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National Aeronautics and Space Administration

Habitation Systems

An HEOMD SBIR Topic

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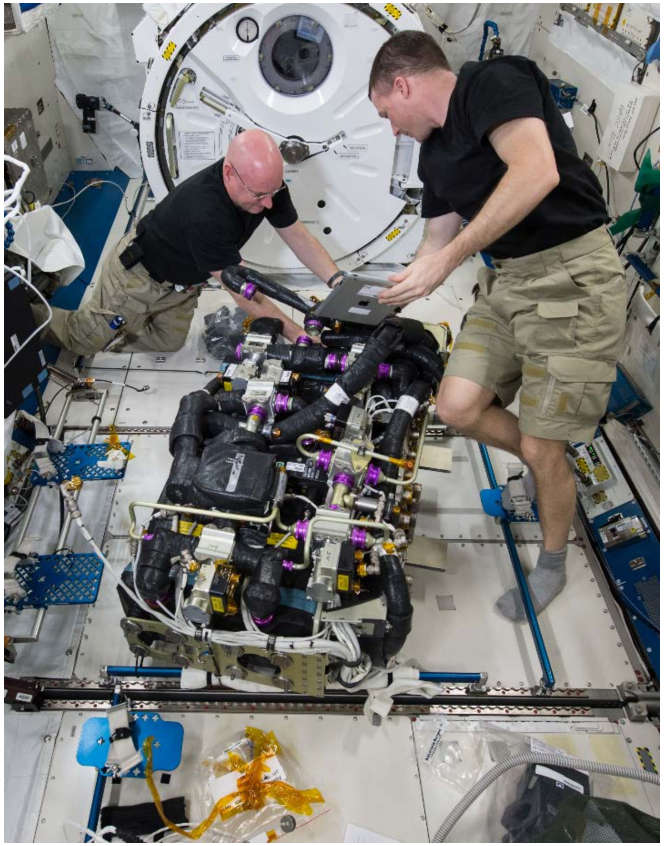
MD: HEOMD
Date: 06/27/2017
TIME: 1:00 pm PST

INNOVATION | PARTNERSHIP | COMMERCIALIZATION

SMALL BUSINESS INNOVATION RESEARCH (SBIR) & SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)

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 CO_2 removal system on the ISS

Mission Considerations for Habitation Systems

Earth Reliant	Proving Ground	Earth Independent
Length: 6 to 12 months	Mission Length: 1 to 12 months	Mission Length: 2 to 3 years
Return: Hours	Return: Days	Return: Months to Years
Resupply: frequent	Resupply: costly and difficult	Resupply: not possible
Sample Analysis on Earth	Sample return is difficult	In-flight analysis capability
Waste burns up on re-entry	Waste storage	Planetary Protection

Environmental Control and Life Support Systems (ECLSS) Considerations for Long Duration Deep Space Missions

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.

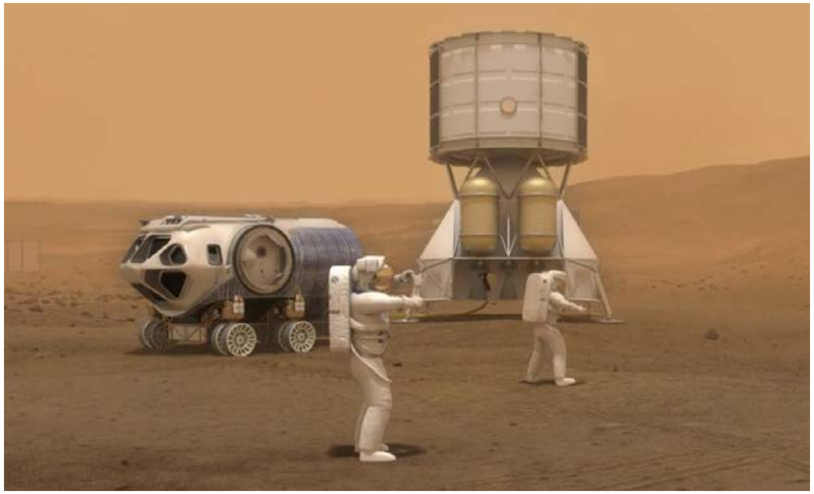
Recycling Life Support Consumables is Enabling for Long Duration Missions

- 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

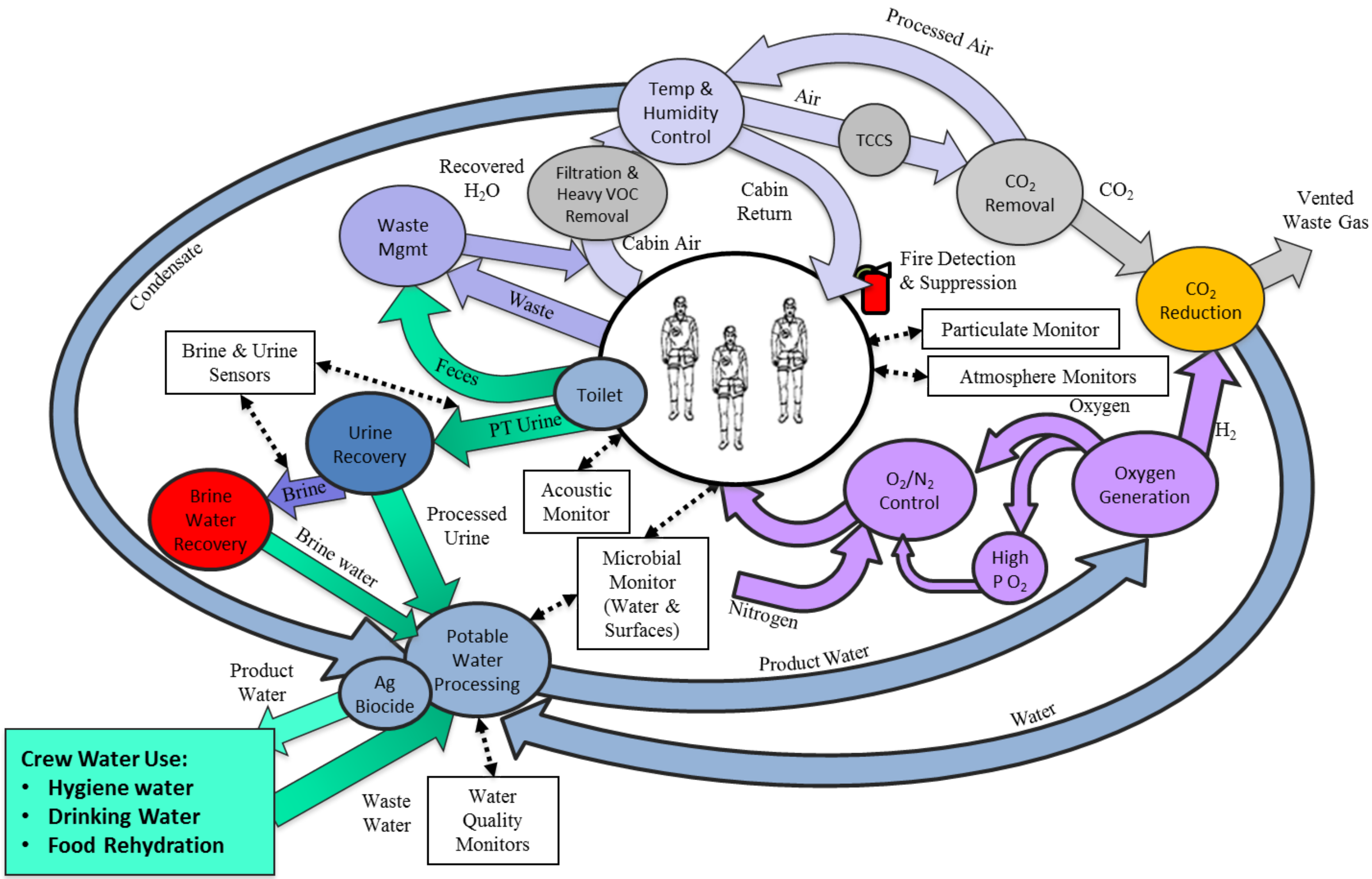
- Systems may need to process water derived from in situ planetary resources.
- Planetary protection requirements will need to be met, including controls and processes to prevent forward and backward contamination.

Astronaut Susan J. Helms in front of Contingency Water Containers (CWCs) on the ISS



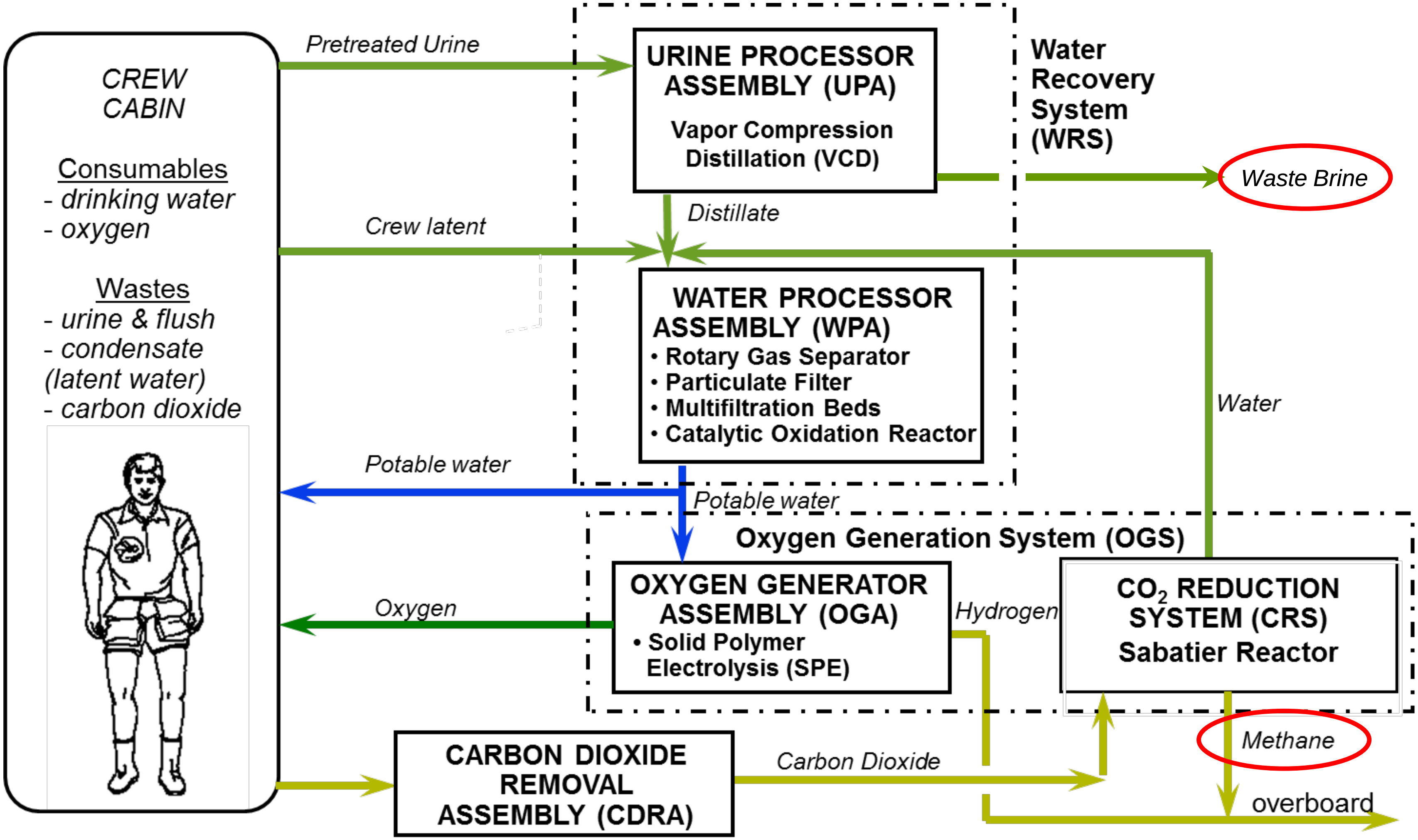
Environmental Control and Life Support (ECLSS)

- Environmental Control and Life Support (ECLSS) contains many subsystems with common interfaces, interdependencies and synergies.



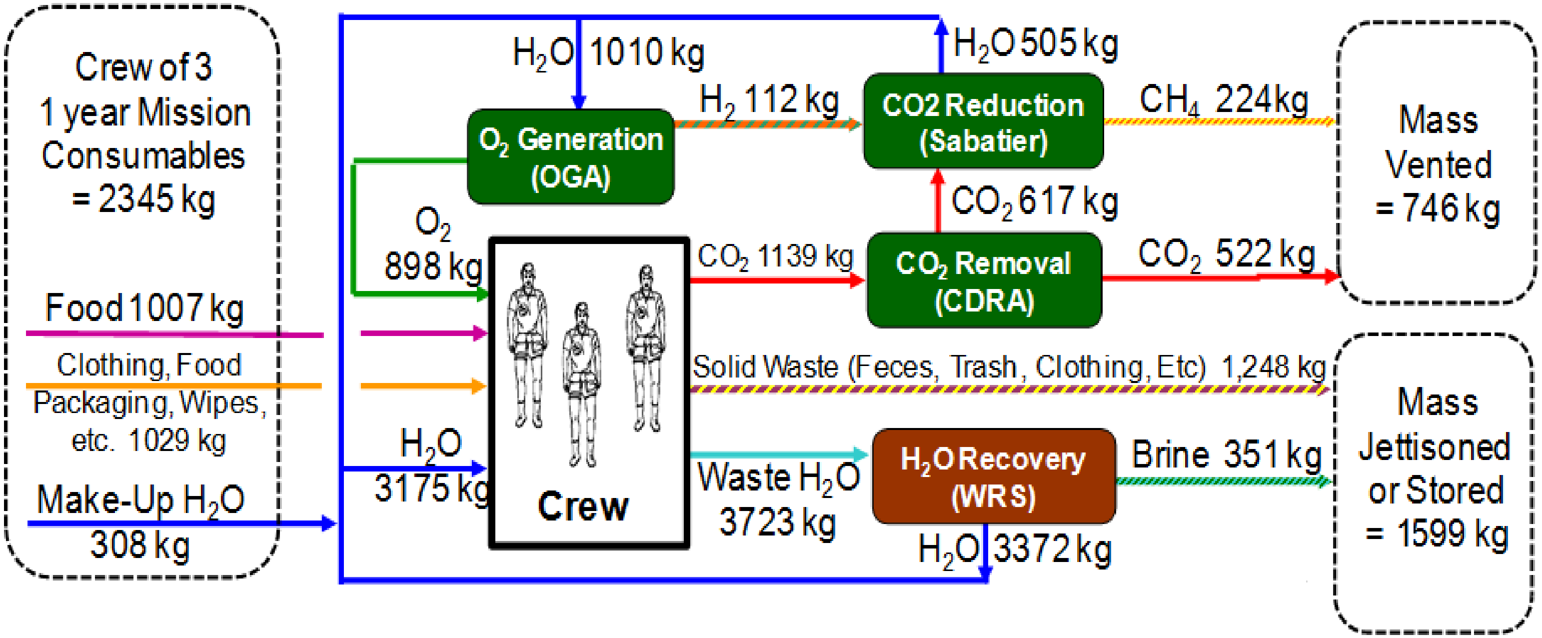
ISS Regenerative ECLSS: The Point of Departure for an Exploration ECLSS

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



ISS ECLSS is not fully "closed"

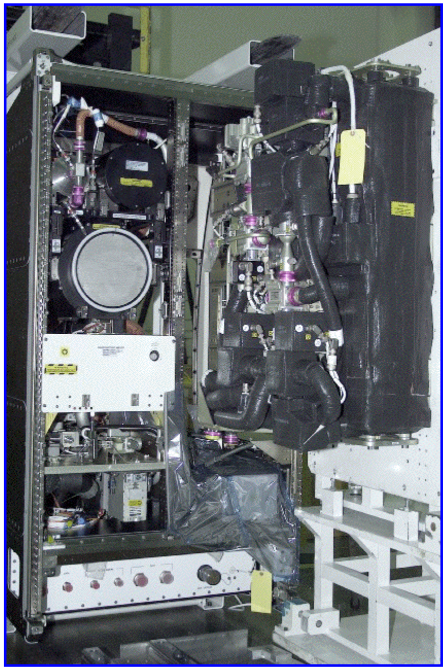
Notional Mass Balance, Crew of 3, One Year Mission



- 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_2 and contaminants
  - ISS: Regenerative zeolite CDRA, supports ~2.3 mmHg ppCO2 for 4 crew. MTBF <6 months. Obsolete contaminant sorbents.
  - Challenges: Bed & valve reliability, $ppCO_2$ <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_2
  - ISS: Oxygen Generation Assembly (H_2O electrolysis, ambient pressure); high pressure stored O_2 for EVA
  - Challenge: Smaller, alternate H_2 sensor, high pressure 3,000 psi O_2 for EVA replenishment; contingency medical oxygen
- Recovery of O_2 from CO_2
  - ISS: Sabatier process reactor, recovers 42% O_2 from CO_2
  - Challenge: >75% recovery of O_2 from CO_2



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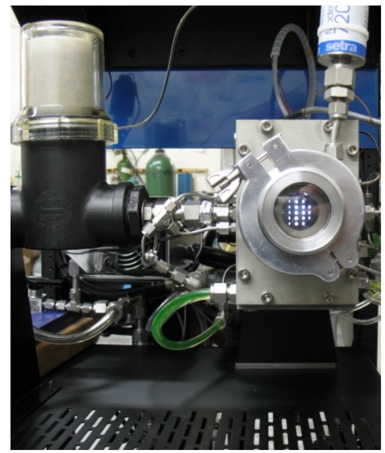
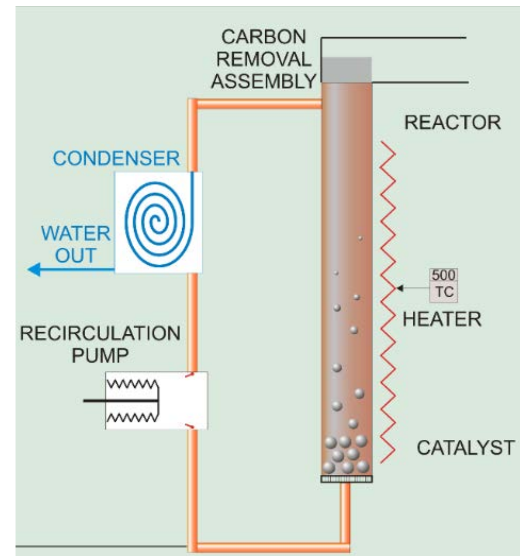
Success Stories – Carbon Dioxide Reduction

- 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



Plasma Pyrolysis Reactor



Continuous Bosch Reactor

- Continuous Bosch Reactor
  - Catalytic reduction of carbon dioxide by hydrogen, resulting in solid carbon and water. Would replace the SOA ISS Sabatier. Potential O_2 Recovery from CO_2: ≈95%
- Methane Pyrolysis of Methane
  - Decomposition of methane (originating from the Sabatier) to hydrogen and acetylene. Returns hydrogen to the Sabatier for further CO_2 reduction. Potential O_2 Recovery: ≈70%

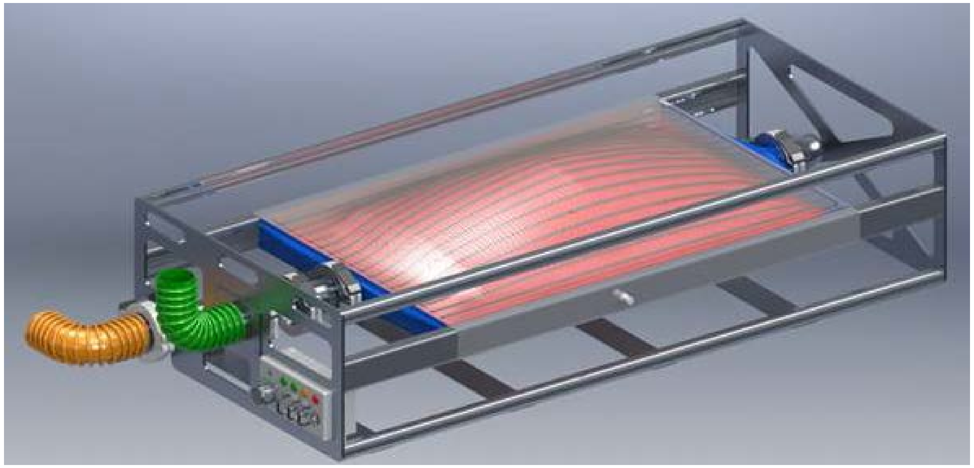
Current ISS Capabilities and Challenges/Needs: Water Management

- 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.

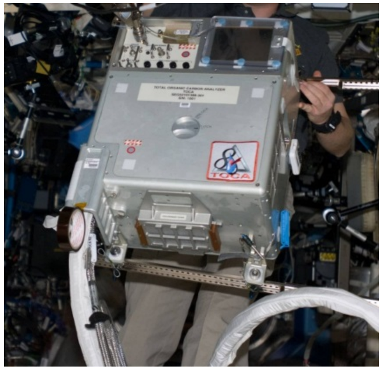


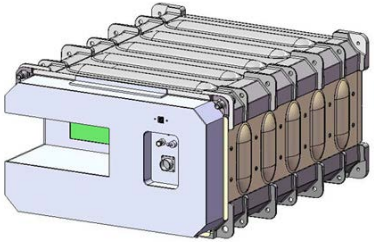
Flight hardware concept. Hardware delivery is expected in November 2018, with a flight demonstration in 2019.

- 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





Environmental Monitoring - Spacecraft Maximum Allowable Concentrations (SMACs) for Airborne Contaminants

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

Selected Chemicals (list is not complete)	Concentration (ppm)*					
	1 hr	24 hrs	7 days	30 d	180 d	1000 d
Acetaldehyde	10	6	2	2	2	NS
Acetone	500	200	22	22	22	NS
Ammonia	30	20	3	3	3	3
Benzene	10	3	0.5	0.1	0.07	0.013
Carbon dioxide*	20,000	13,000	7,000	7,000	7,000	5,000
Carbon monoxide	425	100	55	15	15	15
Benzene	10	3	0.5	0.1	0.07	0.013
Ethanol	5,000	5,000	1,000	1,000	1,000	1,000
Ethylene glycol	25	25	5	5	5	NS
Formaldehyde	0.8	0.5	0.1	0.1	0.1	0.1
Freon 21	50	50	15	12	2	NS
Glutaraldehyde	0.12	0.04	0.006	0.003	0.0006	NS
Hydrazine	4	0.3	0.04	0.02	0.004	NS
Mercury	0.01	0.002	0.001	0.001	0.001	NS
Methane	5,300	5,300	5,300	5,300	5,300	NS
Methanol	200	70	70	70	70	23
Methyl ethyl ketone	50	50	10	10	10	NS
Methyl hydrazine	.002	.002	.002	.002	.002	NS
Propylene glycol	32	17	9	3	1.5	1.5
Toluene	16	16	4	4	4	4
Xylene	50	17	17	17	8.5	1.5

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*

Environmental Monitoring - Spacecraft Water Exposure Guidelines (SWEGs) for Potable Water

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

Selected Chemicals (list is not complete)	Concentration (mg/L)			
	1 day	10 days	100 days	1000 days
Acetone	3500	3500	150	15
Alkylamines (di)	0.3	0.3	0.3	0.3
Ammonia	5	1	1	1
Antimony (soluble salts)	4	4	4	4
Barium (salts), soluble	21	21	10	10
Benzene	21	2	0.07	0.07
Cadmium (salts), soluble	1.6	0.7	0.6	0.022
Caprolactam	200	100	100	100
Chloroform	60	60	18	6.5
Di-n-butyl phthalate	1200	175	80	40
Dichloromethane	40	40	40	15
Ethylene glycol	270	140	20	4
Formaldehyde	20	20	12	12
Formate	10,000	2500	2500	2500
Manganese (salts), soluble	14	5.4	1.8	0.3
Mercaptobenzothiazole	200	30	30	30
Methanol	40	40	40	40
Methyl Ethyl Ketone	540	54	54	54
Nickel	1.7	1.7	1.7	0.3
Phenol	80	8	4	4
Silver	5	5	0.6	0.4
Zinc soluble compounds	11	11	2	2

Spacecraft Water Exposure Guidelines (SWEGs), JSC-63414, 2008

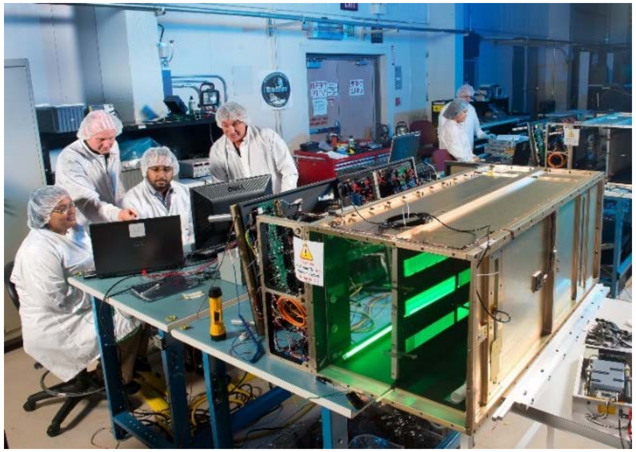
Fire Safety Needs

Function	Capability Gaps
Fire Suppression	ECLSS-compatible and rechargeable fire suppression. Compatible with small cabin volumes.
Emergency Crew Mask	Single filtering cartridge mask (fire, ammonia, toxic spill), compatible with small cabin volumes (no O_2 enrichment).
Combustion Product Monitoring	Contingency air monitor for relevant chemical markers of post-fire cleanup; CO, CO_2, HF, HCl, HCN; battery-operated; hand-held calibration duration 1-5 years; survives vacuum exposure.
Low- and partial-gravity material flammability	Identify material flammability limits in low-g environment
Post-fire cleanup/smoke eater	Contingency air purifier for post-fire and leak cleanup. Reduce incident response time by 75% compared to getting in suits and purging atmosphere.
Fire Scenario Modeling and Analysis	Definition of a realistic spacecraft fire to size.
Fire Detection	Early fire detection. Particle size discrimination (false alarms).

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 O_2/low pressure atmospheres
- Provide data to validate models of realistic spacecraft fire



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

Success Stories - Spacecraft Fire Safety Demonstration

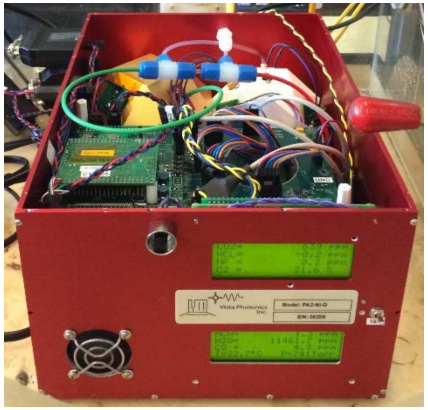
Saffire	Description	Dates	Cygnus
IV	Assess flame spread of large-scale microgravity fire in exploration atmospheres; demonstrate post-fire monitoring and cleanup technologies	Jul 2019	CRS2-1
V	Evaluate fire behavior on realistic geometries; demonstrate post-fire monitoring and cleanup technologies	Feb 2020	CRS2-2
VI	Assess existing material configuration control guidelines; demonstrate post-fire monitoring and cleanup technologies	May 2020	CRS2-3

An Advanced Smoke-Eater for Post-Fire Cabin Atmosphere Cleanup

- H3.02-9398 (SBIR 2014-2), TDA Research, Inc., Wheat Ridge, CO
- 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



Vista Photonics

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 (CO_2) portable fire extinguishers (PFE) was necessary.
    - They are not compatible with spacecraft ECLSS or small cabin volumes
    - They are not rechargeable inflight

Microgravity Aircraft Evaluations

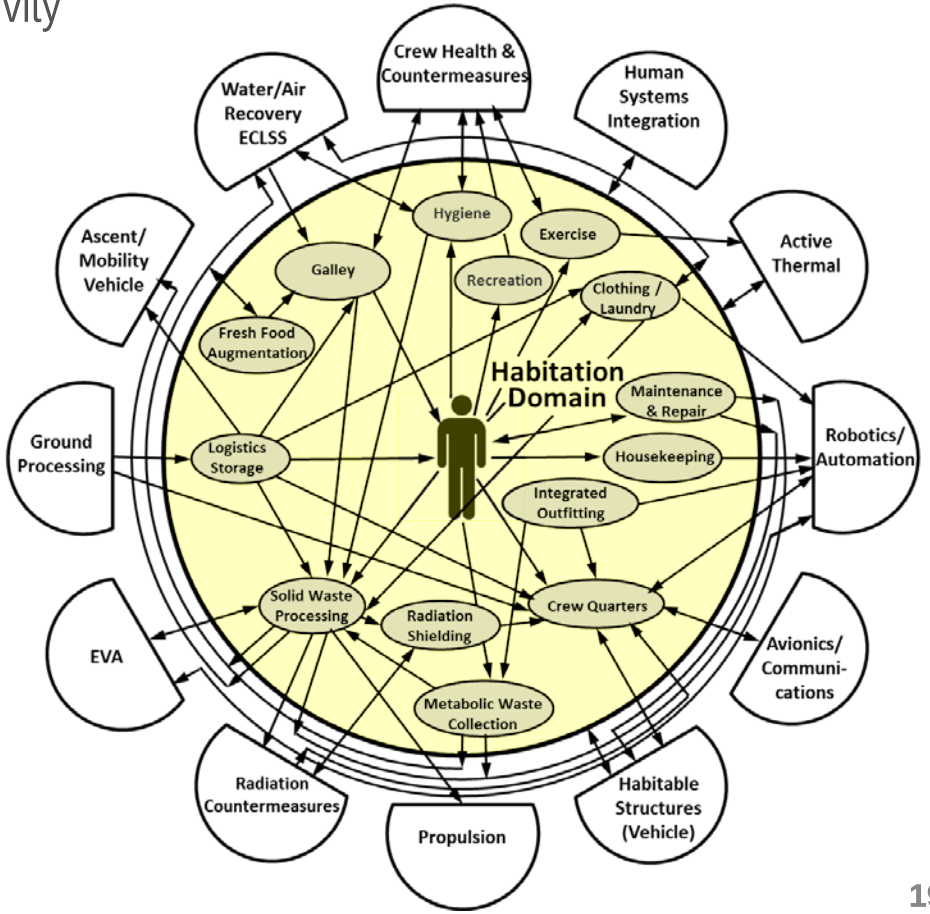
ISS Fine Water Mist Portable Fire Extinguisher Engineering Unit

- 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**
  - Hab Sys Interior Architecture
  - Human Systems Integration

  Habitation systems performance, Human Factors Analysis

- **Habitable Structures**
  - Vehicle Structure
  - Crew Structures

  Prime structures, secondary structures

  Crew Quarters, Waste and Hygiene Compartment, Galley, Restraints & Mobility Aids

- **Integrated Outfitting**
  - Lighting-vehicle
  - Acoustic Control
  - Odor Control
  - Radiation Protection

  Fans, dampening, adsorption

- **Housekeeping**
  - Cleaning
  - Trash Management

  Wipes, cleaners, vacuum

  Trash stowage/monitoring, processing, jettison, ECLSS ORU disposal, biological waste stowage

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

  Tools, tool caddies and stowage, power provisions, portable lighting

  Basic kits, specialized kits, L2L kits, additive manufacturing

- **Logistics**
  - Stowage Systems
  - Crew Provisions

  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

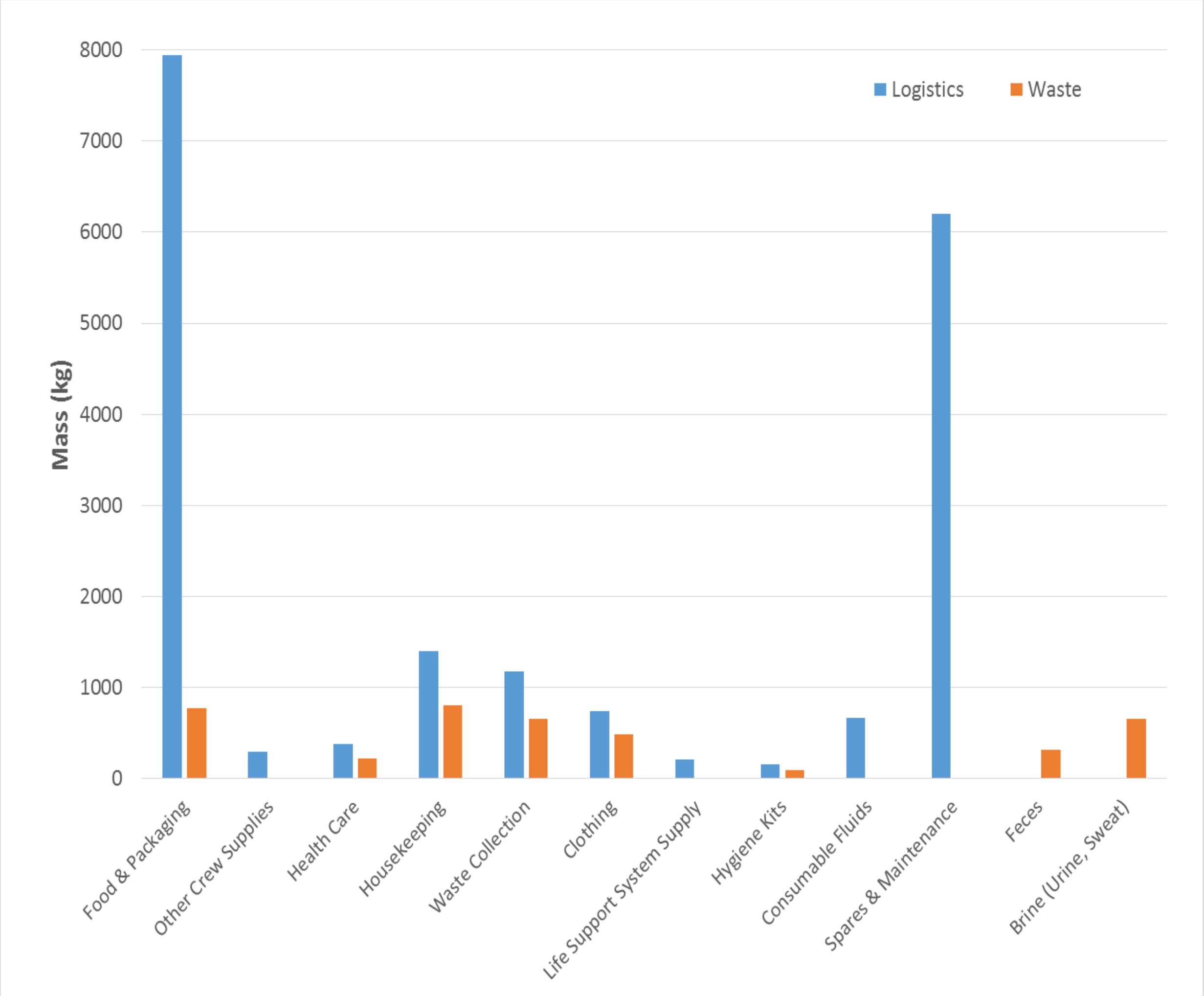
Used wipes and clothing

Reduce
Reuse
Recycle!

Cargo Transfer Bags

Logistics and Waste Masses

1,000 day mission w/ crew of 4



Crew Provisions/Fluids

Item	Mass (kg.)	
	600-Day Transit	400-Day Mars Vicinity
Food	4,394	2,930
Personal Stowage	200	-
Operational Supplies	100	-
Personal Hygiene Kit	29	22
Hygiene Consumables	190	126
Healthcare Consumables	216	144
Wipes & Towels	468	312
Trash Bags	26	18
Clothes	528	352
Waste Collection: Fecal Canisters	540	360
Waste Collection: Urine Prefilters	150	100
Total Mass	***6,845***	***4,367***

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

Brown = Logistics Reduction goals

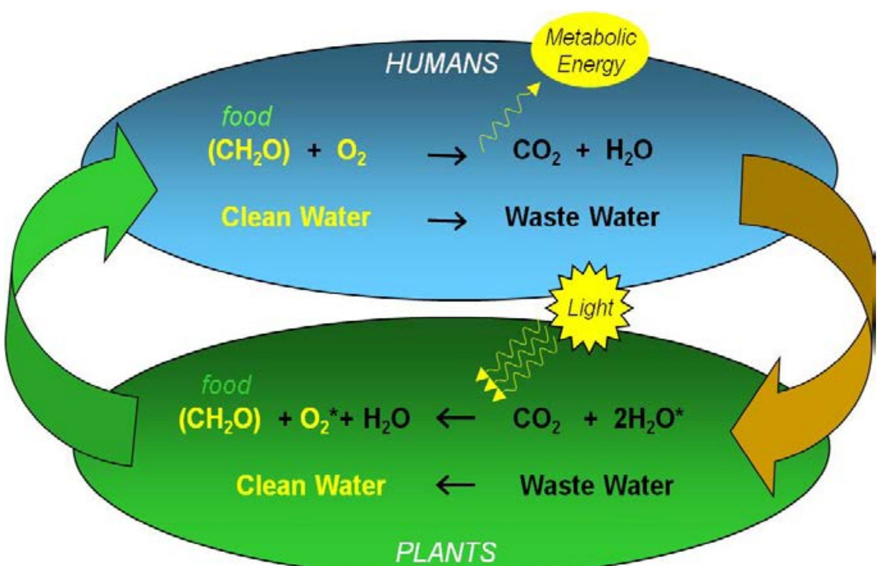
- Automatic and autonomous logistics tracking to reduce crew time and support crew autonomy during time delay missions
- Common waste collection hardware
- Reduce fecal consumable mass and volume <0.1 kg/crew-day
- Reduce packaging material mass and volume
- Reuse or repurpose logistical packaging for 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

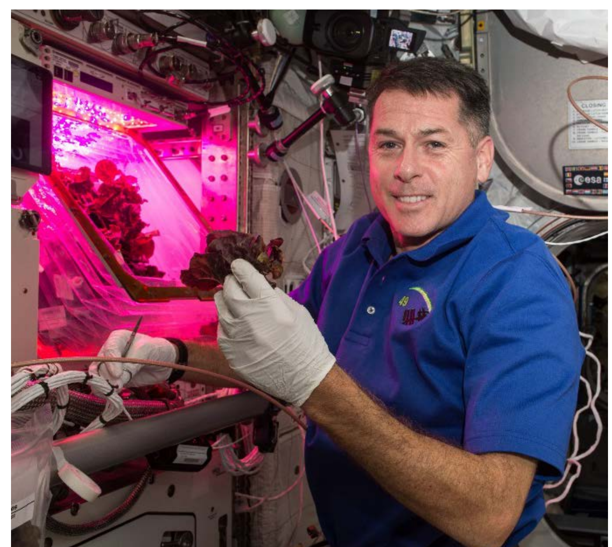
Heat Melt Compactor

Advanced Clothing Systems

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





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.

Year	Titles of Subtopics from Past Solicitations	# of Awards
2012 2013	H3.01 Atmosphere Revitalization H3.02 Environmental Monitoring & Fire Protection for Spacecraft Autonomy H3.03 Crew Accommodations and Water Recovery H3.04 Thermal Control Systems	12 Phase I 5 Phase II
2014	H3.01 Thermal Control for Future Human Exploration Vehicles H3.02 Atmosphere Revitalization and Fire Recovery H3.03 Human Accommodations and Habitation Systems H3.04 Treatment Technologies and Process Monitoring for Water Recovery	18 Phase I 6 Phase II
2015	H3.01 Environmental Monitoring H3.02 Bioregenerative Technologies H3.03 Spacecraft Cabin Atmospheric Quality and Thermal Management	14 Phase I 5 Phase II
2016	H3.01 Environmental Monitoring H3.02 Environmental Control and Life Support for Spacecraft and Habitats	11 Phase I 4 Phase II
2017	H3.01 Habitat Outfitting H3.02 Environmental Monitoring H3.03 Environmental Control and Life Support H3.04 Logistics Reduction	12 Phase I

Summary: Deep Space Habitation Systems Objectives

Habitation Systems Elements	TODAY ISS	FUTURE Deep Space
LIFE SUPPORT Atmosphere Management, Water Management, Waste Management	42% O_2 Recovery from CO_2 90% H_2O Recovery < 6 mo mean time before failure (for some components)	75%+ O_2 Recovery from CO_2 98%+ H_2O Recovery >30 mo mean time before failure
ENVIRONMENTAL MONITORING Pressure O_2 & N_2, Moisture, Particles, Microbes, Chemicals, Sound	Limited, crew-intensive on-board capability Reliance on sample return to Earth for analysis	On-board analysis capability with no sample return Identify and quantify species and organisms in air & water
FIRE SAFETY Detection, Protection, Suppression, Cleanup	Large CO_2 Suppressant Tanks 2-cartridge mask Obsolete combustion prod. sensor Only depress/repress clean-up	Water Mist portable fire extinguisher Single Cartridge Mask Exploration combustion product monitor Smoke eater
HABITATION & LOGISTICS Tracking, Clothing, Packaging, Trash	Manual scans, displaced items Disposable cotton clothing Packaging disposed Bag and discard	Automatic, autonomous RFID Long-wear clothing/laundry 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
  - Schneider, W., et. al. (2016) "NASA Environmental Control and Life Support (ECLS) Technology Development and Maturation for Exploration: 2015 to 2016 Overview", 46th International Conference on Environmental Systems, Paper # ICES-2016-40
  - Anderson, Molly S., et. al. (2017) "NASA Environmental Control and Life Support (ECLS) Technology Development and Maturation for Exploration: 2016 to 2017 Overview", 47th International Conference on Environmental Systems, Paper # ICES-2017-226
  - Anderson, Molly S., Ewert, Michael K., Keener, John F., Wagner, Sandra A. (2015) "Life Support Baseline Values and Assumptions Document" NASA/TP-2015–218570
- Trace Contaminant Exposure Guidelines
  - https://www.nasa.gov/feature/exposure-guidelines-smacs-swegs
  - John T. James and J. Torin McCoy (2008) "Spacecraft Water Exposure Guidelines (SWEGs)", JSC-63414
  - John T. James and Toxicology Group (2008) Spacecraft Maximum Allowable Concentrations for Selected Airborne Contaminants, JSC-20584

Acknowledgements

- Gary Ruff, NASA Glenn Research Center
- Molly Anderson, Mike Ewert and Jim Broyan, NASA Johnson Space Center
- Robyn Gatens and Jitendra Joshi, NASA Headquarters
- Walter Schneider, NASA Marshall Space Flight Center
- Laura Kelsey and Barry Finger, Paragon Space Development Corporation
- William Michalek and Ray Wheeler, Umpqua Research Company

Questions?

In future solicitations we may begin to consider technologies for use during human planetary surface missions