



Advanced Habitation Systems (AHS) Overview

(Environmental Control and Life
Support Systems – Crew Health and Performance
System Capability Leadership Team: ECLSS-CHP SCLT)

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Advanced Habitation Systems (AHS) Interfaces with multiple strategic outcomes from other PT/SCLTs

AHS Outcome: Enable long duration human exploration missions with Advanced Life Support & Human Performance techs

Thrusts	Outcomes
 <p>Go Rapid, Safe, and Efficient Space Transportation</p>	<ul style="list-style-type: none"> Develop nuclear technologies enabling fast in-space transits. Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications. Develop advanced propulsion technologies that enable future science/exploration missions.
 <p>Land Expanded Access to Diverse Surface Destinations</p>	<ul style="list-style-type: none"> Enable Lunar/Mars global access with ~20t payloads to support human missions. Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies. Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards.
 <p>Live Sustainable Living and Working Farther from Earth</p>	<ul style="list-style-type: none"> Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities <ul style="list-style-type: none"> Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations. Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar & Mars surface. Technologies that enable surviving the extreme lunar and Mars environments. Autonomous excavation, construction & outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in situ resources. Enable long duration human exploration missions with Advanced Life Support & Human Performance technologies.
 <p>Explore Transformative Missions and Discoveries</p>	<ul style="list-style-type: none"> Develop next generation high performance computing, communications, and navigation. Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions. Develop technologies supporting emerging space industries including: Satellite Servicing & Assembly, In Space/Surface Manufacturing, and Small Spacecraft technologies. Develop vehicle platform technologies supporting new discoveries. Develop transformative technologies that enable future NASA or commercial missions and discoveries

↔ **In Space Transportation SCLT** – AHS technology improvements in CO2 reduction, food, trash management, and improved reliability reduce cargo mass ~5 MT x propulsion gear ratio

↔ **Entry Descent and Landing SCLT** – AHS technology improvements in CO2 reduction, food, reduce landed cargo mass

↗ **Avionics PT** – Improved crew displays and electronics for deep space radiation environments

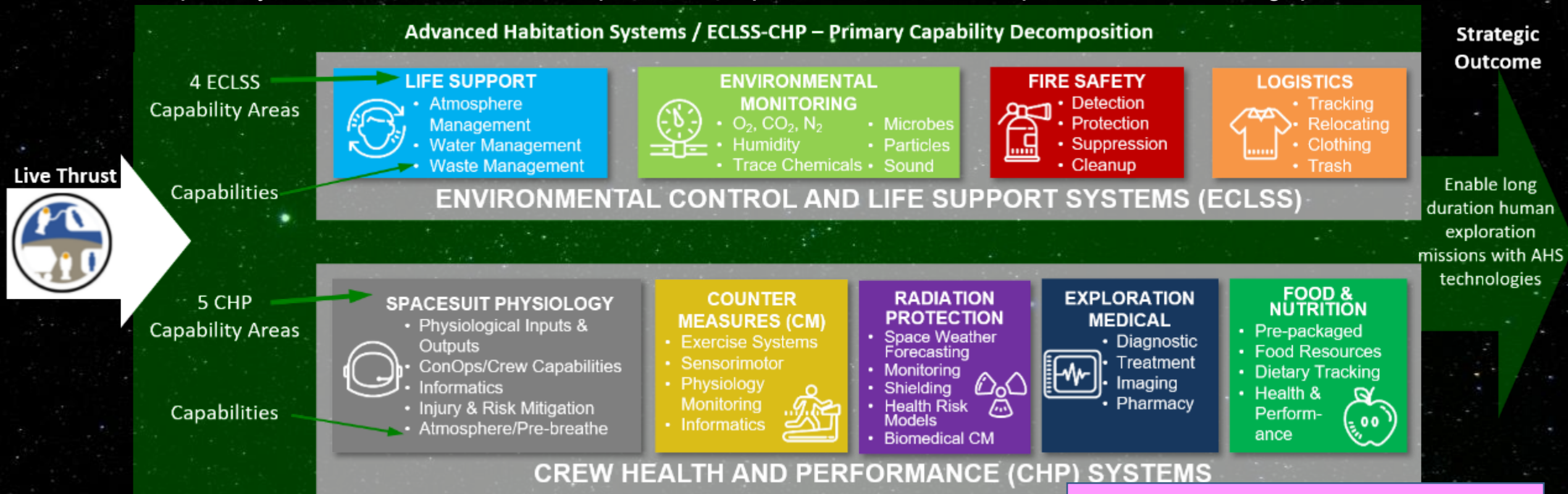
↗ **ISRU SCLT** – Provide consumables; receive waste & trash reduce loop closure requirements. AHS investments in CO2 reduction, gas separation, gas/water contaminant removal and monitoring are extensible to ISRU

↗ **Advanced Habitation Systems (AHS)**
 – Capabilities captured in NASA taxonomy TX06 & TX07
 – Largest technology challenges: CO2 reduction (O2 recovery), in-flight food nutrition, earth independent human operations (decision support), system reliability, environmental monitoring, and crew health countermeasures

↘ **Autonomous Systems & Robotics** – Advances in robotics and autonomy support AHS system maintenance to prepare for crew arrival, allow crew to focus on science.
 - Earth Independent Human Operation: Common interfaces and computational technologies to for crew decision support due to

Advanced Habitation Systems Capability Areas

- AHS capabilities keep astronauts healthy and productive while living in space and planetary vehicles
- Broadly characterized into vehicle Environmental Control and Life Support Systems (ECLSS) and Crew Health and Performance (CHP) Capability Areas
 - Capability Areas are further decomposed to capabilities and sub-capabilities to define gaps



- New: EARTH INDEPENDENT HUMAN OPERATIONS**
- Decision Support & Situation Awareness Tools
 - Human-Hardware Maintenance Interfaces and Tools
 - Procedure Execution Support Tools
 - Asynchronous Distributed Operations Mng Systems
 - Integrated Earth-Independent Human Systems Simulation

Mission Characteristics That Drive AHS Capability Needs



- Mission Duration

- Crew consumables and waste generation are fixed kg/crew-day
- Duration needs to be long enough to offset system closure mass

- Crew safety and mission success goals

- Longer duration increases risk
- Increased Probability of Sufficiency (POS) - increase spares & certainty of spares life
- Increased ability for Earth independent diagnostics and repair

- Microgravity vs Surface

- μg adds complexity to address liquid-gas-solids separation and other phenomena

- Frequent planned EVAs

- Loss of water and oxygen (less available for recycling)
- Increased crew fatigue and injury risk
- Reduced cabin pressure to reduce pre-breathe time, impacts 14.7 psia/23% O₂ systems
- Mitigating surface dust from EVA

- Number of crew members

- Crew consumables are fixed kg/d

- Planetary protection and science integrity

- Monitoring/sterilization/treatment/containment adds mass

- Long uncrewed periods

- Adds mass to prevent or recover from microbial upset
- Importance of habitat autonomy and robotic caretaking increases

- Availability of In-Situ Resource Utilization (ISRU) products (water and gases)

- Influences recycling break-even point, possible ISRU-ECLS sensor and processor commonalities



Advanced Habitation Systems 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 CO₂
- 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
- CO₂ 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
- Limited informatics; primarily ground-monitored
- Ground, ISS, and Apollo suit injuries occur (27 injury mechanisms identified)
- Prebreathe protocols for 14.7 and 10.2 psia microgravity 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-mission 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-mission nutrient intake monitoring in development

AHS Envisioned Future Decomposition by Capability Area

(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)
- 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 CO₂ (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)

ENVIRONMENTAL MONITORING

- Identify and quantify chemical (>12 water, >33 air) and microbial species in-mission 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)

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)

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)

SPACESUIT PHYSIOLOGY

- 100% of tasks within human performance (L,T,M)
- Predict and mitigate decompression sickness for surface EVA (L,M)
- Predict and mitigate suited 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-mission diagnostics and treatment for 100 of 120 medical risk conditions (L,T,M)
- Autonomous medical skill and decision support systems (T, M)
- Integrated data architecture (L,T,M)

FOOD & NUTRITION

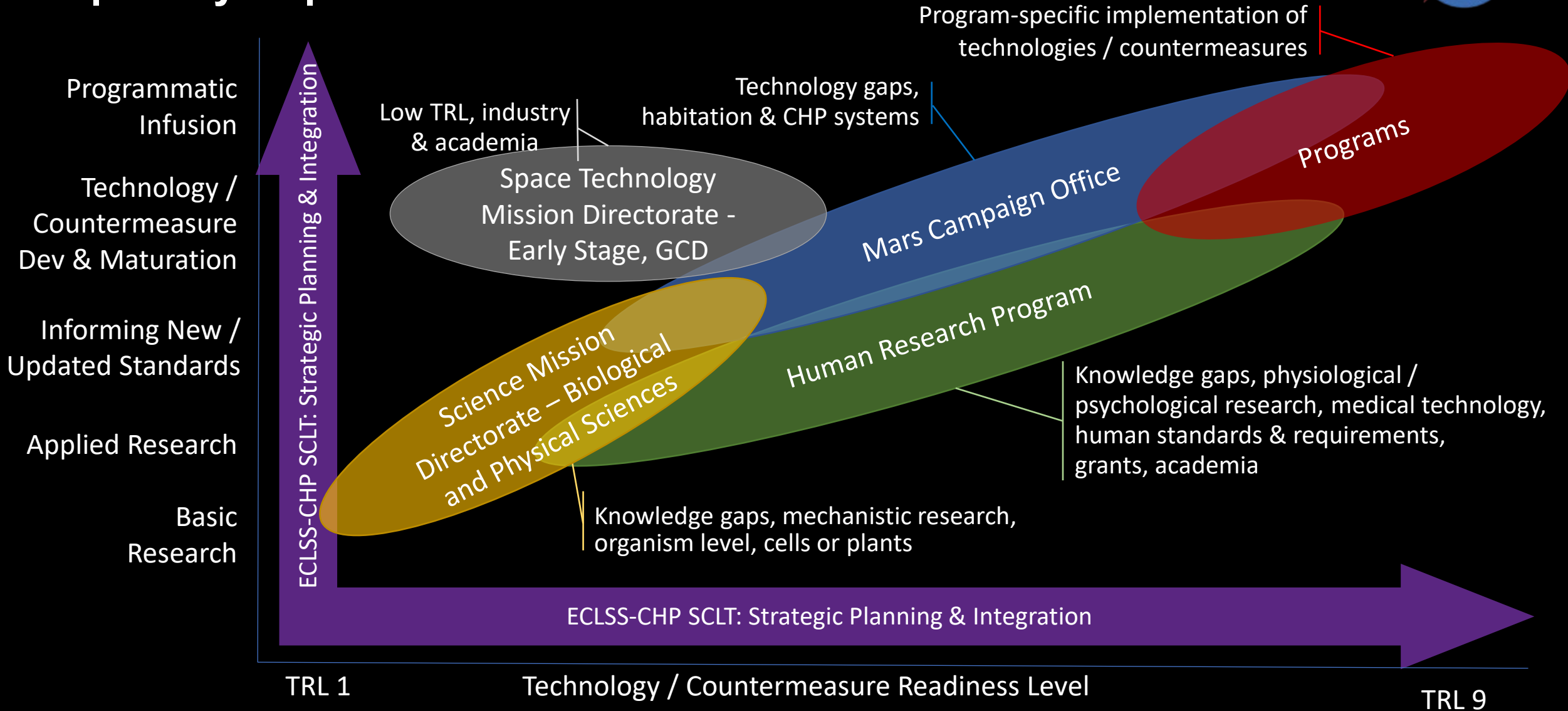
- 100% of nutrient stability >5-year shelf life (T,M)
- Food acceptability >90% (L,T,M)
- <30% launched water content (T,M)
- Exploration counter-measure in-mission nutrition intake monitoring (L,T,M)

AHS – Top Priorities for Technology Development (STMD focused tech dev)

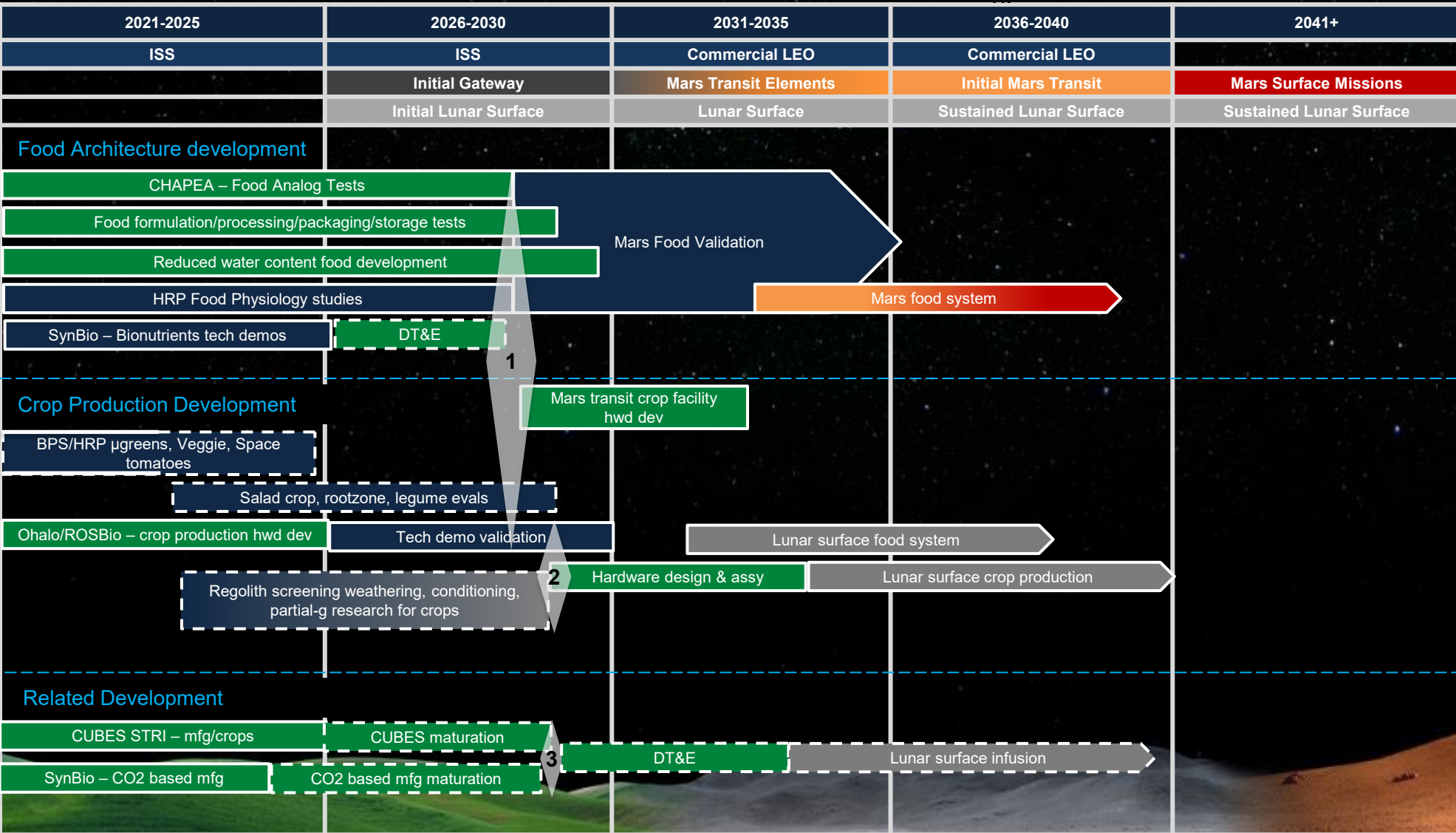


- **In-flight and surface manufactured food and logistics**
 - Bio-engineered foods/pharmaceutical technologies (i.e. GCD SynBio)
 - Reliable crop water/nutrient delivery (i.e. DSF Challenge)
 - Logistics production (i.e. CO₂ conversion Challenge)
- **Advanced oxygen recovery**
 - >75% oxygen recovery from crew member metabolic CO₂ (i.e. GCD SpaceCraft Oxygen Recover {SCOR})
 - Effective capture, transport/storage of carbon fines from CO₂ reduction systems (use in ISRU or jettison)
- **ISRU derived oxygen and water for ECLSS**
 - Production, separation, contamination removal from oxygen and water (i.e. GCD CaRD, others)
 - Long operation duration trace contaminant monitoring without sample return to allow safe consumption
- **Human operations autonomy for communication delay/blackout periods**
 - Decision support, asynchronous distributed operations, and situational awareness tools
- **Low mass human exercise vibration systems**
 - Active (robotic/automatic/autonomous) isolation systems to reduce vibration loads to vehicle solar panels and radiators to reduce fatigue
- **Radiation shielding and modeling technologies for galactic cosmic ray mitigation**
 - Active shielding feasibility and development for in-space and surface habitats
- **Low mass, moderate temperature stowage technologies for large food volumes to improve shelf-life**
 - Ug vapor compression and thermal rejection technologies

SCLT Scope – Range of Programs and TRLs as Capability Gap Closure Matures



Notional Roadmap of Crop Research Support for Food, Nutrition, and Crew Health Countermeasures

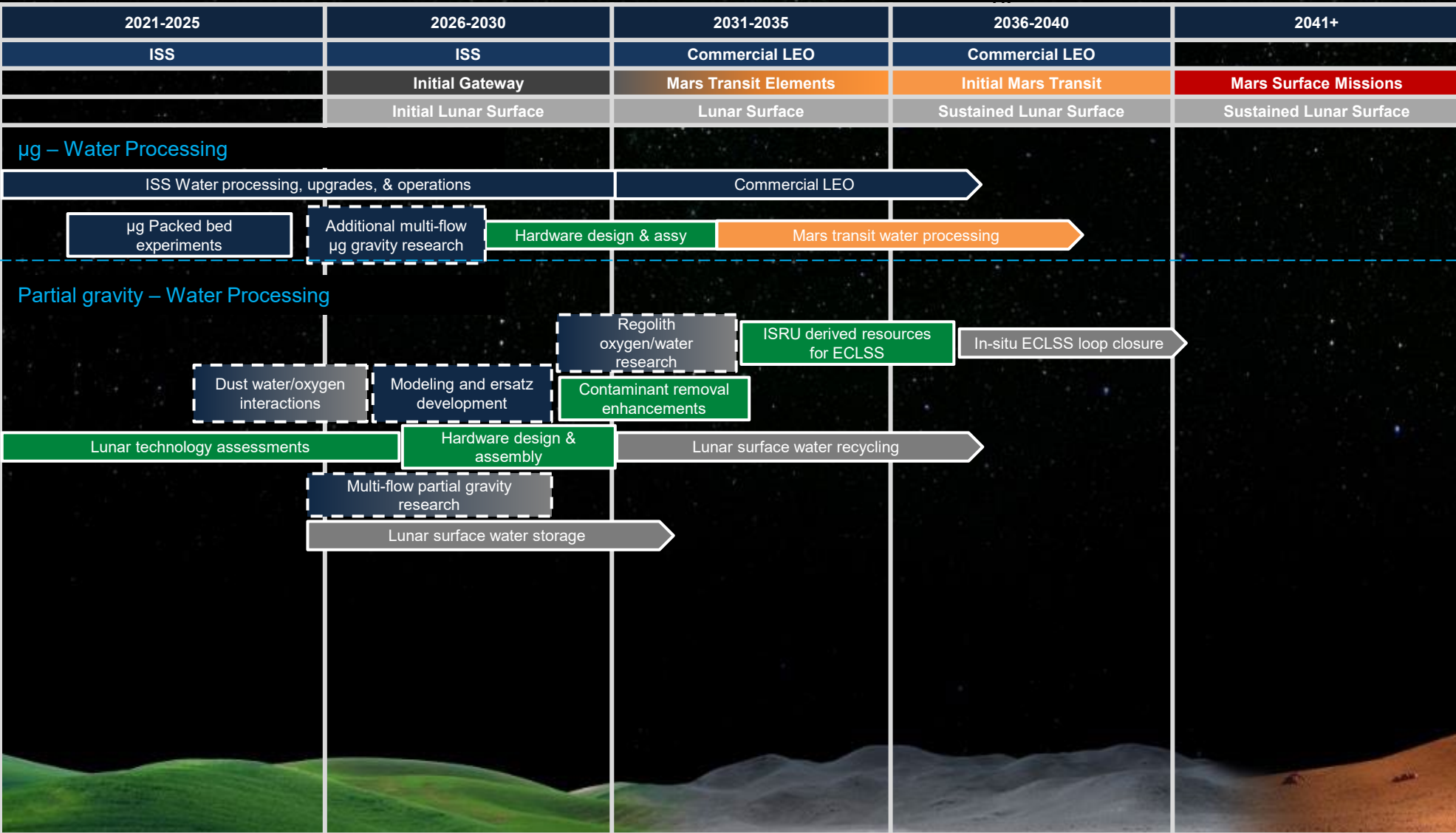


1. Determine food architecture composition of pre-packaged, cold stored, in-flight produced food architecture for Mars transit missions
2. Determine crop/food architecture for long duration surface lunar missions
3. Determine alignment to advanced manufacturing architecture

Note: Technology roadmaps are not yet formalized and will be updated in 2024 to align with updated NASA Architecture Definition Document

■ Ground ■ Mars transit Notional development
■ LEO ■ Mars surface Potential BPS contributions
■ Lunar orbit ◆ Decision point
■ Lunar surface

Notional Roadmap of Multiphase Flow, Dust, and ISRU Resources Research Support for Exploration Water Processing



- Ground
- LEO
- Lunar orbit
- Lunar surface
- Mars transit
- Mars surface
- Notional development
- Potential BPS contributions
- Decision point

Concluding Comments



- **AHS technology development is need to ensure crew health and productivity for long duration Mars transit and lunar surface missions**
- **STMD GCD provides a key step in technology development prior to maturing – often within ESDMD**
- **Important to use performance metrics to communicate how a technology helps close a gap over the state of the art**
 - Due to complexities and variability of human systems, important to test with humans and trace process contaminants to understand system capabilities and sensitivities
- **Additional ECLSS & CHP information:**

International Conference on Environmental Systems (ICES) **ECLSS** Paper: [Link](#)



International Conference on Environmental Systems (ICES) **CHP** Paper: [Link](#)

Backup Information



Advanced Habitation Systems – Examples of Current Investments (1/2)

(There are many SBIR/STTR/ECI/ECF/CIF/STRG investments supporting lower TRL innovation not list below)



LIFE SUPPORT



Advanced Oxygen Generator

- Long duration reliability testing on ISS & ground
- Oxygen generation improved maintainability
- High Pressure O₂ EVA resupply
- Sabatier enhancements
- 4-bed, Thermal amine, and CapiSORB CO₂ scrubbers
- Bosch CO₂ Reduction
- Methane Pyrolysis
- Hydrogen Separation
- Medical oxygen
- Long life condensing heat exchangers
- Wetted systems dormancy tolerance and recovery
- I₂ and Ag water biocides
- Partial-g water systems
- Compact toilet and lower mass fecal containers
- Urine pretreat storage and delivery
- Trace gas catalytic oxidizer
- Scroll & cyclone particulate filtration



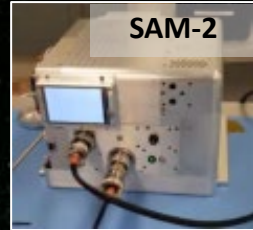
Urine Brine Processor Assembly



Compact Toilet System



ENVIRONMENTAL MONITORING



SAM-2



MiniTOCA



Airborne Particle Monitor



Minlon/Biomole

- Long duration reliability testing on ISS
- Minlon-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



FIRE SAFETY

- Anomaly Gas Analyzer
- Water Spray mist fire extinguisher
- Smoke cleanup device
- Improved realistic fire training
- Saffire VI on Cygnus – ug (varies ~2000-3700 cm²)
- CLPS partial-g (~150 cm²)
- Blue Origin partial-g (~40 cm²)
- Partial gravity drop tower spin test and development of non-spin capability



Drop tower spin rig



Combustion Product Monitor



Saffire-VI (planned)



LOGISTICS

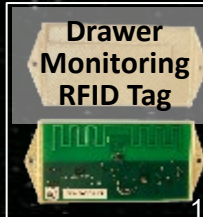
- Trash Compactor Processing System (TCPS)
- Trash-to-gas / OSCAR
- RFID Enabled Autonomous Logistics Management (REALM)
- Long wear clothing / laundry
- In-flight disinfectant solution generation for reusable wipes
- ISS Bishop airlock jettison bag
- Exploration trash jettison trade study
- Lunar vacuum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



REALM-2 on Astrobee



TCPS Tile



Drawer Monitoring RFID Tag

Advanced Habitation Systems – Examples of Current Investments (2/2)

(There are many SBIR/STTR/ECI/ECF/CIF/STRG investments supporting lower TRL innovation not list below)



SPACESUIT PHYSIOLOGY

- Suit-independent analytics tool
- Suit user injury tracking system
- MEDPRAT
- Contingency CO₂ limits
- Crew state model & risk tool
- Physical & cognitive EVA simulations
- Personalized EVA informatics and decision support
- JARVIS informatics display
- Exploration Atmospheres pre-breathe validation
- Decompression sickness risk tool



Suit-human load modeling



Real-time NBL-suit expired CO₂ informatics



COUNTER-MEASURES

- Exploration exercise device (E4D) development
- Vibration isolation systems
- No-Treadmill (T2) exercise ISS evaluation
- EVA muscle/aerobic standards
- EPIC informatics tools
- Heart rate/blood pressure/OCT monitors
- In-flight sensorimotor balance trainer validation
- In-flight bone assessment

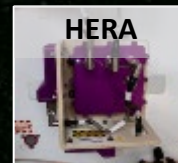


E4D Prototype and VIS modeling

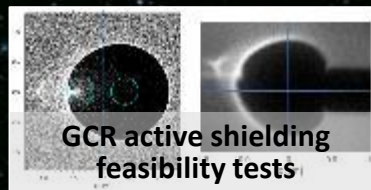


RADIATION PROTECTION

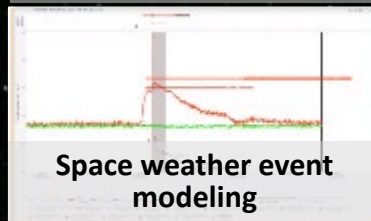
- Lunar/Mars space weather forecasting
- Solar particle event (SPE) forecasting ML
- HERMES Gateway suite
- Orion-HERA
- EVA-ARD
- Active electrostatic shielding modeling study
- ISS-RAD and Adv Neutron Spectrometer
- Bio-dosimetry Polaris Project



HERA



GCR active shielding feasibility tests



Space weather event modeling



EXPLORATION MEDICAL

- Impact analysis tool
- Exploration medical risk database
- Medical levels of care tool
- Handheld microscope
- Multi Med device
- Mini IntraVenous-fluid Generation (mini-IVGen)
- HoloLens MedTED
- Integrated Sim test bed
- Exploration Formulary
- Stability/toxicity study
- Automated med inventory tool dev
- CHP Integrated Data Architecture



FOOD & NUTRITION

- Crew Health And Performance Analog (CHAPEA)
- Ohalo/ROSBio plant growth facility
- Hurdle processing/storage/temp study
- BPS crop evaluations
- CUBES & Synthetic Bio
- NextSTEP Xroots aeroponics
- Deep Space Food Challenge



CHAPEA



Synthetic nutrient production



Acronyms



- AHS – Advanced Habitation Systems
- ARD – Active Radiation Dosimeter
- CHAPEA – Crew Health and Performance Analog
- CHP – Crew Health and Performance
- CM – Counter Measures
- CLPS – Commercial Lunar Payload Services
- CUBES – Center for the Utilization of Biological Engineering in Space
- E4D – Exploration Exercise Device
- ECI – Early Career Initiative
- ECF – Early Career Faculty
- ECLS - Environmental Control and Life Support
- ECLSS – Environmental Control and Life Support System
- EPIC – Exercise and Performance Information Console
- EVA – Extravehicular Activity
- GCR – Galactic Cosmic Rays
- HEPA – High Efficiency Particulate Air
- HERA - Hybrid Electronic Radiation Assessor
- HERMES - Heliophysics Environmental and Radiation Measurement Experiment Suite
- ISRU – In-situ Resource Utilization
- ISS – International Space Station
- IVGen – IntraVenous Generation
- JARVIS – Joint Augmented Reality Visual Informatics System
- MEDPRAT - Medical Extensible Dynamic Probabilistic Risk Assessment Tool
- MedTED – Medical Technology Demonstration
- ML – Machine Learning
- NBL – Neutral Buoyancy Laboratory
- OCT - Optical coherence tomography
- OSCAR - Orbital Syngas/Commodity Augmentation Reactor
- POS – Probability of Sufficiency
- RAD - Radiation Assessment Detector
- REALM – RFID Enabled Autonomous Logistics Management
- SAM – Spacecraft Atmosphere Monitor
- SBIR – Small Business Innovative Research
- SCLT – System Capability Leadership Team
- SPE – Solar Particle Event
- STRG – Space Technology Research Grants
- STTR – Small Business Technology Transfer
- SWIM – Spacecraft Water Impurities
- TCPS – Trash Compactor Processing System
- TRL – Technology Readiness Level