NASA Environmental Control and Life Support Technology Development and Maturation for Exploration: 2021 to 2022

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Agenda

- Capability alignments to NASA objectives
- ECLSS-CHP capabilities and mission drivers
- ECLSS envisioned future and exploration ECLSS
- Technology development progress toward envisioned futures
- Validating performance and reliability
- Summary

Capabilities Alignment to NASA Objectives

- ECLSS-CHP technology development has been capability focused for several years
  - Approaching technology development using capability needs and gaps is robust way supporting higher level NASA goals
- NASA released 50 blueprint objectives in May 2022 (Transportation-Habitation, Lunar and Mars Infrastructure, Operations, and Science)
  - Most ECLSS-CHP capabilities directly align to four transportation-habitation blueprint objectives (TH-3, TH-4, TH-7, TH-8)
- NASA's Space Technology Mission Directorate released its strategic framework of 4 'Thrusts' (Go, Land, Live, and Explore) in January 2022
  - Most ECLSS-CHP capabilities directly align to the Live thrust

What are ECLSS-CHP Systems?

- The systems and technologies that keep our astronauts healthy and productive while living and working in space
- 9 Capability Areas are further decomposed to capabilities and sub-capabilities to define gaps

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS (ECLSS)

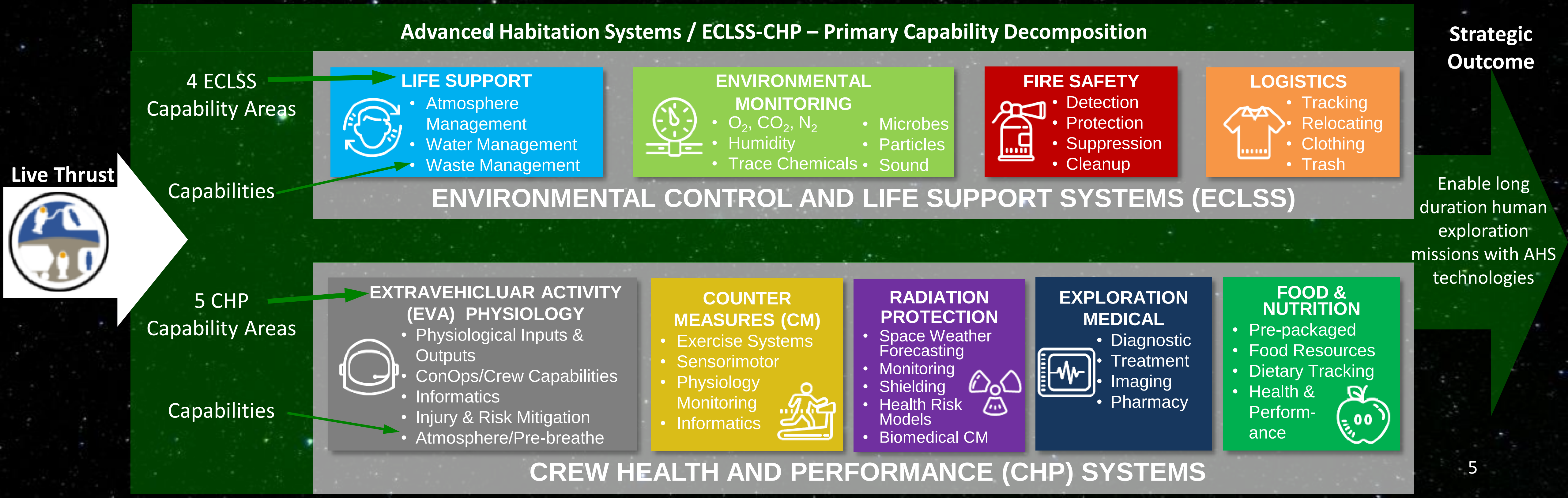
- Life Support
- Environmental Monitoring
- Fire Safety
- Logistics

CREW HEALTH AND PERFORMANCE SYSTEMS (CHP)

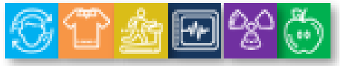
- Spacesuit Physiology
- Crew Health Countermeasures
- Radiation Protection
- Exploration Medical
- Food and Nutrition

ECLSS-CHP SCLT Capability Areas and Capabilities

- Capability areas are divided into 25 technology development roadmaps
  - Roadmaps capture development, tech demos, validation, reliably testing and mission infusion targets
  - Roadmaps are directorate (e.g. ESDMD, SOMD, STMD) and program (EC, ISS, HRP, GCD) agnostic
- ECLSS-CHP has 76 ESDMD Capability Integration Team (CIT) recognized gaps plus numerous related gaps

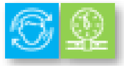


Mission Characteristics Influence on Capability Areas (1/2)

Mission characteristics the drive capability needs	Lunar Surface	Mars Transit	Mars Surface	Most affected capability areas
Mission Duration				
Crew consumables and waste generation are fixed kg/d	I	C	C	
Duration needs to be long enough to offset system closure mass	S	C	S	
Crew safety and mission success goals				
Longer duration increases risk	I	C	C	
Increased Probability of Sufficiency (POS) - increase spares & certainly of spares life	I	C	S	
Increased ability for Earth independent diagnostics and repair	I	C	C	
Microgravity vs Surface				
µg adds complexity to address liquid-gas-solids separation and other phenomena	I	S	N/A	
Frequent planned EVAs				
Loss of water and oxygen (less available for recycling)	S	N/A	S	
Increased crew fatigue and injury risk	S	N/A	S	
Reduced cabin pressure to reduce pre-breath time, impacts 14.7 psia/23% O_2 systems	S	I	S	

I = influences
S = strong
C = critical

Mission Characteristics Influence on Capability Areas (2/2)

Mission characteristics the drive capability needs	Lunar Surface	Mars Transit	Mars Surface	Most affected capability areas
Number of crew members				
Crew consumables are fixed kg/d	I	I	I	
Planetary protection and science integrity				
Monitoring/sterilization/treatment/containment adds mass	I	S	C	
Long uncrewed periods				
Adds mass to prevent or recover from microbial upset	S	C	I	
Importance of habitat autonomy and robotic caretaking increases	I	S	I	
Availability of In-Situ Resource Utilization (ISRU) products (water and gases)				
Influences recycling break even point, possible ISRU-ECLS sensor and processor commonalities	S	N/A	S	

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Capability Gaps Definition

CAPABILITY | The ability to meet an exploration objective through Architecture, Engineering, Development, Technology, Operations or Research for a given set of constraints and level of risk.

Current Capabilities (state of the art)

Capabilities we have today, supporting or available for human or robotic missions….

THE DIFFERENCE IS THE

GAP

Envisioned Future (Future Needed Capabilities)

Anticipated future capabilities based)on future mission architectures and agency strategic planning

GAP CLOSURE APPROACH

- Policy Decisions
- Operational Concepts
- Architecture Changes
- Scientific Research (Knowledge)
- Technology
- Development
- Engineering

TEST / Demo LOCATION

- Mars
- Lunar
- Gateway/Cislunar
- ISS/LEO
- Ground Activity

GAP CLOSURE MILESTONE

- Modeling and Analysis
- Ground Simulation
- In-Space Demo
- Long-term Testing

OUTCOMES

- Updated Standards
- Enable Architecture
- Updated Procedures
- Crew Health Countermeasures
- TRL Advancement
- Technology Infusion
- Reliable Exploration ECLSS-CHP

ECLSS Envisioned Futures (CHP covered in ICES-2022-299)

(Mission need)
- L = Lunar surface
- T = Transit to Mars
- M = Mars surface

LIFE SUPPORT

- Reliable long-duration life support, >800 days w/o resupply (L,T,M)
- >20% reduction in spares and installed mass (T)
- Repeated missions with >9 months dormancy (L,T,M)
- >75% oxygen recovery at 2 mm-Hg CO_2 (T)
- High pressure oxygen recharge for EVA (L,M)
- >98% water recovery (L,T,M)
- Remove respirable lunar and Mars dust (L,M)
- Planetary protection compatible ECLSS venting (M)

FIRE SAFETY

- Test-verified partial gravity flammability characteristics and countermeasures (L,M)
- ECLSS compatible fire suppression (L,T,M)
- Reduce post fire clean-up time (L,T,M)
- Common fire safety strategy across element architectures (L,T,M)

ENVIRONMENTAL MONITORING

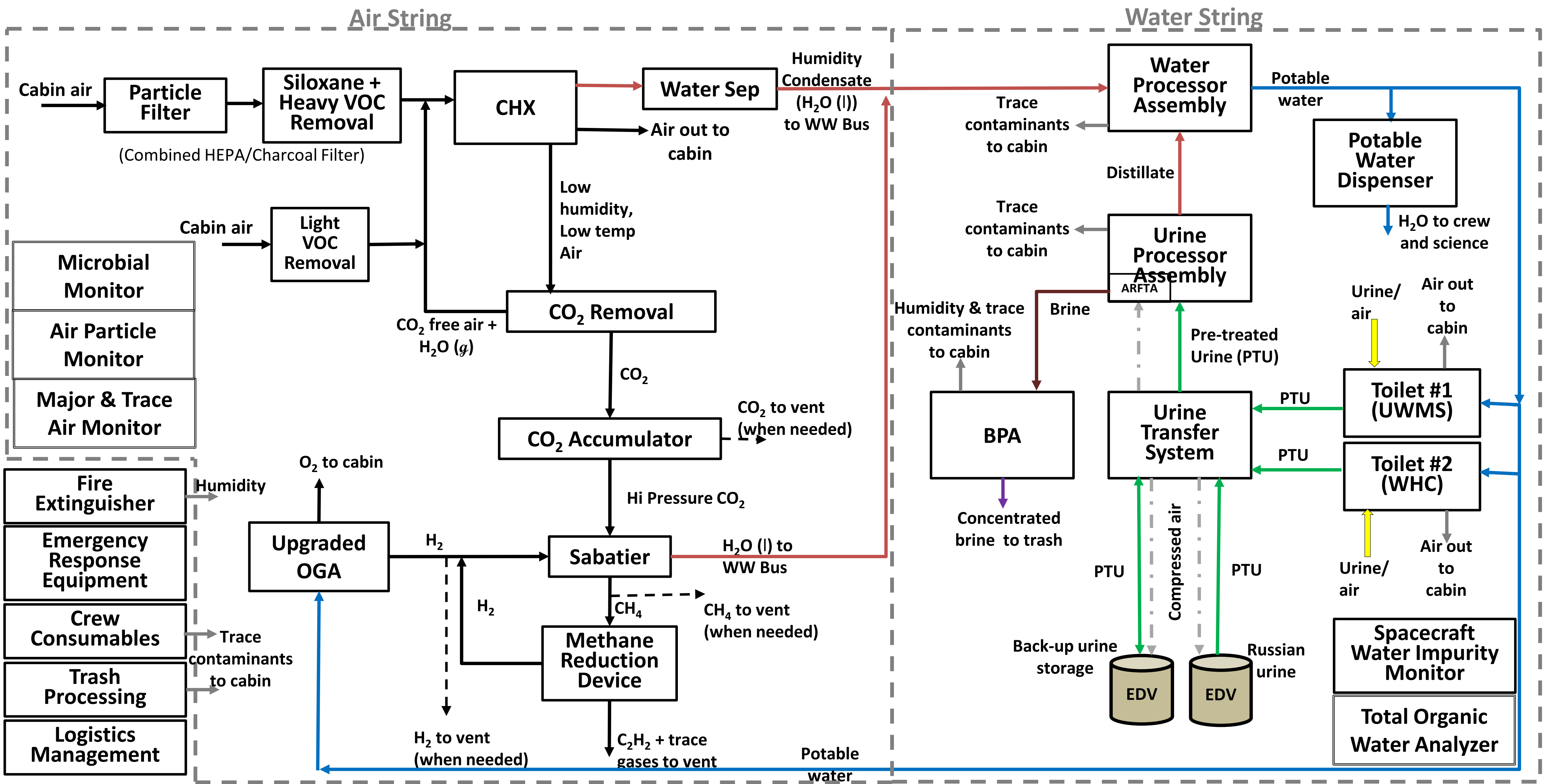
- Identify and quantify chemical (>12 water, >33 air) and microbial species in-flight with out sample return (L,T,M)
- Ability to detect unknown constituents (T,M)
- Distinguish between fire, habitat dust, and surface dust particles (L,M)
- Support forward and backward planetary protection detection (both microbial and non-DNA techniques) (M)

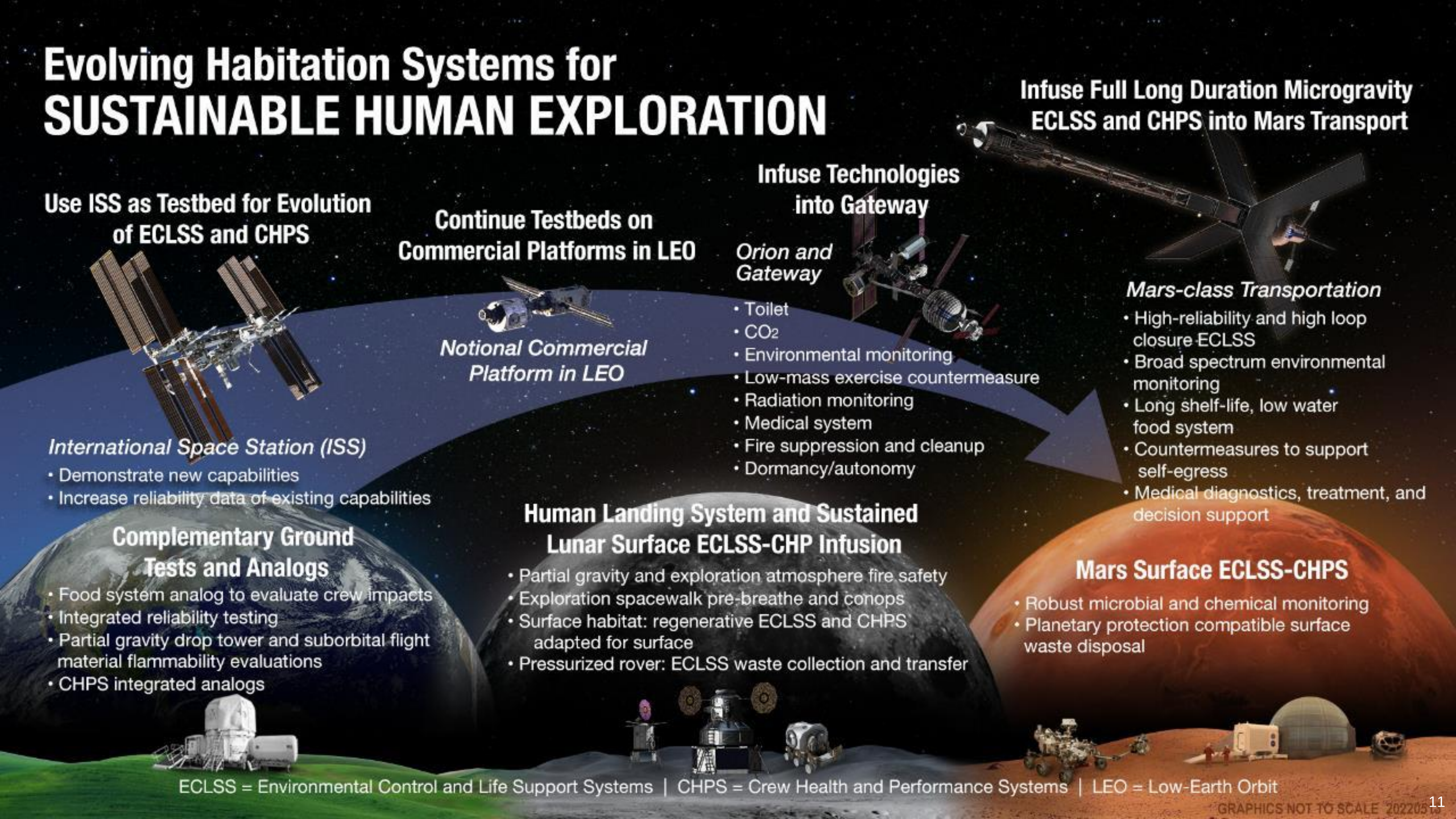
LOGISTICS

- Jettison >90% of trash mass during Mars transit (T)
- Mars trash disposal compatible with planetary protection (M)
- In-flight autonomous logistics (L,T,M)
- Reducing clothing and wipes mass by >50% (L,T,M)
- Clothing flammability (and other non-metallics) >36% O_2 (L,M)

Exploration ECLSS on ISS

Getting to 98% water & >75% oxygen recovery requires integration and verification of many systems




Evolving Habitation Systems for
SUSTAINABLE HUMAN EXPLORATION
Use ISS as Testbed for Evolution of ECLSS and CHPS
Continue Testbeds on Commercial Platforms in LEO
Infuse Technologies into Gateway
Infuse Full Long Duration Microgravity ECLSS and CHPS into Mars Transport
International Space Station (ISS)
• Demonstrate new capabilities
• Increase reliability data of existing capabilities
Notional Commercial Platform in LEO
Orion and Gateway
• Toilet
• CO_2
• Environmental monitoring
• Low-mass exercise countermeasure
• Radiation monitoring
• Medical system
• Fire suppression and cleanup
• Dormancy/autonomy
Mars-class Transportation
• High-reliability and high loop closure ECLSS
• Broad spectrum environmental monitoring
• Long shelf-life, low water food system
• Countermeasures to support self-egress
• Medical diagnostics, treatment, and decision support
Complementary Ground Tests and Analogs
• Food system analog to evaluate crew impacts
• Integrated reliability testing
• Partial gravity drop tower and suborbital flight material flammability evaluations
• CHPS integrated analogs
Human Landing System and Sustained Lunar Surface ECLSS-CHP Infusion
• Partial gravity and exploration atmosphere fire safety
• Exploration spacewalk pre-breathe and conops
• Surface habitat: regenerative ECLSS and CHPS adapted for surface
• Pressurized rover: ECLSS waste collection and transfer
Mars Surface ECLSS-CHPS
• Robust microbial and chemical monitoring
• Planetary protection compatible surface waste disposal
ECLSS = Environmental Control and Life Support Systems | CHPS = Crew Health and Performance Systems | LEO = Low-Earth Orbit
GRAPHICS NOT TO SCALE

Life Support – Atmosphere Management

LIFE SUPPORT

Reducing resupply oxygen from increased metabolic carbon dioxide recycling, support EVA high pressure and medical needs

- **Reliable long-duration life support with Earth independent diagnostics and repair (L,T,M)**
- **>20% reduction in spares and installed mass (T)**
- **Enable single missions >800 days w/o resupply (T)**
- **Repeated missions with >9 months dormancy (L,T,M)**
- **>75% oxygen recovery at 2 mm-Hg CO_2 (T)**
- **High pressure oxygen recharge for EVA (L,M)**
- **Remove respirable lunar and Mars dust (L,M)**
- **Planetary protection compatible ECLSS venting (M)**

- Benefit from evaluation 5 CO_2 removal flight demonstrations
- Improved O_2 generation maintenance
- Robust TCCS
- Identified and resulted unexpected integrated chemical interactions with cabin air trace contaminants
- Validated operation

Thermal Amine CO_2 Scrubber

Current Technology

- ~47% of ISS air is currently recycled
- ~Carbon Dioxide Removal Assembly (CDRA)
- Oxygen Generation Assembly (OGA)
- Condensing Heat Exchanger (CHX)
- Trace Contaminate Control System (TCCS)
- HEPA particle filtration

Technology Development and Demonstration

- Long duration reliability testing on ISS & ground
- Thermal Amine CO_2 Scrubber
- 4-bed CO_2 Scrubber
- Ionic Liquid CO_2 Scrubber
- Advanced OGA
- Sabatier 2.0 enhancements (>47%)
- High pressure/purity O_2 for EVA
- On-demand medical O_2
- Long-life condensing heat exchanger
- Methane Pyrolysis and Bosch
- Trace gas catalytic oxidizer upgrades
- Scroll and cyclone particulate filtration

4BedCO_2 Scrubber

Medical Oxygen Generator

Life Support – Water Management

LIFE SUPPORT

Reducing resupply water with increased water recovery

- **Reliable long-duration life support with Earth independent diagnostics and repair (L,T,M)**
- **>20% reduction in spares and installed mass (T)**
- **Enable single missions >800 days w/o resupply (T)**
- **Repeated missions with >9 months dormancy (L,T,M)**

Brine Processor Assembly

Current Technology

- ~93% of ISS water is currently recycled
  - ~100% of humidity condensate
  - ~85% of urine
- Urine Processor Assembly (UPA)
- Water Recovery System (WRS)
- Potable Water Dispenser (PWD)
- Microbial check valves (MCVs)
- Iodine biocide
- Chromic-phosphoric urine pretreatment

Technology Development and Demonstration

- Long duration reliability testing on ISS & ground
- Wetted systems dormancy tolerance and recovery
- Water Processor Assembly (WPA) Upgrades
- UPA Upgrades
- Brine Processor Assembly (BPA)
- Exploration Potable Water Dispenser
- Disinfection development for dormancy
- Partial-g planetary water system

- Demonstrated high level of water recovery
- Identified and resulted unexpected integrated chemical interactions with cabin air trace contaminants
- Safe high quality potable water
- Reliable operation

Exploration Potable Water Dispenser

Urine Processor Assembly Upgraded Distillation Assembly

Life Support – Waste Management

LIFE SUPPORT

Collection, stabilization and drying of waste; lower mass and volume

- **Reliable long-duration life support with Earth independent diagnostics and repair (L,T,M)**
- **>20% reduction in spares and installed mass (T)**
- **Enable single missions >800 days w/o resupply (T)**
- **Repeated missions with >9 months dormancy (L,T,M)**

WHC/UWMS Dual Stall

Current Technology

- Russian commode – frequent component changeout, large mass and volume
- Precise pretreatment allows 85% water recovery in UPA
- No fecal processing

Technology Development and Demonstration

- Universal Waste Management System (UWMS)
- UWMS Alternate Fecal Container to reduce logistics mass
- Fecal drying technologies under development to recover water and reduce logistics mass

UWMS and Acoustic Cover Mockups

- Compact volume and reduced mass toilet
- Provides precise urine pretreatment dose
- Identified acoustic and pre-treatment measurement issues with redesign solutions in-work

UWMS Rigid Fecal Canister (left) and Alternate Fecal Canister (right)

Environmental Monitoring

ENVIRONMENTAL MONITORING

Ensure habitat safe air, water, surfaces without sample return analysis

- **Includes air, water, microbial, particulate, and acoustic monitoring**
- **Identify and quantify chemical (>12 water, >33 air) and microbial species in-flight with out sample return (L,T,M)**
- **Ability to detect unknown constituents (T,M)**
- **Distinguish between fire, habitat dust, and surface dust particles (L,M)**
- **Support forward and backward planetary protection detection (both microbial and non-DNA techniques) (M)**

Airborne Particulate Monitor

Spacecraft Atmospheric Monitor

Current Technology

- Distinct technologies for different types of monitoring
- Major Constituent Analyzer
- Air Quality Monitor
- Potable Water Total Organic Analyzer
- Reliance on return sample and ground analysis

Technology Development and Demonstration

- Long duration reliability testing on ISS
- MinIon-DNA sequencer
- Air and water microbial sequencing sample preparation
- Air Particle Monitor
- Miniature air monitor
- Spacecraft Atmosphere Monitor (SAM)
- Potable Water Total Organic Carbon Analyzer
- Spacecraft Water Impurities Monitor (SWIM)
- Acoustic monitors, low mass acoustic materials, and quiet fan modeling

MinIon/Biomole

Mini-Total Organic Carbon Analyzer

- Long term operation and reliability testing planned
- Developing smaller particulate and TOC
- Developing broad spectrum air and water monitors

Fire Safety

Materials, procedures, and fire safety equipment for ug and partial-g environments

- **Test-verified partial gravity flammability characteristics and countermeasures (L,M)**
- **ECLSS compatible fire suppression (L,T,M)**
- **Reduce post fire clean-up time (L,T,M)**
- **Common fire safety strategy across element architectures (L,T,M)**

Current Technology

- Partial understanding of large ug fire propagation and properties
- Very limited knowledge of partial gravity fire properties
- Obsolete monitoring
- Cleanup by depress/repress
- Limited mask emergency response
- CO2 based fire extinguishers

Technology Development and Demonstration

- Anomaly Gas Analyzer
- Water Spray mist fire extinguisher
- Smoke cleanup device
- Improved realistic fire training
- Saffire VI on Cygnus – ug (varies ~2000-3700 cm^2)
- CLPS partial-g (~150 cm^2)
- Blue Origin partial-g (~40 cm^2)
- Partial gravity drop tower spin test and development of non-spin capability

ISS Emergency Mask Donning Practice

Water Spray Mist Fire Extinguishers

Anomaly Gas Analyzer

Saffire IV ug Material Tests (planned)

Partial-g Spin Drop Tower Test Rig

- Common emergency response equipment across vehicles

Logistics Reduction

Logistics Reduction

In-flight trash stabilization/disposal, flame resistant crew clothing, and autonomous logistics

- **Jettison >90% of trash mass during Mars transit (T)**
- **Mars trash disposal compatible with planetary protection (M)**
- **In-flight autonomous logistics (L,T,M)**
- **Reducing clothing and wipes mass by >50% (L,T,M)**
- **Clothing flammability (and other non-metallics) >36% O2 (L,M)**

REALM-1 Fixed Reader

REALM-2 Mobile Reader on Astrobee

REALM Smart Drawer Tag

Current Technology

- Trash removed from the space station by resupply vehicles
- Manual bar code scanning with partial implementation of RFID automatic reading in 3 modules
- Flammable crew clothing
- Disposable Cargo Transfer Bag (MCTB) usage

- Improved logistics localization and crew time savings
- Zero trash logistics outfitting
- Reduced trash volume and stability improves habitability

Technology Development and Demonstration

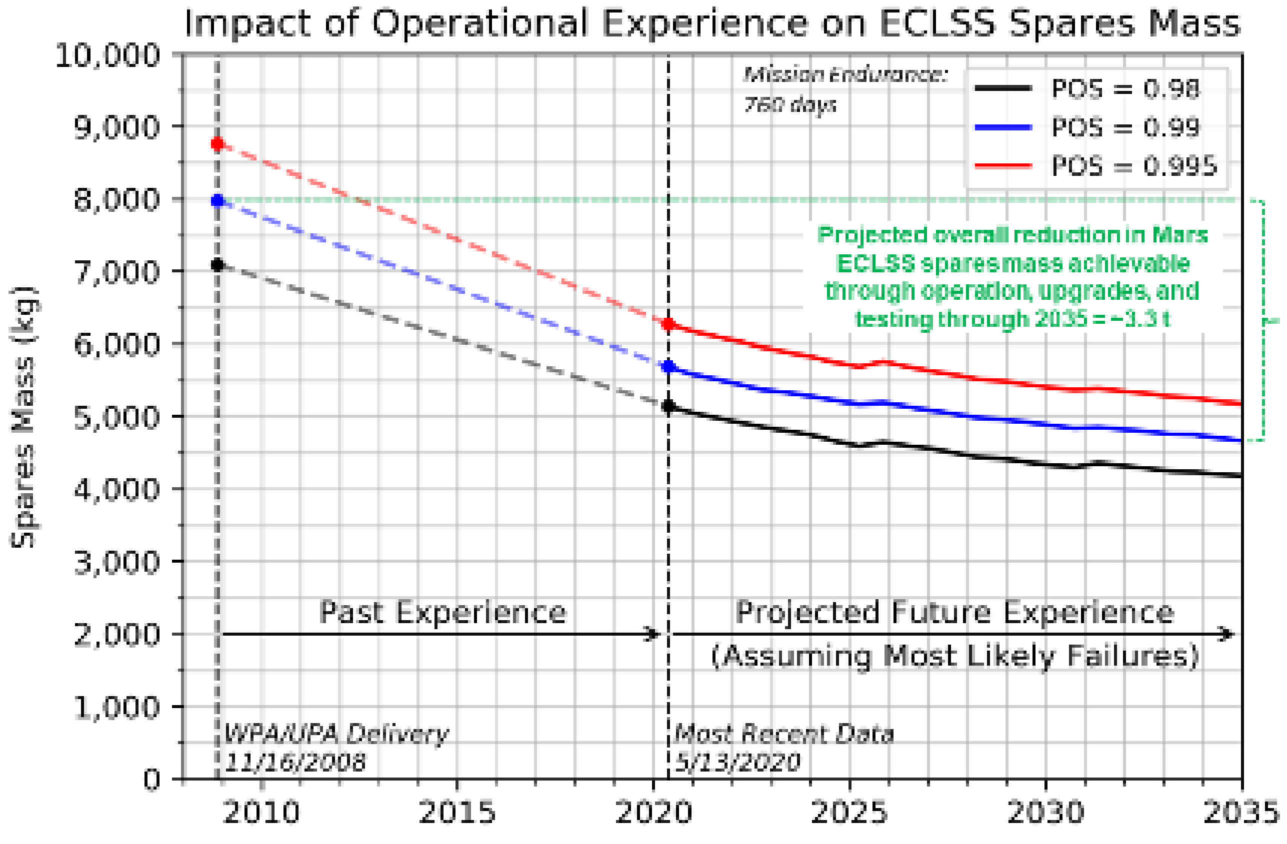
- Trash Compactor Processing System (TCPS)
- Trash-to-gas / OSCAR
- RFID Enabled Autonomous Logistics Management (REALM)
- Multipurpose Cargo Transfer Bag (MCTB) usage
- Long wear clothing / laundry
- In-flight disinfectant solution generation for reusable wipes
- ISS Bishop airlock jettison bag
- Exploration trash jettison trade study
- Lunar vacuum cleaner testing

MCTB as cargo bag

MCTBs deployed to adsorb treadmill noise

TCPS compacted trash tile

Long-term Test Verified ECLSS is Critical for Mars Reduces Mass and Improves Crew Safety



*ECLSS spares allocated to achieve a **reasonable range** of Probability of Sufficient (POS) spares for a **760-day Mars-class mission** using initial, current, and projected future failure rate estimates.*

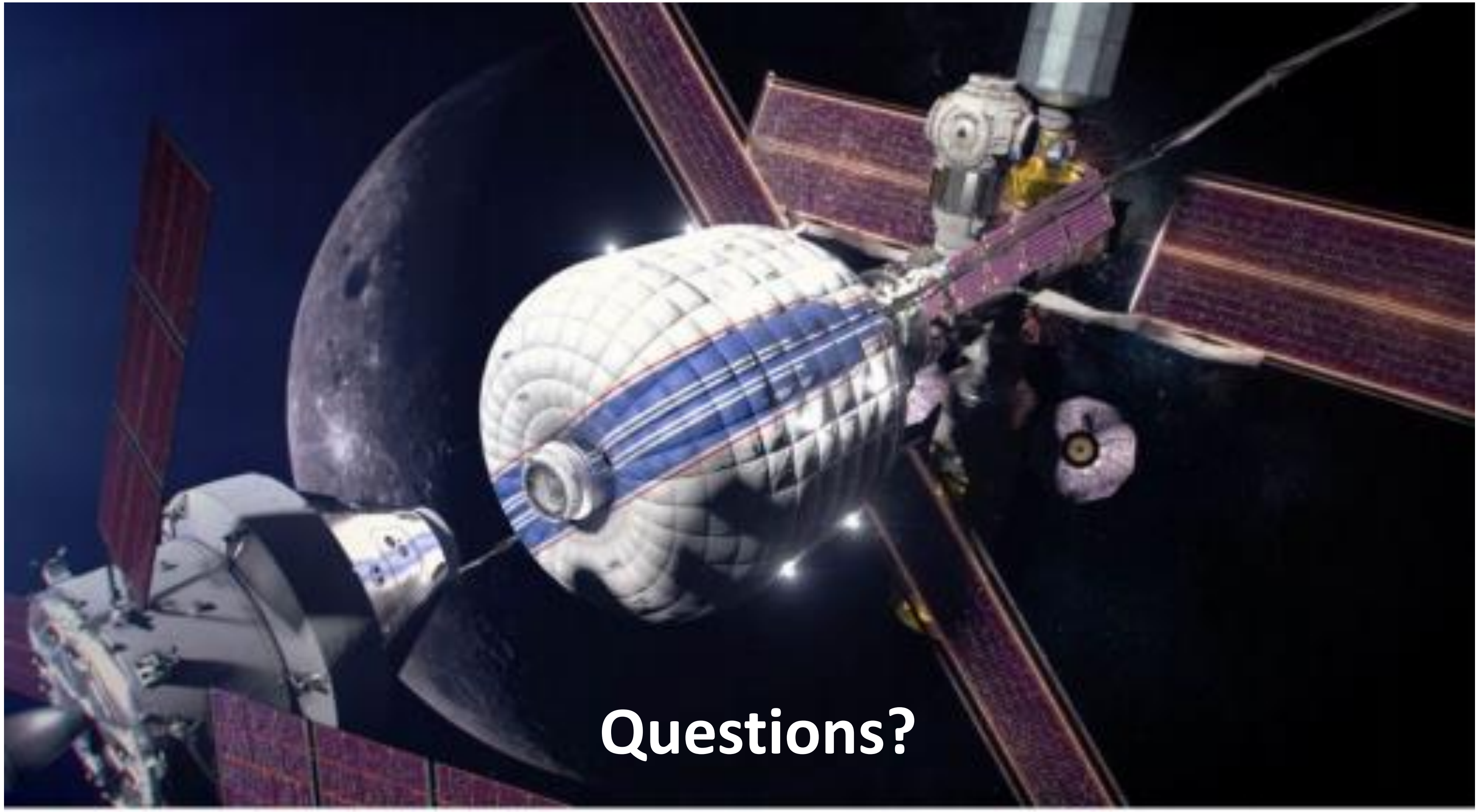
- **Failure rates cannot be measured directly**
- **Must be statistically estimated from test & operational data**
  - **ISS experience shows that initial failure rate estimates are often incorrect, sometimes by >4x**
  - **ISS flight experience has been extremely valuable, providing data to refine failure rate estimates**
    - 30% reduction in spares mass
    - Improved crew safety via identification and mitigation of hidden risk from underestimated failure rates (too low a spares mass allocation or taking the wrong complement of spares)

Open loop ECLSS for 4 Crew on round trip Mars mission (860 days) requires:

- **~16,500 kg water**
- **~3,300 kg oxygen**
- **~ 6,000 kg food (@25% hydration)**
- **Does not include tankage, packaging and structure**

Summary

- The interactions of air, water, crew consumables, and crew in a closed loop habitat are chemically and physically complex and understanding issues evolves over time
- Reducing spares mass with reliability testing and CO_2 reduction/reduced launched food water content are the largest knobs to turn to reduce Mars Transit departure mass
- Test verified ECLSS-CHP systems requires many years of ground and LEO operation
  - Systems fail and interact in unexpected ways
  - New failure modes still being identified after 10+ years of operational time
- Long term NASA ECLSS-CHP investments have dramatically improved loop closure, resolved unexpected performance issues, and is prepared for long term reliability testing
- It is possible to on-ramp new ECLSS technologies, but it requires significant test verified performance and understanding of interactions across the habitat


Questions?

ECLSS-CHP Envisioned Future Decomposition by Capability Area

(only a subset of the 77 gaps listed)

(Mission need)
- L = Lunar surface
- T = Transit to Mars
- M = Mars surface

LIFE SUPPORT

- Reliable long-duration life support with Earth independent diagnostics and repair (L,T,M)
- >20% reduction in spares and installed mass (T)
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- Clothing flammability (and other non-metallics) >36% O2 (L,M)

SPACESUIT PHYSIOLOGY

- 100% of tasks within human performance (L,T,M)
- Predict and mitigate decompression sickness (L,M)
- Predict and mitigate of suit or EVA injury (L,M)
- 6 Major physiological informatics parameters provided in-suit to enable real time self assessment or loss of communication areas (L,M)

COUNTER-MEASURES

- Reduce mass and volume (L,T,M)
- Maintain/monitor fitness in-flight to enable unassisted landing egress & EVA (L,T,M)
- Validated lunar and Mars fitness standards (L,M)

RADIATION PROTECTION

- 24-hr prediction of solar storm duration and intensity to >90% (L,T,M)
- High energy neutron detectors (L,T,M)
- Earth independent monitoring/forecasting (T,M)
- GCR shielding (T,M)

EXPLORATION MEDICAL

- In-flight diagnostics and treatment for 100 of 120 medical risk conditions (L,T,M)
- Autonomous medical skill and & decision support systems (T, M)

FOOD & NUTRITION

- 100% of nutrient stability >5-year shelf life (T,M)
- Food acceptability >90% (L,T,M)
- <30% launched water content (T,M)
- Exploration counter-measure in-flight nutrition intake monitoring (L,T,M)

ECLSS-CHP State-of-the-Art by Capability Area

LIFE SUPPORT

- ISS life support demonstrations have identified required system reliability issues – fixes in work
- ~21,700 kg spares + food, 4 crew x 860days x Probability of Sufficiency (POS)=0.99
- Resupply every 2-6 months
- Nearly uninterrupted use of wetted systems
- ~47% oxygen recovery at 2 mm-Hg CO_2
- No in-flight EVA oxygen recharge capability
- ~93% water recovery
- HEPA filters require frequent manual cleaning

ENVIRONMENTAL MONITORING

- Detailed gas/water chemical, microbial identification, and particle analysis only with samples returned to ground
- Major air constituents & limited targeted trace gases in flight
- Water analysis limited to total organic carbon
- Culture based microbial sample return; DNA sequencing limited to surface microbes
- Limited particle measurement capability demonstrated
- Mass intensive passive acoustic adsorption/damping

FIRE SAFETY

- Partial understanding of large ug fire propagation and properties
- Very limited knowledge of partial gravity fire properties
- Obsolete monitoring
- Cleanup by depress/repress
- Limited mask emergency response
- CO_2 based fire extinguishers

LOGISTICS

- Manual trash compaction, short storage time, module level jettison only
- No planetary protection compliance for waste disposal
- Manual & limited In-flight autonomous logistics tracking
- Disposable & flammable clothing, towels, & wipes

SPACESUIT PHYSIOLOGY

- Physiological inputs/outputs adequately known for ISS EVA only
- Only limited ground communicated informatics provided to EVA crew
- Ground, ISS, and Apollo suit injuries occur (27 injury mechanisms identified)
- Prebreath for 14.7 and 10.2 psia only

COUNTER-MEASURES

- 3+ large devices, large mass
- Returning crew egress from landing vehicle requires ground team assistance
- Exercise planning and monitoring via ground
- Limited sensorimotor countermeasures

RADIATION PROTECTION

- Mature shielding design tools
- Reconfigurable SPE shielding & limited GCR shielding
- Crew radiation monitoring
- Short term space weather using earth centric assets

EXPLORATION MEDICAL

- Evacuate <8 hrs
- Resupply 2-3 months
- Limited in-flight diagnostic, treatment
- Ground medical data & decision support systems

FOOD & NUTRITION

- ~1.5 year shelf life, fresh food resupply every 2-3 months
- Only ~215 standard food items, µg plant experiments
- ~47% launched water content
- In-flight nutrient intake monitoring in development