The graph demonstrates the increase in system mass with duration for each trade.]
Effect of Duration on Life Support

![Graph showing the effect of duration on system mass for different durations: 7 Day Optimum, 28 Day Optimum, and 180 Day Optimum. The x-axis represents duration (days) ranging from 0 to 200, and the y-axis represents system mass (kg) ranging from 0 to 7000. The graph indicates an increase in system mass as the duration increases.]
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% \( \text{O}_2 \))
- 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 \( \text{O}_2 \), 4.9 kg \( \text{N}_2 \))
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

<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 (oven + 4 canisters)</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$_2$ 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 CO$_2$ 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


