Human Factor Investigation of Waste Processing System During the HI-SEAS 4 Month Mars Analog Mission in Support of NASA’s Logistic Reduction and Repurposing Project: Trash to Gas

Anne J. Caraccio
Chemical Engineer, NASA Kennedy Space Center
Email: Anne.Caraccio@nasa.gov
Co-Authors: Paul E. Hintze, Ph.D. & John D. Miles – NASA, KSC
Motivation

• Long duration deep space missions will require many closed loop, self-sufficient and highly sustainable technologies.
• Conditions will create a seemingly independent operation from support personnel located back on Earth, especially during day-to-day mission operations.
• Closed-loop life-support-systems with minimal or no re-supply from Earth have the greatest technical challenges to development.
• The Trash to Gas (TtG) is part of the Logistics Reduction and Repurposing (LRR) project. TtG technology has proven successful in laboratory studies, a number of assumptions were made to facilitate testing, leading to questions pertaining to the design of a flight unit.
• Analog tests, where the conditions of long duration, deep space missions are simulated, can be used to evaluate new technologies.
• TtG - Develop space technology alternatives for converting space waste into a gas that may be converted into high-value products or a gas that can be easily vented as a 'jettison function'.
The following tasks were performed during the mission:

1. Monitor and characterize wastes generated during the mission.
2. Monitor power and water usage in the habitat.
3. Evaluate crew time and interactions with waste collection, storage, and disposal.
4. Monitor the frequency at which waste needs to be disposed.
5. Operate a TtG system at KSC using the waste materials similar to what is generated during HI-SEAS.
HI-SEAS Waste Storage
Waste Generation Results
Waste Generation Profile

Week

Mass, kg
<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Mass Waste Total (kg)</th>
<th>Average Mass per Day (kg)</th>
<th>Mass Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>49.94</td>
<td>0.38</td>
<td>33</td>
</tr>
<tr>
<td>Plant</td>
<td>31.11</td>
<td>0.27</td>
<td>21</td>
</tr>
<tr>
<td>Paper/Cardboard</td>
<td>25.18</td>
<td>0.21</td>
<td>17</td>
</tr>
<tr>
<td>Polymers</td>
<td>18.39</td>
<td>0.16</td>
<td>12</td>
</tr>
<tr>
<td>Hygiene</td>
<td>10.52</td>
<td>0.06</td>
<td>7</td>
</tr>
<tr>
<td>Metallics</td>
<td>8.83</td>
<td>0.06</td>
<td>6</td>
</tr>
<tr>
<td>Haz Waste</td>
<td>4.71</td>
<td>0.03</td>
<td>3</td>
</tr>
<tr>
<td>Tissue</td>
<td>2.99</td>
<td>0.03</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>151.67</strong></td>
<td><strong>1.21</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
Volume Reduction via Footballs

• **154 TOTAL FOOTBALLS**  
  – (not everything could be made into a football)

• Uncompressed Volume: 2.65m³

• Compressed Volume: 1.51m³ (43% reduction!)

• Average football mass: 904g (range:60-1200g)

• Average football volume: 0.006m³
KSC Trash to Gas Technology
Reactor System Flow Diagram

Diagram showing the flow of oxygen and steam through a mixing tube, then through a steam reforming reactor, followed by a chiller, condenser, and finally leading to a gas chromatograph.
Steam Reformer Reactor

1. Shell Heaters
2. Trash Bed
3. Catalyst/GAC Bed
4. Chiller
5. Heat Exchanger
6. Water Collection
7. Steam Generator
KSC Trash to Gas Steam Reforming Reactor Results
## Reactor Feed - Football Compositions

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Composition by mass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cardboard</strong></td>
<td>50% corrugated cardboard</td>
</tr>
<tr>
<td></td>
<td>40% food packaging boxes</td>
</tr>
<tr>
<td></td>
<td>10% used paper</td>
</tr>
<tr>
<td><strong>Plastics</strong></td>
<td>50% plastic utensils</td>
</tr>
<tr>
<td></td>
<td>45% plastic food packaging</td>
</tr>
<tr>
<td></td>
<td>5% nitrile gloves</td>
</tr>
<tr>
<td><strong>Food and Plant Mix</strong></td>
<td>75% Coffee grounds, tea bags, food crumbs</td>
</tr>
<tr>
<td></td>
<td>25% spent soil with inedible plant mass</td>
</tr>
<tr>
<td><strong>HFWS</strong></td>
<td>LRR project waste model</td>
</tr>
</tbody>
</table>
## Reactor Projections for Methane Production/Power

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>CH$_4$ (kg)</th>
<th>kWh</th>
<th>Processing time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardboard</td>
<td>22</td>
<td>307</td>
<td>98</td>
</tr>
<tr>
<td>Plastics</td>
<td>12</td>
<td>168</td>
<td>69</td>
</tr>
<tr>
<td>Food and Plant Mix</td>
<td>11</td>
<td>162</td>
<td>162</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>45</strong></td>
<td><strong>637</strong></td>
<td><strong>329</strong></td>
</tr>
</tbody>
</table>
Summary

- 115 days of mission waste collected
- 151.7 kg of wet and dry waste was accounted for (not including human, waste water or brine).

1 Year, 4 person crew:

- HI-SEAS: 385kg
- LRR Full Waste Model: 2,559kg (with feces, brine, clothing, etc.)
- LRR: 735kg (hygiene, food, food packaging, and food storage)

- 52% difference
CONCLUSION

- The amount of waste produced during the HI-SEAS was measured and is less than would be expected from long duration space missions.
- The waste collection data showed that large amounts of waste were generated during certain times, such as when the monthly food supplies were unpacked.
- This indicates that the TtG process must be able to handle a waste stream that will vary in composition, and that it is possible for a crew of five to segregate wastes over a mission.
- The amount of time required to process all the waste during this mission was 12% of the mission time, based on the reaction rates using the existing reactor at KSC.
- A more automated system, would likely require less crew time. (Currently 10%)
- The KSC TtG process successfully processed the three waste types, and could produce 9% of the power needed during the mission.
ACKNOWLEDGEMENTS

• NASA’s Advanced Exploration Systems Program Office
• Logistics Reduction and Repurposing Team, esp. KSC/JSC
• HI-SEAS Mission 2 Crew Members: Lucie Poulet, Tiffany Swarmer, Ross Lockwood, Casey Stedman
• HI-SEAS P.I. Dr. Kim Binsted and Dr. Jean Hunter.
• Gasmet Technologies Inc.
Questions?

Anne Caraccio
Email: Anne.Caraccio@nasa.gov
Backup Slides
# Water, Ash, and Combustible Mass Percentages of Wastes

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Water (%)</th>
<th>Ash (%)</th>
<th>Combustible (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardboard</td>
<td>8.1</td>
<td>7.3</td>
<td>84.6</td>
</tr>
<tr>
<td>Plastics</td>
<td>0.5</td>
<td>9.0</td>
<td>90.4</td>
</tr>
<tr>
<td>Food and Plant Mix</td>
<td>66.7</td>
<td>5.0</td>
<td>28.3</td>
</tr>
<tr>
<td>HFW/S</td>
<td>40.3</td>
<td>5.9</td>
<td>53.8</td>
</tr>
</tbody>
</table>
## Reactor Outputs

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>$\text{CO}_2$ (g/g)</th>
<th>$\text{CO}$ (g/g)</th>
<th>C (g/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardboard</td>
<td>1.64 (1.78)</td>
<td>0.30 (0.33)</td>
<td>0.64 (0.70)</td>
</tr>
<tr>
<td>Plastics</td>
<td>1.34 (1.35)</td>
<td>0.23 (0.23)</td>
<td>0.48 (0.48)</td>
</tr>
<tr>
<td>Food and Plant Mix</td>
<td>0.30 (0.9)</td>
<td>0.04 (0.12)</td>
<td>0.11 (0.33)</td>
</tr>
<tr>
<td>HFWS</td>
<td>0.72 (1.21)</td>
<td>0.18 (0.3)</td>
<td>0.28 (0.47)</td>
</tr>
</tbody>
</table>
Fourier Transform Infrared Spectroscopy (FTIR)
FTIR RESULTS
Carbon monoxide
Nitrous oxide
Methane
Ethylene
Pentane
Toluene
Formaldehyde
Acetaldehyde
Acetone
Methanol
Ethanol

Concentration (ppm)

Storage Container
Food/Plant/
Paper/Cardboard/Plastic...
Living Room
Plant/Lab
Bathroom
Power Use
Water Consumption
6.2 gal/pp/day