Moon/Mars Life Support Systems – How far along are we?

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Phase 0
Solve exploration mission challenges through research and systems testing on the ISS. Understand if and when lunar resources are available.

Phase 1
Conduct missions in cislunar space; assemble Deep Space Gateway and Deep Space Transport.

Phase 2
Complete Deep Space Transport and conduct Mars verification mission.

Phase 3
Mission to Mars surface.
Concepts for New Vehicles Require New Systems

“Deep Space Gateway” provides a point near the moon to demonstrate capabilities, gather components for a Mars mission, and conduct international lunar activities.

Deep Space Transit demonstrates and practices Mars mission capabilities in Earth-Moon space, and is used to perform first human missions to Mars orbit.
Experience in Closed-Loop Life Support

• Humans need the same things to keep them healthy no matter where they are.
• Design technologies and systems to find the most efficient, cost effective, and reliable way to meet those needs.
• The right answer varies depending on the mission and vehicle.
• Life support systems for long duration missions are very interconnected.
Nearly every function in the system will be updated because of lessons learned in previous spaceflight missions and new technology developments. These will make the crew more self-sufficient for future missions, by recycling more waste materials, and having more information on their own systems.
Current ISS Capabilities and Challenges: Atmosphere Management

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

• Remove CO₂ and contaminants
  – ISS: Regenerative zeolite CDRA, supports ~2.3 mmHg ppCO₂ for 4 crew. MTBF <6 months. Obsolete contaminant sorbents.
  – Challenges: Reliability, ppCO₂ <2 mmHg, commercial sorbents

• Remove humidity
  – ISS: Condensing heat exchangers with anti-microbial hydrophilic coatings requiring periodic dryout, catalyze siloxane compounds.
  – Challenge: Durable, inert, anti-microbial coatings that do not require dry-out

• Supply O₂
  – ISS: Oxygen Generation Assembly (H₂O electrolysis, ambient pressure); high pressure stored O₂ for EVA
  – Challenge: Provide high pressure/high purity O₂ for EVA replenishment & medical use

• Recovery of O₂ from CO₂
  – ISS: Sabatier process reactor, recovers 42% O₂ from CO₂
  – Challenge: >75% recovery of O₂ from CO₂
Current ISS Capabilities and Challenges: Water Management

• Water Storage & biocide
  – ISS: Bellows tanks, collapsible bags, iodine for microbial control
  – Challenges: Common biocide (silver) that does not need to be removed prior to crew consumption; dormancy

• Urine Processing
  – ISS: Urine Processing Assembly (vapor compression distillation), currently recovers 80% (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: Reduced expendables; reliability
Current ISS Capabilities and Challenges: Waste Management

- **Logistical Waste (packaging, containers, etc.)**
  - ISS: Gather & store; dispose (in re-entry craft)
  - Challenge: Reduce &/or repurpose

- **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, potential resource recovery, volume and expendable reduction
Current ISS Capabilities and Challenges:
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 organic, inorganic compounds.

• **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 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; Combustion Product Analyzer (CSA-CP, parts now obsolete)
  - Challenges: On-board trace gas capability that does not rely on sample return, optical targeted gas analyzer

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

• **Acoustic**
  - SOA: Hand held sound level meter, manual crew assays
  - Challenge: Continuous acoustic monitoring with alerting
Brine Water Processing to Recover More Water

1. Brine
2. IWP Brine Processing Bag
3. Water
4. Safe Disposal
Air Revitalization to Recover More Oxygen

Electrolysis Reaction

\[ 2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2 + \text{O}_2 \]

Sabatier Reaction

\[ \text{CO}_2 + 4 \text{H}_2 \rightarrow 2 \text{H}_2\text{O} + \text{CH}_4 \]

Conclusion:

• It takes 4 \text{H}_2 to make 2 \text{H}_2\text{O}, but you only get 2 \text{H}_2 back when you split \text{H}_2\text{O} to make \text{O}_2.
• You can’t repeat the cycle 100% because you lost \text{H}_2, so you have to vent unreacted \text{CO}_2 which wastes oxygen.

How can we recycle more? What challenges does that create?

Carbon Formation from Methane

\[ \text{CH}_4 \rightarrow \text{C} + 2 \text{H}_2 \]

Bosch Reactions

\[ \text{CO}_2 + 2 \text{H}_2 \rightarrow 2 \text{H}_2\text{O} + \text{C} \]
Air Revitalization to Recover More Oxygen

Electrolysis Reaction
2 H₂O $\rightarrow$ 2 H₂ + O₂

Sabatier Reaction
CO₂ + 4 H₂ $\rightarrow$ 2 H₂O + CH₄

Conclusion:
- It takes 4 H₂ to make 2 H₂O, but you only get 2 H₂ back when you split H₂O to make O₂.
- You can’t repeat the cycle 100% because you lost H₂, so you have to vent unreacted CO₂ which wastes oxygen.

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Carbon Formation from Methane
CH₄ $\rightarrow$ C + 2 H₂

Bosch Reactions
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Microgravity Science Can Lead to Innovation

Each movie has the same inlet flow: Alternating pulses of water and air

Surface tension vs gravity!
Steps from Science to Design
Condensing Heat Exchanger

Spaceflight condensing heat exchangers:
• Use hydrophilic coating to keep water attached to surface by surface tension, but coating wears out over time
• Suck the water through holes in the heat exchanger
• Do not let water droplets get carried into the air revitalization system!

What if you didn’t have to worry about where the droplets of water went?
ISS stores trash it burns in Earth’s atmosphere when cargo vehicles leave.
Logistics & Waste Processing

ISS stores trash it burns in Earth’s atmosphere when cargo vehicles leave

What should we do for the future?
• Drying?
• Compaction?
• Destruction?
Life Support in Short Duration Vehicles

Orion Suit Loop: Shared life support in cabin air, or spacesuits to survive 6-day emergency return home if the vehicle cabin loses pressure
Pressurized Rovers

• Even small,
## When Will We Be Ready?

### Phase 0 Exploration ECLSS Integrated Demonstration

**2016**
- New sorbents for ISS system
- Alternate zeolite concepts
- Thermal amines
- Other technologies
- Mixture of ground test
- Early ISS flight demo

**2017**
- **Atmosphere Management**
  - Gas exchange and removal
- **CO₂ Removal**
  - Methane Pyrolysis Ground Test & early flight demo
- **Condensing HX**
  - CHX development/downselect
- **CO₂ Reduction**
  - Alt tech dev Ph I
  - Alt Tech Dev Phase II Prototypes
- **O₂ Generation & High Pressure O₂**
  - ISS OGA upgrade ground test

**2018**
- **Urine**
  - ISS UPA performance & new pump
- **Brine**
  - Design, Build, Fly BPA Demo
  - Improved catalyst development
- **Water**
  - RO Membrane Development
- **Biocide**
  - Silver Biocide Development
- **Metabolic Waste**
  - Universal Waste Management System ISS Demo
- **Trash**
  - Fecal processing (SBIR)
  - Heat Melt Compactor or Trash to Gas
- **Water & Microbial**
  - Water Monitoring suite early ISS demo

**2019**
- **Flight Demo Build**
  - ISS OGA Upgrades
  - ISS Water Processor upgrade catalytic reactor

**2020**
- **Flight Demo Build**
  - HPO₂ development

**2021**
- **Design & build demo**

**2022**
- **Transition to fully on-orbit and away from grab sample return**

**2023**
- ISS UPA further improvements
- Long duration Brine Flight Test
- ISS Water Processor upgrade catalytic reactor
- RO Membrane Dev
- Silver biocide on orbit injection develop & test
- Universal Waste Management System ISS Demo
- UWMS ISS demo extension
- Fecal processing follow-on
- Heat Melt Compactor or Trash to Gas

**2024**
- Water & Microbial Monitors Tech Demo Design/Build/Test
Human Space Exploration Phases From ISS to the Surface of Mars as of November 2016

**Today**

Phase 0: Exploration Systems

*Testing on ISS*

Phase 1: *Cislunar Flight Testing* of Exploration Systems

Phase 2: *Cislunar Validation* of Exploration Capability

Asteroid Redirect-Crewed Mission Marks Move from Phase 1 to Phase 2

Ends with testing, research and demos complete*

Ends with one year crewed Mars-class shakedown cruise

Mid-2020s

**Phase 3:** Crewed Missions Beyond Earth-Moon System

**Phase 4a:** Development and robotic preparatory missions

**Phase 4b:** Mars Human Landing Missions

2030

*There are several other considerations for ISS end-of-life*
Earth has Buffers
Earth = 510 km² surface area, 2m tall
1 x 1015 m³ shared by 7.5 Billion People → 136,000 m³ per person on Earth
(Not including ocean depths or atmosphere thickness)

Future spacecraft volume ~25 m³/person

Changes are felt very fast!
Processing equipment must be small!
How do we take advantage of biological processes in microgravity?
How do we take advantage of biological processes in microgravity?

Figure 2. Biological reactions occurring at the surface of the membrane and in the biofilm.
University of Arizona Lunar Greenhouse
Eu:CROPIS: Tomatenzucht im Weltall

Donnerstag, 24. April 2014
New Technology, New Information, New Questions
One Step at a Time!
Questions?