Habitation Systems

An HEOMD SBIR Topic

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MD: HEOMD
Date: 06/27/2017
TIME: 1:00 pm PST
Habitation Systems - Topic Overview

- Environmental Control and Life Support
  - Atmosphere Revitalization
  - Water Recovery
  - Waste Management
  - Environmental Monitoring and Control
  - Fire Protection
  - Thermal Control Systems

- Habitation - Human Accommodations
  - Habitat Outfitting
  - Logistics Reduction
  - Food Systems / Food Production

Expedition 43 crewmembers Scott Kelly and Terry Virts service the CO₂ removal system on the ISS
Mission Considerations for Habitation Systems

Now
Using the International Space Station

2020s
Operating in the Lunar Vicinity

2030s
Leaving the Earth-Moon System and Reaching Mars Orbit

Earth Reliant
Length: 6 to 12 months
Return: Hours
Resupply: frequent
Sample Analysis on Earth
Waste burns up on re-entry

Proving Ground
Mission Length: 1 to 12 months
Return: Days
Resupply: costly and difficult
Sample return is difficult
Waste storage

Earth Independent
Mission Length: 2 to 3 years
Return: Months to Years
Resupply: not possible
In-flight analysis capability
Planetary Protection
Long Distances from Earth Prohibit Resupply and Ground Support
• A spacecraft will require a higher level of self sufficiency and autonomy.
• Sample analysis will be limited to capability within the vehicle, driving the need for greater on board analytical monitoring capability.

Recycling Life Support Consumables is Enabling for Long Duration Missions
• For example, a 1000 day mission for a crew of 4 will require over 12 metric tons of potable water for drinking and hygiene.
• To save mission and launch costs, recycling air, water & solid wastes, and reducing other logistical needs will be essential.

Planetary Surface Missions are Unique
• Systems may need to process water derived from in situ planetary resources.
• Planetary protection requirements will need to be met, including controls and processes to prevent forward and backward contamination.
Environmental Control and Life Support (ECLSS) contains many subsystems with common interfaces, interdependencies and synergies.
ISS Regenerative ECLSS: The Point of Departure for an Exploration ECLSS

- ISS ECLSS is not fully “closed”, i.e., not all consumables are fully recycled
ISS ECLSS is not fully “closed”

Notional Mass Balance, Crew of 3, One Year Mission

- Crew of 3 1 year Mission Consumables = 2345 kg
  - Food 1007 kg
  - Clothing, Food Packaging, Wipes, etc. 1029 kg
  - Make-Up H₂O 308 kg

- H₂O 1010 kg → O₂ Generation (OGA) → H₂ 112 kg → CO₂ Reduction (Sabitier) → H₂O 505 kg + CH₄ 224 kg
- CO₂ 1139 kg → CO₂ Removal (CDRA) → CO₂ 522 kg
- Solid Waste (Feces, Trash, Clothing, Etc) 1248 kg
- Waste H₂O 3723 kg → H₂O Recovery (WRS) → Brine 351 kg
- H₂O 3372 kg

Mass Ventilated = 746 kg
Mass Jettisoned or Stored = 1599 kg

- There are opportunities for improvements
  - Improved sorbents and catalysts for trace contaminants
  - New technologies for water recovery from wastewater brines
  - New technologies for water recovery from solid waste
  - On board environmental monitoring for water and wastewater
  - Simpler, more robust, serviceable subsystems and processors
Current ISS Capabilities and Challenges/Needs:
Atmosphere Management

• Circulation
  – ISS: Fans (cabin & intermodule), valves, ducting, mufflers, expendable HEPA filter elements
  – Challenges: Quiet fans, filters for surface dust

• Remove CO\textsubscript{2} and contaminants
  – ISS: Regenerative zeolite CDRA, supports \(\sim 2.3 \text{ mmHg ppCO}_2\) for 4 crew. MTBF <6 months. Obsolete contaminant sorbents.
  – Challenges: Bed & valve reliability, ppCO\textsubscript{2} <2 mmHg, sorbents, replace obsolete sorbents w/ higher capacity; siloxane removal

• Remove humidity
  – ISS: Condensing heat exchangers with anti-microbial hydrophilic coatings requiring periodic dryout, catalyze siloxane compounds.
  – Challenge: Durable, inert, improved anti-microbial coatings

• Supply O\textsubscript{2}
  – ISS: Oxygen Generation Assembly (H\textsubscript{2}O electrolysis, ambient pressure); high pressure stored O\textsubscript{2} for EVA
  – Challenge: Smaller, alternate H\textsubscript{2} sensor, high pressure 3,000 psi O\textsubscript{2} for EVA replenishment; contingency medical oxygen

• Recovery of O\textsubscript{2} from CO\textsubscript{2}
  – ISS: Sabatier process reactor, recovers 42\% O\textsubscript{2} from CO\textsubscript{2}
  – Challenge: >75\% recovery of O\textsubscript{2} from CO\textsubscript{2}
Success Stories – Carbon Dioxide Reduction

- Umpqua Research Company, Myrtle Creek, Oregon
  - X12.01-9587 (SBIR 2005-2) “Hydrogen Recovery by ECR Plasma Pyrolysis of Methane”
  - X3.01-9783 (SBIR 2010-1) “Regenerative Bosch Reactor”

- Description
  - Two unique technologies were developed that allow for improved recovery of oxygen from carbon dioxide over the state of the art
  - Both have received Phase III funding
  - Both are under consideration for selection for a flight demonstration and possible use for an advanced regenerative ECLSS

- Continuous Bosch Reactor
  - Catalytic reduction of carbon dioxide by hydrogen, resulting in solid carbon and water. Would replace the SOA ISS Sabatier. Potential O₂ Recovery from CO₂: ≈95%

- Methane Pyrolysis of Methane
  - Decomposition of methane (originating from the Sabatier) to hydrogen and acetylene. Returns hydrogen to the Sabatier for further CO₂ reduction. Potential O₂ Recovery: ≈70%
Current ISS Capabilities and Challenges/Needs: Water Management

- Water Storage & Biocide
  - ISS: Bellows tanks, collapsible bags, iodine for microbial control
  - Challenges: Common silver biocide with on-orbit dosing, dormancy survival

- Urine Processing
  - ISS: Urine Processing Assembly (vapor compression distillation), currently recovers 85% of water (brine is stored for disposal)
  - Challenges: 85-90% recovery (expected with alt pretreat formulation just implemented); reliability; recovery of urine brine water

- Water Processing
  - ISS: Water Processor Assembly (filtration, adsorption, ion exchange, catalytic oxidation, gas/liquid membrane separators), 100% recovery, 0.11 lbs consumables + limited life hw/lb water processed.
  - Challenges: Reliability (ambient temp, reduced pressure catalyst), reduced expendables, dormancy survival
Success Stories - Ionomer Water Processor for Water Recovery from Brines

• Paragon Space Development Corporation, Tucson, Arizona
  — X3.01-9280 (SBIR 2010-1) “Employing Ionomer Membrane Technology to Extract Water from Brine”
    (SBIR 2010-2) “Ionomer-membrane Water Processor System Design and EDU Demonstration”

• NASA’s Problem
  — Production of brine wastewater by the ISS Urine Processor Assembly results in a considerable loss of water on a yearly basis.
  — The brine is highly toxic.
  — Consumable containers are used to dispose of the brine, which adds significant consumable mass.

• Paragon’s Solution:
  — Membrane pair forms a bag or bladder to contain brine and transmit water vapor
  — Cabin air sweep gas delivers recovered water vapor to cabin where it enters the cabin condensing heat exchanger and the vehicle water processing system
  — Recovers 80-90% of residual water in brine, boosting urine water recovery to 98%
Current ISS Capabilities and Challenges/Needs: Environmental Monitoring

- **Water Monitoring**
  - ISS: On-line conductivity; Off-line total organic carbon, iodine; Samples returned to earth for full analysis
  - Challenge: On-orbit identification and quantification of specific organics & inorganics

- **Microbial**
  - ISS: Culture-based plate count, no identification, 1.7 hrs crew time/sample, 48 hr response time; samples returned to earth.
  - Challenge: On-orbit, non culture-based monitor with species identification & quantification, faster response time and minimal crew time

- **Atmosphere**
  - ISS: Major Constituent Analyzer (mass spectrometry – 6 constituents); COTS Atmosphere Quality Monitors (GC/DMS) measure ammonia and some additional trace gases; remainder of trace gases via grab sample return
  - Challenges: Smaller, more reliable major constituent analyzer, in-flight trace gas monitor (no ground samples), targeted gas (event) monitor

- **Particulate**
  - ISS: N/A
  - Challenge: On-orbit monitor for respiratory particulate hazards & planetary dust

- **Acoustic**
  - SOA: Hand held sound level meter, manual crew assays
  - Challenge: Continuous acoustic monitoring with alerting
Considerations

- Set in cooperation with the National Research Council Committee on Toxicology.
- Consider unique factors such as space-flight stress on human physiology, uniform good health of astronauts, absence of pregnant and very young individuals.
- Spaceflight relevant chemicals
- Consider exposure durations critical for spaceflight

Exposure Groups

- Short-term (1 & 24 hr) SMACs are set to manage accidental releases and permit risk of minor, reversible effects, such as mild irritation.
- Long-term SMACs are set to fully protect healthy crewmembers from adverse effects

<table>
<thead>
<tr>
<th>Selected Chemicals (list is not complete)</th>
<th>Concentration (ppm)*</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1 hr</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>10</td>
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<tr>
<td>Acetone</td>
<td>500</td>
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<tr>
<td>Ammonia</td>
<td>30</td>
</tr>
<tr>
<td>Benzene</td>
<td>10</td>
</tr>
<tr>
<td>Carbon dioxide*</td>
<td>20,000</td>
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<tr>
<td>Carbon monoxide</td>
<td>425</td>
</tr>
<tr>
<td>Benzene</td>
<td>10</td>
</tr>
<tr>
<td>Ethanol</td>
<td>5,000</td>
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<tr>
<td>Ethylene glycol</td>
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<td>Formaldehyde</td>
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<td>Freon 21</td>
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<tr>
<td>Glutaraldehyde</td>
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<tr>
<td>Hydrazine</td>
<td>4</td>
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<tr>
<td>Mercury</td>
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</tr>
<tr>
<td>Methane</td>
<td>5,300</td>
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<tr>
<td>Methanol</td>
<td>200</td>
</tr>
<tr>
<td>Methyl ethyl ketone</td>
<td>50</td>
</tr>
<tr>
<td>Methyl hydrazine</td>
<td>.002</td>
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<tr>
<td>Propylene glycol</td>
<td>32</td>
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<tr>
<td>Toluene</td>
<td>16</td>
</tr>
<tr>
<td>Xylene</td>
<td>50</td>
</tr>
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</table>

Spacecraft Maximum Allowable Concentrations for Airborne Contaminants, JSC-20584, 2008
*NS = Value Not Set
*SMAC likely to be reduced. Interim working value for R&D = 2,600 ppm
Considerations

- Protection of Crew Health
- Strengths & susceptibilities of astronauts
- Spaceflight relevant chemicals
- Consider exposure durations critical for spaceflight
- Account for higher drinking water consumption rates
- These drive design goals for water recycling, but are purposefully not so stringent to cause over-design
- Total Organic Carbon is the sum of contributions of individual constituents

Exposure Groups

- Acute Exposure – for contingencies
- Prolonged Consumption - drives requirements for water processor design

<table>
<thead>
<tr>
<th>Selected Chemicals (list is not complete)</th>
<th>Concentration (mg/L)</th>
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<tbody>
<tr>
<td></td>
<td>1 day</td>
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<tr>
<td>Acetone</td>
<td>3500</td>
</tr>
<tr>
<td>Alkylamines (di)</td>
<td>0.3</td>
</tr>
<tr>
<td>Ammonia</td>
<td>5</td>
</tr>
<tr>
<td>Antimony (soluble salts)</td>
<td>4</td>
</tr>
<tr>
<td>Barium (salts), soluble</td>
<td>21</td>
</tr>
<tr>
<td>Benzene</td>
<td>21</td>
</tr>
<tr>
<td>Cadmium (salts), soluble</td>
<td>1.6</td>
</tr>
<tr>
<td>Caprolactam</td>
<td>200</td>
</tr>
<tr>
<td>Chloroform</td>
<td>60</td>
</tr>
<tr>
<td>Di-n-butyl phthalate</td>
<td>1200</td>
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<tr>
<td>Dichloromethane</td>
<td>40</td>
</tr>
<tr>
<td>Ethylene glycol</td>
<td>270</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>20</td>
</tr>
<tr>
<td>Formate</td>
<td>10,000</td>
</tr>
<tr>
<td>Manganese (salts), soluble</td>
<td>14</td>
</tr>
<tr>
<td>Mercaptobenzothiazole</td>
<td>200</td>
</tr>
<tr>
<td>Methanol</td>
<td>40</td>
</tr>
<tr>
<td>Methyl Ethyl Ketone</td>
<td>540</td>
</tr>
<tr>
<td>Nickel</td>
<td>1.7</td>
</tr>
<tr>
<td>Phenol</td>
<td>80</td>
</tr>
<tr>
<td>Silver</td>
<td>5</td>
</tr>
<tr>
<td>Zinc soluble compounds</td>
<td>11</td>
</tr>
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</table>
## Fire Safety Needs

<table>
<thead>
<tr>
<th>Function</th>
<th>Capability Gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fire Suppression</strong></td>
<td>ECLSS-compatible and rechargeable fire suppression. Compatible with small cabin volumes.</td>
</tr>
<tr>
<td><strong>Emergency Crew Mask</strong></td>
<td>Single filtering cartridge mask (fire, ammonia, toxic spill), compatible with small cabin volumes (no O₂ enrichment).</td>
</tr>
<tr>
<td><strong>Combustion Product Monitoring</strong></td>
<td>Contingency air monitor for relevant chemical markers of post-fire cleanup; CO, CO₂, HF, HCl, HCN; battery-operated; hand-held calibration duration 1-5 years; survives vacuum exposure.</td>
</tr>
<tr>
<td><strong>Low- and partial-gravity material flammability</strong></td>
<td>Identify material flammability limits in low-g environment</td>
</tr>
<tr>
<td><strong>Post-fire cleanup/smoke eater</strong></td>
<td>Contingency air purifier for post-fire and leak cleanup. Reduce incident response time by 75% compared to getting in suits and purging atmosphere.</td>
</tr>
<tr>
<td><strong>Fire Scenario Modeling and Analysis</strong></td>
<td>Definition of a realistic spacecraft fire to size.</td>
</tr>
<tr>
<td><strong>Fire Detection</strong></td>
<td>Early fire detection. Particle size discrimination (false alarms).</td>
</tr>
</tbody>
</table>
Spacecraft Fire Safety Demonstration (Saffire)

Objectives

- Determine low-g flammability limits for spacecraft materials
- Investigate/define realistic fires for exploration vehicles
  - Fate of a large-scale spacecraft fire
- Demonstrate spacecraft fire detection, monitoring, and cleanup technologies in a realistic fire scenario
- Characterize fire growth in high O₂/low pressure atmospheres
- Provide data to validate models of realistic spacecraft fire

<table>
<thead>
<tr>
<th>Saffire</th>
<th>Description</th>
<th>Dates</th>
<th>Cygnus</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Assess flame spread of large-scale microgravity fire (spread rate, mass consumption, heat release)</td>
<td>Jun 2016</td>
<td>OA-6</td>
</tr>
<tr>
<td>II</td>
<td>Verify oxygen flammability limits in low gravity</td>
<td>Nov 2016</td>
<td>OA-5</td>
</tr>
<tr>
<td>III</td>
<td>Same as Saffire-I but at different flow conditions</td>
<td>Jun 2017</td>
<td>OA-7</td>
</tr>
<tr>
<td>IV</td>
<td>Assess flame spread of large-scale microgravity fire in exploration atmospheres; demonstrate post-fire monitoring and cleanup technologies</td>
<td>Jul 2019</td>
<td>CRS2-1</td>
</tr>
<tr>
<td>V</td>
<td>Evaluate fire behavior on realistic geometries; demonstrate post-fire monitoring and cleanup technologies</td>
<td>Feb 2020</td>
<td>CRS2-2</td>
</tr>
<tr>
<td>VI</td>
<td>Assess existing material configuration control guidelines; demonstrate post-fire monitoring and cleanup technologies</td>
<td>May 2020</td>
<td>CRS2-3</td>
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</table>
Success Stories - Spacecraft Fire Safety Demonstration

<table>
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<th>Saffire</th>
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<th>Cygnus</th>
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<td>Feb 2020</td>
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<td>May 2020</td>
<td>CRS2-3</td>
</tr>
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</table>

An Advanced Smoke-Eater for Post-Fire Cabin Atmosphere Cleanup
— Demo in Saffire-IV-VI will only include CO catalyst. Sized for the Cygnus vehicle and anticipated fire in Saffire

Advanced Fire Detector for Space Applications
— X3.04-9258 (SBIR 2007-2), Vista Photonics, Inc., Las Cruces, NM
— To be demonstrated in Saffire-IV-VI
— Also under development for ISS/Orion flight hardware
Success Stories – Fine Water Mist Fire Extinguisher

• ADA Technologies, Littleton, Colorado
  — X12.03-8217 (SBIR 2005-2) “Fine Water Mist Fire Extinguisher for Spacecraft”
  — X2.05-9375 (SBIR 2008-2) “Advanced Portable Fine Water Mist Fire Extinguisher for Spacecraft”

• NASA’s Problem
  — A replacement for gaseous carbon dioxide (CO₂) portable fire extinguishers (PFE) was necessary.
    ○ They are not compatible with spacecraft ECLSS or small cabin volumes
    ○ They are not rechargeable inflight

• ADA Technology’s Solution:
  — Leverages the unique thermal properties of micro-atomized water droplets.
  — Environmentally safe - uses only water and nitrogen, the technology does not pose a health or environmental hazard.
  — Can be used in any orientation
Overview – Habitation

- Habitation
  - To enable highly effective crew accommodations and optimization of logistical mass to support exploration class missions of increasing length and distance from earth
  - Habitation is discrete crew hardware and logistics as well as integrated systems required to utilize vehicle systems and to maintain crew productivity
  - Does not include the habitat module itself, ECLSS, medical, science or robotic hardware, but may include interfaces to these systems

Astronaut Chris Hatfield in Crew Quarters
Habitation - Notional Hardware/System Breakout

Habitation Domain

Human Sys. Integration – Habitable Volume
- Habitation systems performance, Human Factors Analysis
- Prime structures, secondary structures
- Crew Quarters, Waste and Hygiene Compartment, Galley, Restraints & Mobility Aids
- Fans, dampening, adsorption

Habitation Domain

Human Sys. Integration
- Cleaning
- Trash Management

Habitability Structures
- Vehicle Structure
- Crew Structures
- Integrated Outfitting
- Lighting-vehicle
- Acoustic Control
- Odor Control
- Radiation Protection

Maintenance/Repair
- Repair Equipment
- Diagnostics Instruments
- Maintenance Work Area
- Subsystem Spares

Logistics
- Stowage Systems
- Crew Provisions

Wipes, cleaners, vacuum
Trash stowage/monitoring, processing, jettison, ECLSS ORU disposal, biological waste stowage
Tools, tool caddies and stowage, power provisions, portable lighting
Basic kits, specialized kits, L2L kits, additive manufacturing
Bags, stowage structures, cold stowage, inventory mgmt., packaging materials
Clothing, recreation, personal items, hygiene, office supplies, survival kit, food & nutrition
Overview – Logistics reduction

• Logistics
  – As with spacecraft and subsystem mass and volume, mission architects strive to minimize the amount of “logistics” or consumables required to support human exploration missions.
  – As mission duration increases, logistics reduction, as well as dealing with the associated waste products, becomes increasingly important.

• Definition - Logistics:
  – Crew Consumables (food, clothing, water, gasses, etc.)
  – Maintenance and Spares
  – Packaging and Overhead (e.g. cargo transfer bags)
  – Waste products may include:
    o Wet and dry trash
    o Empty containers and packaging
    o Human metabolic wastes

Reduce
Reuse
Recycle!

Cargo Transfer Bags

Used wipes and clothing
Logistics and Waste Masses

1,000 day mission w/ crew of 4

Crew Provisions/Fluids

<table>
<thead>
<tr>
<th>Item</th>
<th>600-Day Transit</th>
<th>400-Day Mars Vicinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>4,394</td>
<td>2,930</td>
</tr>
<tr>
<td>Personal Stowage</td>
<td>200</td>
<td>-</td>
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<tr>
<td>Operational Supplies</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Personal Hygiene Kit</td>
<td>29</td>
<td>22</td>
</tr>
<tr>
<td>Hygiene Consumables</td>
<td>190</td>
<td>126</td>
</tr>
<tr>
<td>Healthcare Consumables</td>
<td>216</td>
<td>144</td>
</tr>
<tr>
<td>Wipes &amp; Towels</td>
<td>468</td>
<td>312</td>
</tr>
<tr>
<td>Trash Bags</td>
<td>26</td>
<td>18</td>
</tr>
<tr>
<td>Clothes</td>
<td>528</td>
<td>352</td>
</tr>
<tr>
<td>Waste Collection: Fecal Canisters</td>
<td>540</td>
<td>360</td>
</tr>
<tr>
<td>Waste Collection: Urine Prefilters</td>
<td>150</td>
<td>100</td>
</tr>
</tbody>
</table>

Total Mass: 6,845 kg for 600-Day Transit, 4,367 kg for 400-Day Mars Vicinity
Current ISS Capabilities and Challenges/Needs: Waste Management

- Trash
  - ISS: Gather & store; dispose (in re-entry craft)
  - Challenge: Compaction, stabilization, resource recovery

- Metabolic Waste
  - ISS: Russian Commode, sealed canister, disposal in re-entry craft
  - Challenge: Long-duration stabilization, volume and expendable reduction, potential resource recovery

- Logistics Waste (packaging, containers, etc.)
  - ISS: Gather & store; dispose (in re-entry craft)
  - Challenge: Reduce &/or repurpose
Habitation and Logistics Reduction Goals/Needs

- Automatic and autonomous logistics tracking to reduce crew time and support crew autonomy during time delay missions
- Common waste collection hardware
- Reduce fecal consumable mass and volume <0.1 kg/crew-day
- Reduce packaging material mass and volume
- Reuse or repurpose logistical packaging for crew outfitting and crew items
- Reduce trash/waste volume by >85%
- Waste stabilization and long term stowage
- Waste processing to produce useful mission resources
- >90% water recovery from metabolic waste and trash
- Robust contingency metabolic waste collection
- Logistics systems that enable robotic reconfiguration in un-crewed or crewed mission phases.
- Increase food nutritional stability to ensure crew performance during mission phases
- Reduce clothing and towel mass for exploration missions <0.06 kg/crew-day
- Acoustic noise attenuation >25 dB for quiet crew cabin volumes
- Reduce required tools and maintenance kit mass
Bioregenerative Loop Life Support & *In Situ* Food Production

- **Space Exploration and Plant Growth**
  - Atmosphere revitalization via photosynthesis
  - Water recycling through transpiration
  - In situ production of food

- **Capability Needs**
  - Cultivation and growth systems
  - Dwarf highly productive cultivars
  - Nutrient recycling and reusable media
  - Greenhouse films and efficient lighting

![Diagram of the bioregenerative loop life support system](image)

Astronaut Shane Kimbrough harvesting lettuce from the Veggie plant growth system on the ISS
Guidance for SBIR Solicitation Responses

• Technical content in the solicitation will vary year to year. Different technical areas may be combined into a single subtopic. A technical area may rotate year to year and be skipped.

• Check the subtopic descriptions carefully. A proposal must address content requested in the current solicitation to be considered for award, otherwise it may be judged non-responsive.

• The proposed research and development plan should focus on the core technology or innovation. Don’t dilute the effort building commonly available supporting hardware.

• Show an understanding of the state of the art. Objectively state the advantages of the proposed technology over it. Include estimates for mass, power, volume and thermal requirements.

• Spend adequate time building the requested summary charts. These are used by NASA and if poorly written or too general they have limited value.

• Phase I
  — Focus should be to demonstrate proof of concept and feasibility of the technical approach.
    — Focus on questions that need to be answered and risks that need to be addressed to develop a more informed Phase II proposal with reduced technical risk.

• Phase II
  — Contracts should lead to development and evaluation of prototype breadboard hardware for delivery to NASA.
    — Consider NASA safety and other standards in design and fabrication of the hardware intended for delivery to NASA. Delivered hardware needs to meet pressure systems, oxygen safety and other standards to be tested at NASA facilities.
## Past Solicitations - Role of Small Businesses

- Small businesses bring innovative solutions to address challenges and gaps faced by ECLSS and Habitation Systems, and have been effective in moving ideas from concept to technical maturity.

<table>
<thead>
<tr>
<th>Year</th>
<th>Titles of Subtopics from Past Solicitations</th>
<th># of Awards</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>H3.01 Atmosphere Revitalization</td>
<td>12 Phase I</td>
</tr>
<tr>
<td></td>
<td>H3.02 Environmental Monitoring &amp; Fire Protection for Spacecraft Autonomy</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>H3.03 Crew Accommodations and Water Recovery</td>
<td>5 Phase II</td>
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<tr>
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<td>H3.04 Thermal Control Systems</td>
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<td>H3.04 Logistics Reduction</td>
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Summary: Deep Space Habitation Systems Objectives

Habitation Systems Elements

**LIFE SUPPORT**
- Atmosphere Management
- Waste Management

**ENVIRONMENTAL MONITORING**
- Pressurized O₂ & N₂
- Moisture
- Particles
- Microbes
- Chemicals
- Sound

**FIRE SAFETY**
- Detection
- Protection
- Suppression
- Cleanup

**HABITATION & LOGISTICS**
- Tracking
- Packaging
- Trash
- Disposable cotton clothing
- Packaging disposed
- Bag and discard

**TODAY - ISS**
- 42% O₂ Recovery from CO₂
- 90% H₂O Recovery
- < 6 mo mean time before failure (for some components)

**FUTURE - Deep Space**
- 75%+ O₂ Recovery from CO₂
- 98%+ H₂O Recovery
- >30 mo mean time before failure

**TODAY - ISS**
- On-board analysis capability with no sample return
- Identify and quantify species and organisms in air & water

**FUTURE - Deep Space**
- Limited, crew-intensive on-board capability
- Reliance on sample return to Earth for analysis

**FIRE SAFETY**
- Large CO₂ Suppressant Tanks
- 2-cartridge mask
- Obsolete combustion prod. sensor
- Only depress/repress clean-up

**HABITATION & LOGISTICS**
- Manual scans, displaced items
- Disposable cotton clothing
- Long-wear clothing/laundry

**ENVIRONMENTAL MONITORING**
- Water Mist portable fire extinguisher
- Single Cartridge Mask
- Exploration combustion product monitor
- Smoke eater

**FUTURE - Deep Space**
- Automatic, autonomous RFID
- Bags/foam repurposed w/3D printer
- Resource recovery, then disposal
Resources

- NASA SBIR/STTR 2017 Program Solicitation SBIR Research Topics by Focus Area
  — https://sbir.nasa.gov/solicit/58007/detail?data=ch9&s=58000

- ECLSS and Habitation Systems

- Trace Contaminant Exposure Guidelines
  — https://www.nasa.gov/feature/exposure-guidelines-smacs-swegs
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- William Michalek and Ray Wheeler, Umpqua Research Company
In future solicitations we may begin to consider technologies for use during human planetary surface missions