National Aeronautics and Space Administration

ECLSS & Habitation Systems

Remarks to Human Health and Surface Exploration Panel

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Life Support & Habitation Systems
Exploration Technology Development Program

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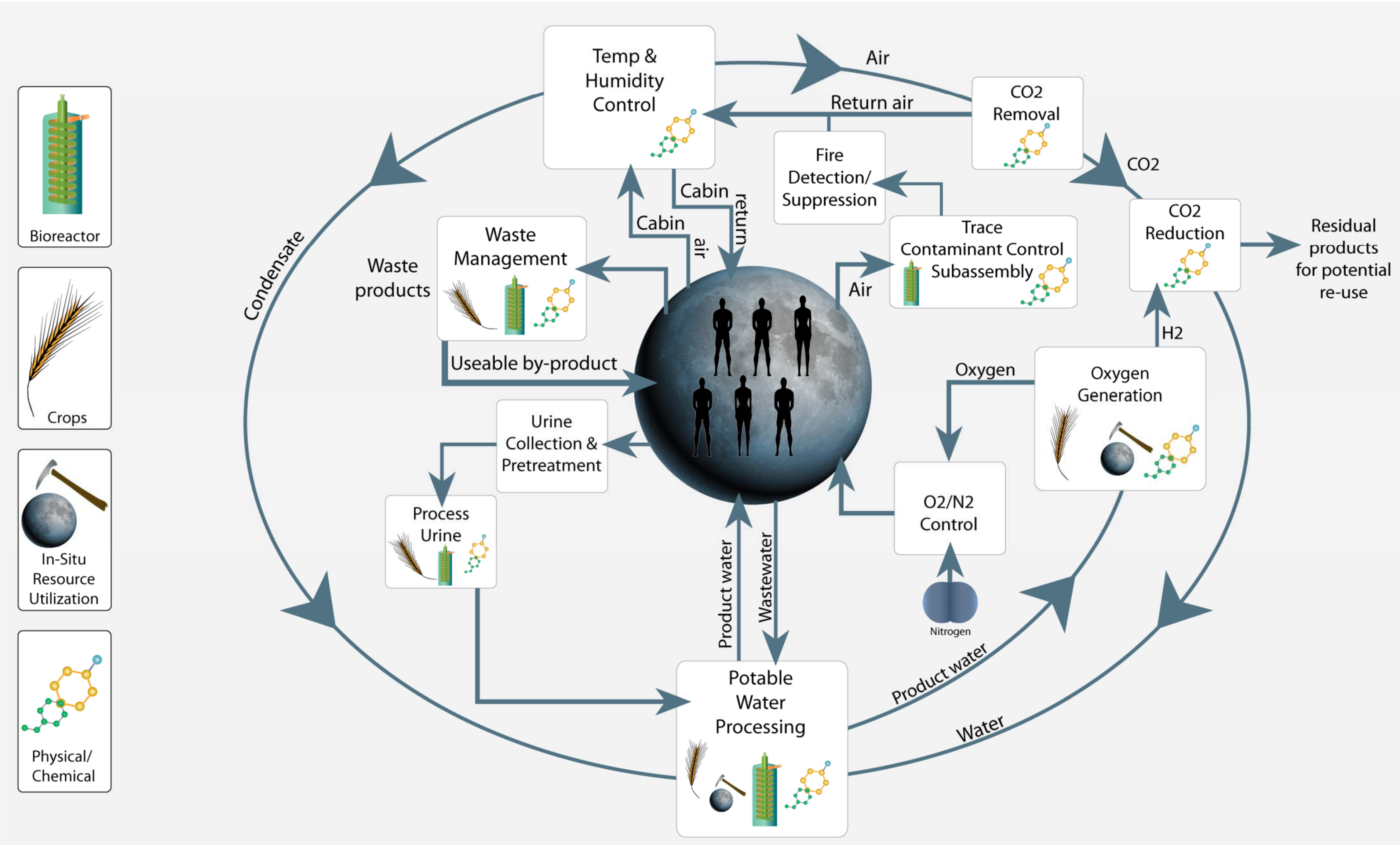
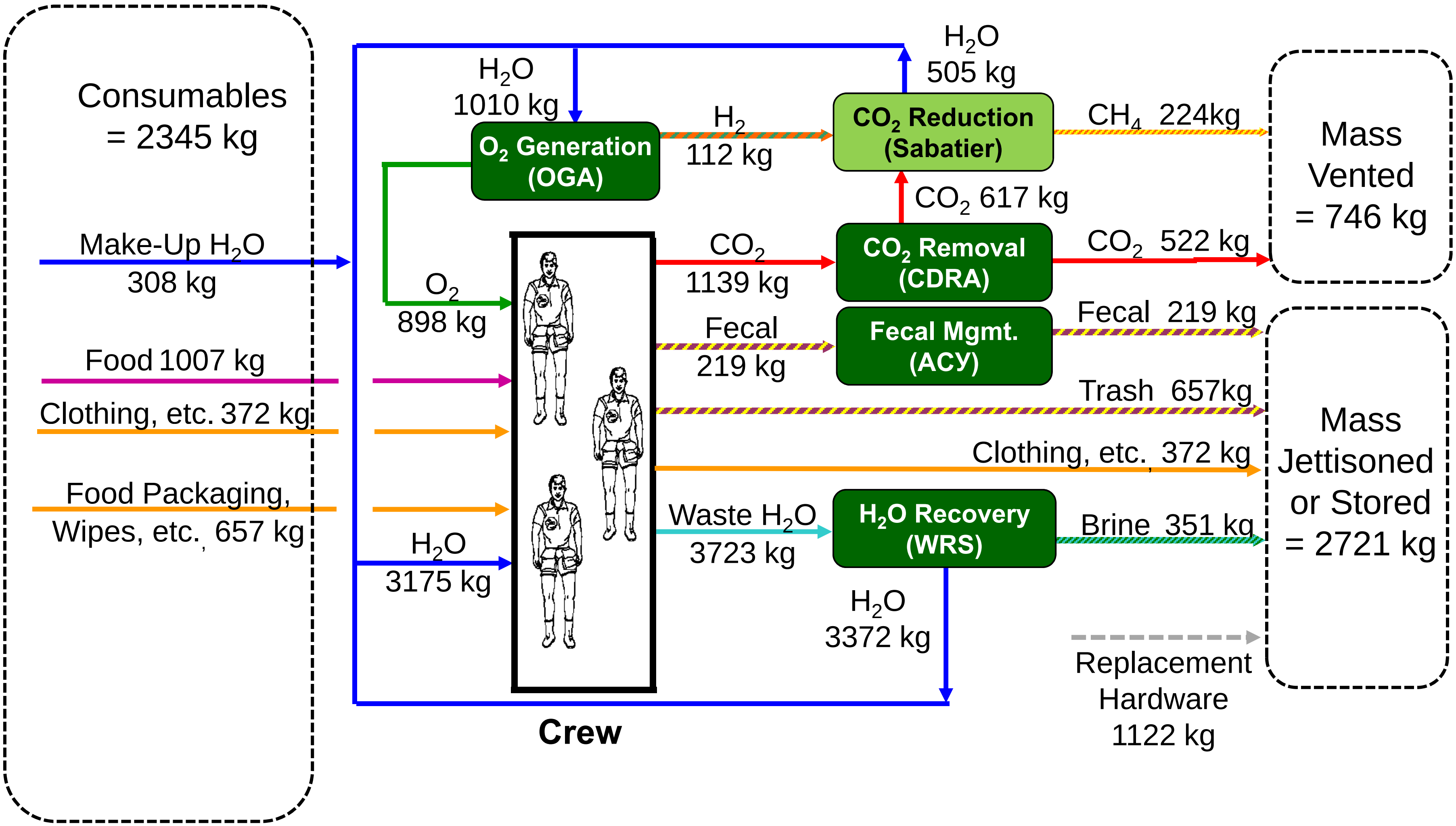
Integrated Life Support Systems

Mission Appropriate Level of Closure and Technology Selection



State of the Art Partially Closed ECLSS
Fate of Consumable Mass, 3 crew, 365 day mission



Based on content courtesy Robert Bagdigian, MSFC

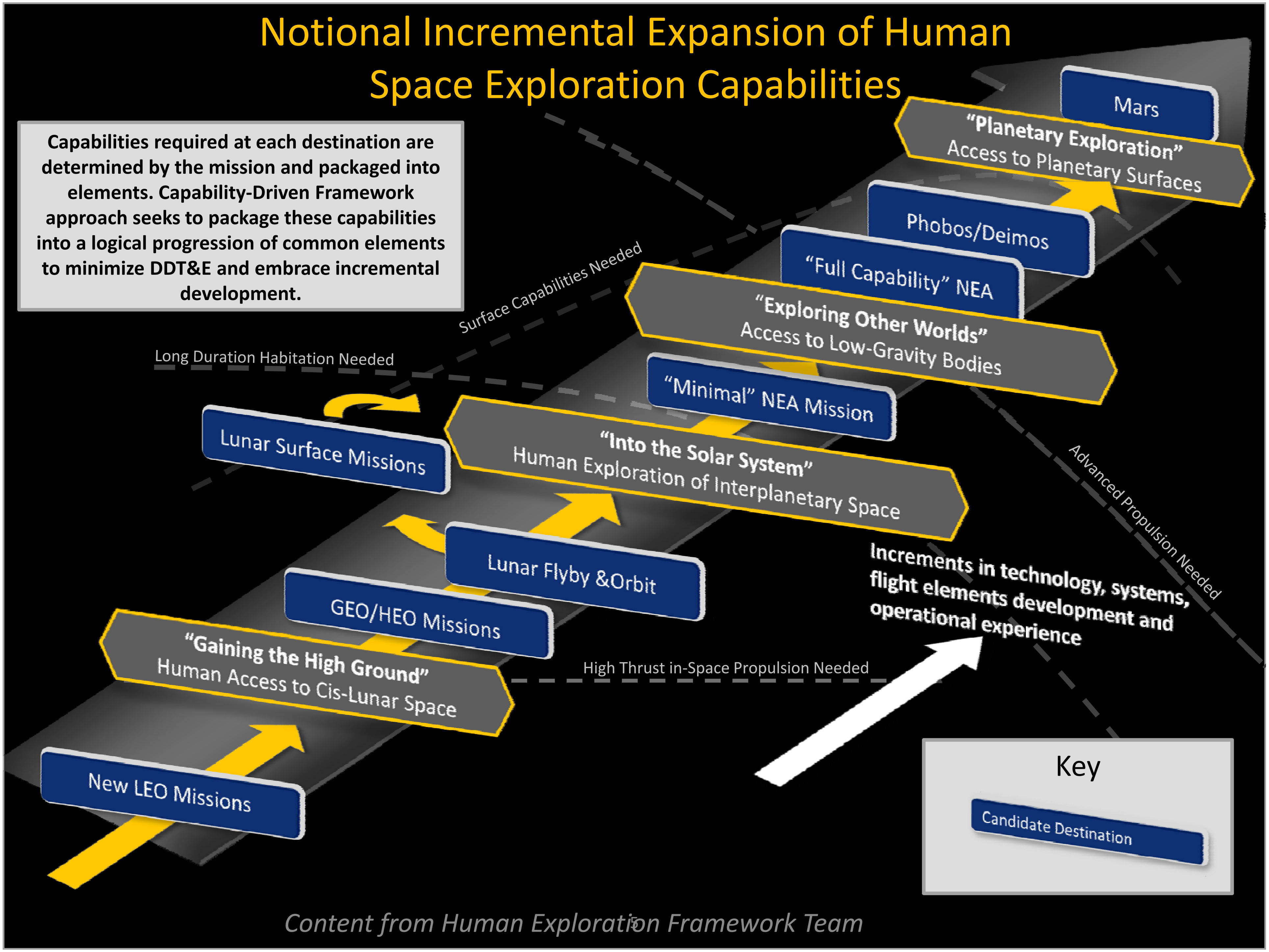
Note: Not all necessary ECLSS functions are depicted

Selected Technical Performance Goals

Technical Element	State of the Art	R&TD Goals	Example Technologies
Atmosphere Revitalization			
CO_2 removal (W-h/kg CO_2)	2,174	560	Structured sorbents
Recovery of O_2 from CO_2	0 to 50 %[1]	≥ 97%	CO_2 Reduction
Recovery & Use of H_2	0 %	≥ 50%	Pyrolysis
Water Recovery			
Hygiene Water Recycling	0 %[2]	≥ 98%	Advanced Primary Treatment
Water Recovery from Urine	65-70%	≥ 98%	Brine Recovery
Condensate Recycling	~100%	~100%	
Solid Waste Management			
% of Mass Recovery	0 %	50-90 %	Dewatering
Volume Reduction	0 %	10:1 to 100:1	Compaction & Mineralization
Food Production			
Food Augmentation	0 %	5-50%	Crop Systems
Air & Water Recovery	0 %	5-100%	Bioregenerative LS

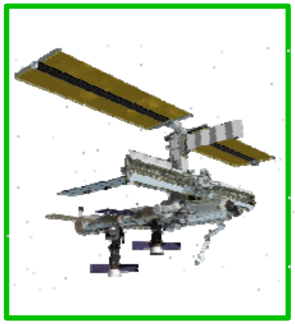
[1] If successful, commercial deployment of Sabatier on ISS may increase values to ~50%

[2] There is no dedicated hygiene water processing, Wipes are consumable materials and end up as waste.


Notional Incremental Expansion of Human Space Exploration Capabilities
Capabilities required at each destination are determined by the mission and packaged into elements. Capability-Driven Framework approach seeks to package these capabilities into a logical progression of common elements to minimize DDT&E and embrace incremental development.
Mars
"Planetary Exploration" Access to Planetary Surfaces
Phobos/Deimos
"Full Capability" NEA
Surface Capabilities Needed
"Exploring Other Worlds" Access to Low-Gravity Bodies
Long Duration Habitation Needed
"Minimal" NEA Mission
Lunar Surface Missions
"Into the Solar System" Human Exploration of Interplanetary Space
Advanced Propulsion Needed
Lunar Flyby &Orbit
Increments in technology, systems, flight elements development and operational experience
GEO/HEO Missions
"Gaining the High Ground" Human Access to Cis-Lunar Space
High Thrust in-Space Propulsion Needed
New LEO Missions
Key
Candidate Destination
Content from Human Exploration Framework Team

Architecture Elements
with ECLS Systems, Interfaces or Common Hardware

Grouped by Similarity of Requirements



ISS

Deep Space Habitat (DSH)

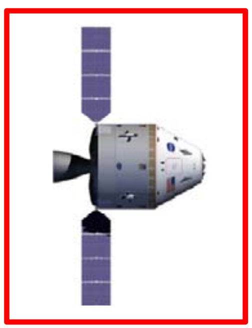
Lunar Surface Habitat

Mars Surface Habitat

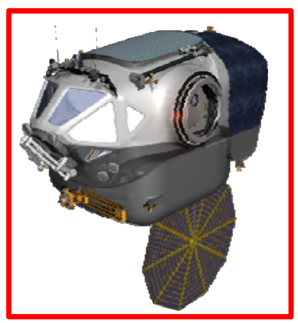
ISRU Plant

Power Module

EVA Suit

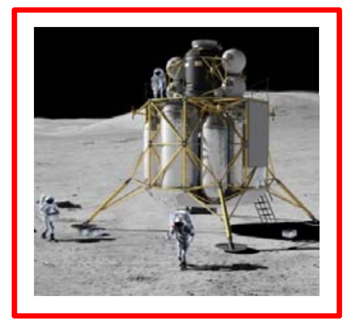


Multi-purpose Crew Vehicle (MPCV)



Multi-Mission Space Exploration Vehicle (MMSEV)

Pressurized Rover



Lander

Mission Factors, Decisions & Drivers that Impact Life Support & Crew Protection

Mission Factors	SOA - LEO Space Station (ISS)	NEO Space	Moon & Mars (Space & Surface)
Mission Duration	Short to Long	Intermediate	Short or Long
Consumables	Progress, ATV, HTV	Transport or Recycle	Transport, Recycle, Pre-deploy, ISRU
Location Factors	Within Van Allen Belts Thermal – Cyclic Orbit Return on Demand	Radiation Protection & Warning Thermal – Deep Space Constrained Return Possible Interplanetary Dust	Radiation Protection & Warning Thermal – Deep Space & Cyclic Constrained Return Surface Dust
Autonomy, Constrained Return	Dependency on Earth (Resupply, Sample Analysis, Spares, Return to Earth)	Autonomy with High Reliability No Resupply Certify Consumables in Place Repair; Recovery from Upsets	Autonomy with High Reliability No Resupply or Deployed Certify Consumables in Place Repair, Recovery from Upsets
Human/Spacecraft Requirements	Ambient Atmosphere Large Volume Simple Waste Streams Partly Closed ECLSS Consumables/ORUs	Reduced Pressure, Elevated O_2 Small to Intermediate Volume More Complex Waste Streams Partly Closed ECLSS Reduced Consumables/ORUs	Reduced Pressure, Elevated O_2 Small to Intermediate Volume More Complex Waste Streams More Fully Closed ECLSS Reduced Consumables/ORUs
Solid Waste Management	Limited Use Materials No Recovery Store & Jettison	Reduce/Extended Use Recover Water Compact, Stabilize & Return	Reduce/Reuse/Repurpose Recover Other Resources Process Waste & Return Residuals
Spacecraft/Mobility	CEV to ISS; EVA	Deep Space Habitat, Excursion Vehicle, suit port, new EVA suit	Deep Space & Surface Habitats, Excursion Vehicles, Landers, Rovers, suit port, & surface suit
Planetary Protection	N/A	Protection of Science	Mars: Forward & Backward Moon: Protection of Science

Life Support & Habitation Systems
Project Analysis

Element Description:

Perform analysis for trade studies, design, and test support. Assist technology developers and managers understand technology performance in an integrated system or mission application. Provide relevant mission frameworks for requirements, reference missions, and baseline assumptions. Provide other systems engineering and integration support including analytical tool development, data management, reporting, and archiving.

Sub-Elements	Center(s)
Systems Engineering	ARC, JSC
Systems Analysis & Simulations	ARC, JSC
Technology Analysis & Simulations	ARC, JSC
Reference Documents	JSC
Test Analysis	JSC

Systems Engineering

- Provide metric assessments of
  - Figures of Merit (FOM),
  - Key Performance Parameters (KPP)
  - Technology Readiness Level (TRL)

Systems Analysis and Simulations

- System-level assessments
  - Overall life support system or element-level trade studies
  - Overall mass and energy balances
- Mission studies and Equivalent Systems mass

Technology Analysis and Simulations

- Technology-level modeling
- Modeling using specialty engineering software
- Test Support and Modeling

References and Documentation

- Baseline Values and Assumptions
- Reference Missions
- Requirements

Data Management

- Data collection and “knowledge management”

Life Support & Habitation Systems
Atmosphere Revitalization

Element Description:

The Atmosphere Revitalization identifies and matures process technologies for a flexible core atmosphere revitalization process design that enables a highly reliable, efficient closed loop Environmental Control and Life Support (ECLS) system. Process technology maturation tasks are conducted for water-save gas drying; trace contaminant control; CO_2 removal, conditioning, and reduction to useful products; particulate matter removal and disposal; atmospheric gas supply, storage, and conditioning; resource recovery, storage, conditioning, and recycling; and supporting infrastructure.

Issues with current SOA Systems

- Carbon Dioxide Removal Assembly (CDRA) – Media dusting and containment issues (reliability) and high energy requirement
- SOA is only 0 to 50% closed with respect to oxygen, depending on use of Sabatier
- Filtration systems not suitable for planetary dust

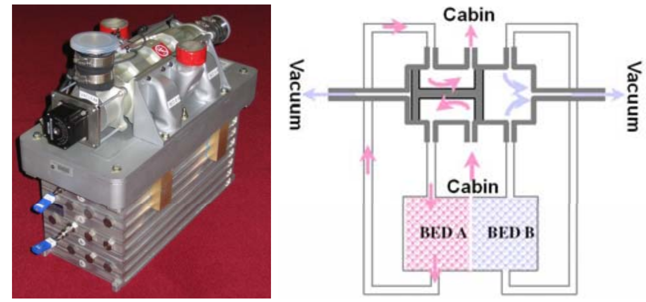
Sub-Elements	Field Center(s)
Carbon Dioxide Partial Pressure Control	ARC, JSC, MSFC
Control Trace VOC Concentrations	KSC, MSFC
Particulate Matter Removal	GRC, MSFC
Resource Recovery and Recycling	ARC, JSC, MSFC
Gas Storage and Supply	ARC, GRC, JSC, MSFC
Supporting Infrastructure	ARC, GRC, MSFC

New Requirements/Needs

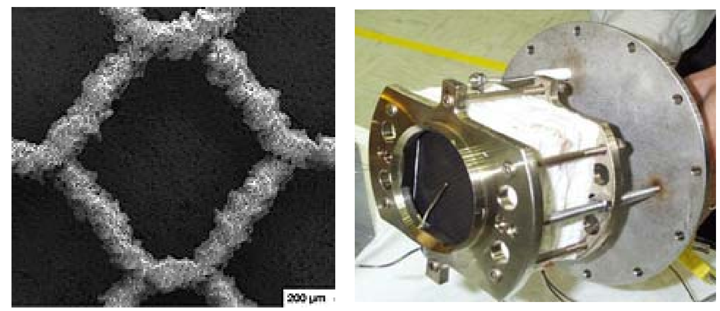
- Compatible with cabin environment at elevated oxygen (32%) and reduced pressure (8 psi) to facilitate EVA
- Operationally robust, reliable, in-flight reparability
- CO_2 removal process incorporating energy-efficient water saving function; Capture of CO_2 and atmospheric moisture from mobility elements
- Loop closure processes enabling >97% O_2 recovery from CO_2
- Non-venting systems to enable and protect mission science objectives and meet planetary protection requirements
- Resource distribution with mobility systems and surface elements – gas conditioning, pressurization, storage, supply, and recovery (EVA, SEV, ISRU, Power)
- Purification and certification of gases derived from ISRU sources prior to use
- Extra-terrestrial dust intrusion mitigation – dust air quality standards; dust intrusion barriers; regenerable particulate filtration, separation, and disposal – logistics reduction
- Autonomous control architecture

Life Support & Habitation Systems
Atmosphere Revitalization FY11 Tasks

ATMOSPHERE REVITALIZATION - Tasks	
Task Milestone Title: Description	**TRL**
Atmosphere Revitalization	
Carbon Dioxide Partial Pressure Control	
Low-Power CO2 Removal (LPCOR) System	4 to 4+
Engineered Structured Sorbent (ESS)	4
Open Loop Regenerable CO2 Removal	4 to 4+
CO2 and Moisture Removal Swing Bed	5+ to 6
Control Trace VOC Concentrations	
Advanced Trace Contaminant Control (ATCC)	3
Photocatalytic System Development	3
Particulate Matter Removal	
Indexing Media Filter	3
FAST Multi-Stage Filtration System	3
Modeling of Cabin Particulate Environment	n/a
Commercial Filter Evaluation	3
Resource Recovery and Recycling	
Closed Loop- Carbon Dioxide Reduction	3
Gas Storage and Recycling	
Subcritical Liquid Storage Task	2 to 3
Scavenging of Oxygen from Gaseous Mixture	2 to 3



CO2 and Moisture Removal Amine Swing-Bed (CAMRAS)



Engineered Structured Sorbents and Microlith Module

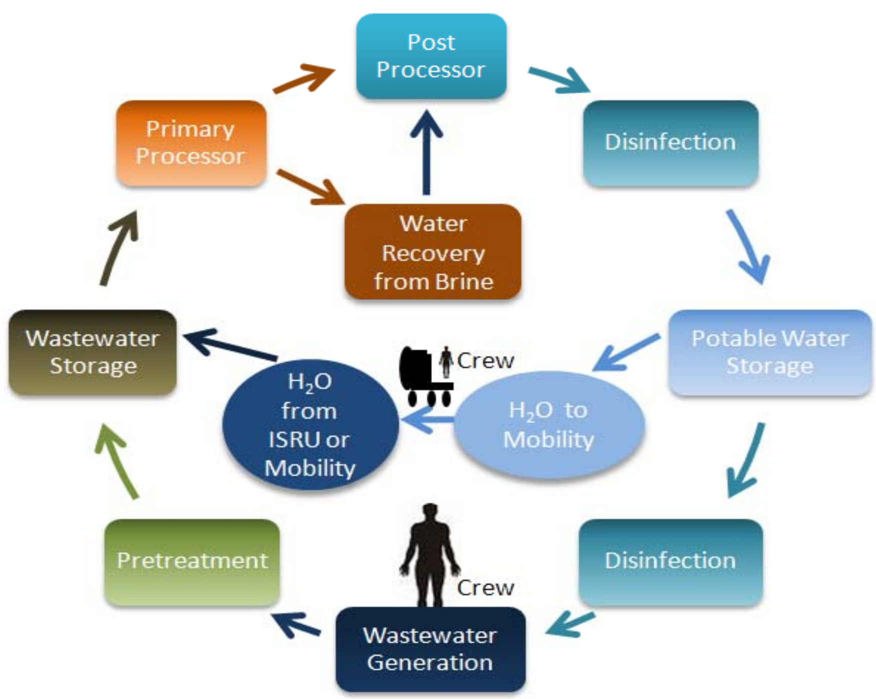
Bosch

Life Support & Habitation Systems
Water Recovery Systems

Element Description:

Technologies for water recovery systems will enable long duration missions by increasing the percent closure of the water loop and reducing consumable cost for water recovery. Reliable primary treatment systems, technologies to recover water from brine, and improved wastewater stabilization and disinfection systems are among the major areas of interest for technology development.

Closed-Loop Water Recovery System



Sub-Elements	Field Center(s)
Wastewater Composition and Storage Systems	JSC, KSC, MSFC
Primary Processing	ARC, JSC, MSFC
Secondary Processing	JSC
Post-processing, Disinfection & Potable Water Storage	ARC, JSC, KSC, MSFC
Water Recovery from Brine Systems	ARC, JSC

Issues with current SOA Systems

- Regenerative ECLSS – Water & Urine Processors
  - Biological growth; catalytic reactor performance
  - Precipitation & wastewater chemistry
  - Limited life items, including recycle filter tank assembly, filters, multi-filtration beds, biocide

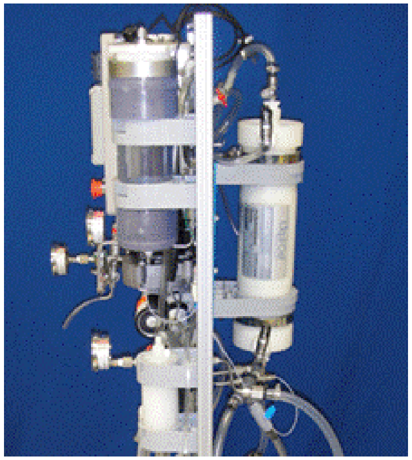
New Requirements/Needs

- Operationally robust, reliable, in-flight reparability, scalability
- Cannot dump liquid wastes - no re-supply vehicles will be available; planetary protection concerns
- Technologies for recovery and treatment of water from solid wastes and brines
- Treatment of more complex wastewater
  - Water recovered from solid wastes and brines
  - EVA/SEV wastes; hygiene & laundry;
  - ISRU derived water (including certification of potability)

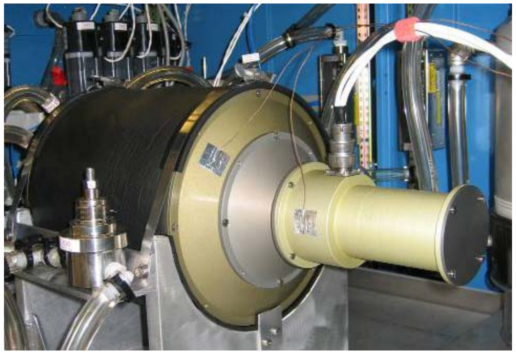
Life Support & Habitation Systems
Water Recovery Systems FY11 Tasks

WATER RECOVERY - Tasks	
Task Milestone Title: Description	**TRL**
Water Recovery	
Wastewater Composition and Storage Systems	
Stabilization and Composition Assessment	3
Wastewater Storage	3
Primary Processing	
Osmotic Distillation (OD) System Development	4
Direct Osmotic Concentration (DOC) Evaluation	4
Cascade Distillation	5
Vapor Compression Distillation (VCD) Development	6
Post-processing, Disinfection & Potable Water Storage	
Biocide and Antimicrobial Technology	3 to 4
Thermal Catalyst Development	3
Processed Water Polishing	
Water Recovery from Brine Systems	
Brine Membrane Enlcosure for Heat Melt Compactor	4
Brine Residual In-Containment (BRIC)	2
Water Recovery Systems	
Radiation Water Wall Concept	
Microbiology Support Task	n/a

Pretreatment & Composition Studies



Osmotic Distillation



Cascade Distillation

Life Support & Habitation Systems
Solid Waste Management

Element Description:

Waste management technologies recover resources, increase crew safety and performance, and protect planetary surfaces while decreasing mission cost. Technology gaps to be addressed for future missions include water/resource recovery for cost savings, safening and stabilization, disposal and containment, waste/trash volume reduction, waste collection, and odor control.

Sub-Elements	Field Center(s)
Volume Reduction	ARC
Resource Recovery	ARC
Waste Stabilization and Storage	ARC, KSC
Source Odor & Containment Control	ARC
Waste Collection	ARC

Issues with current SOA Systems

- There is no processing of solid waste in flight. It is packaged and returned to Earth or disposed of using expendable cargo vehicles (Progress)

New Requirements/Needs

- Cargo vehicles will not available to dump solid and liquid wastes
- Stabilization of trash to control biological hazards
- Technologies for recovery of water from wastes to further recycling of consumables
- Compaction/volume reduction of solid waste
- Mineralization of solid wastes and/or long term stabilization and storage, including extended duration storage of human metabolic wastes
- Waste management compliant with planetary protection

WASTE MANAGEMENT - Tasks	
Task Milestone Title: Description	**TRL**
Waste Management	
Volume Reduction	
Heat Melt Compaction (HMC)	4
Waste Stabilization & Storage	
Microbial Characterization of Solid Wastes	n/a

Shuttle Trash

Heat Melt Compactor

Life Support & Habitation Systems
Crew Accommodations

Element Description:

Focus is on human accommodations, provisions, housekeeping and crew interfaces with vehicle systems. Addresses interfaces between the crew and ECLS subsystems, including Atmosphere Revitalization, Waste Management, and Water Recovery Systems. There are three main areas: Habitability Outfitting (sleep areas and common areas, advanced lighting, conversion of logistics byproducts to resources, acoustically quiet Interiors); Hygiene and Housekeeping Technologies (partial and full body cleaning, metabolic waste collection interfaces, surface cleaning) and Clothing and Laundry (crew clothing, life extension, washing, drying and reuse). Long duration missions with reduced resupply and limited external human interaction increases the importance of Crew Accommodations on crew functions, comfort and quality of life to ensure crew productivity. Validation is done using advanced mission analogs.

Sub-Elements	Field Center(s)
Habitability Outfitting	JSC
Hygiene	JSC
Clothing and Laundry	ARC, JSC

Issues with current SOA Systems

- Clothing is worn then thrown away, at a cost of about 0.5 kg/cm/day.
- There are no hygiene systems except for wipes, which are expendables. Hygiene water is not treated currently in flight
- A lot of materials, such as cargo containers, have single purposes become waste products

New Requirements/Needs

- Long-wear and/or re-usable clothing compatible with elevated oxygen levels
- Sink, freezer, microwave oven, dish water, shower, hand/mouth wash faucet, washer & dryer and trash compactor
- Re-purposing materials

CREW ACCOMMODATIONS - Tasks	
Task Milestone Title: Description	**TRL**
Crew Accommodations	
Habitability Outfitting	
Habitability Outfitting Integration	2
Clothing Laundry	
Clothing Logistics Reduction Technology	2

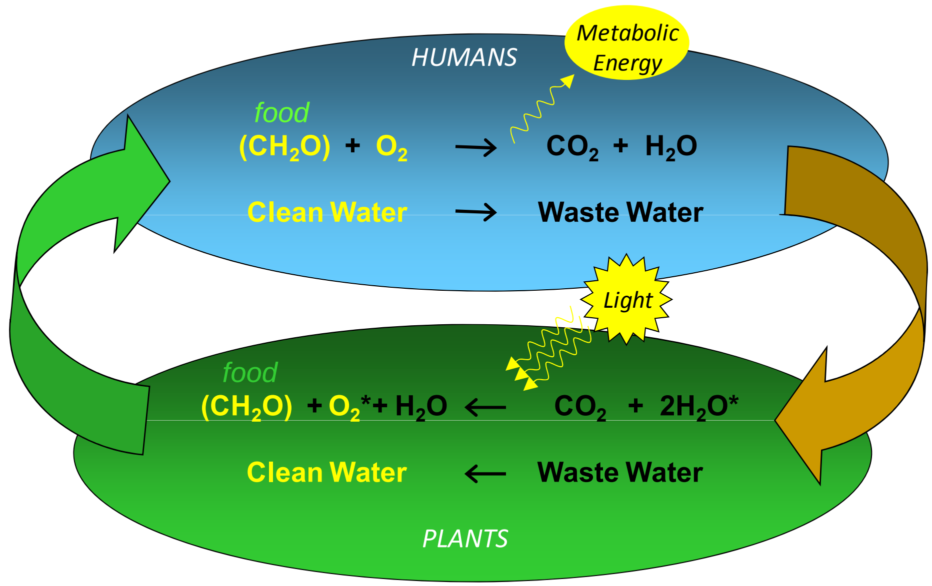
Life Support & Habitation Systems
Food Production

Element Description:

Full closure of life support systems will involve the *in situ* production of food. The level that this capability is manifested on a mission will depend on numerous factors. An initial implementation of food production technology will provide the capability to grow vegetables and fruits to augment the crew's diet of packaged foods. These fresh foods will add texture, flavor, and variety to the diet and provide a source of bio-available nutrients, which can serve as a radiation countermeasure. Expanded food production systems for future missions will reduce the need for stowed foods and contribute to CO_2 removal/reduction, O_2 production, and water recycling.

Sub-Elements	Field Center(s)
Crop Development	KSC
Crop Production	KSC
Crop Processing	KSC

FOOD PRODUCTION - Tasks		
WBS	Center	Task Milestone Title: Description
.04.05.		Food Production
.04.05.02		Crop Production
.04.05.02.11	KSC	Crop Production Hardware and Concepts



Challenges/Needs for Food Production

- Energy efficient electric lighting
- Solar lighting
- µ-gravity watering
- Dwarf crops
- Sustainability
- Integration with other ECLS components
- Genetically modified crops for space
- Radiation tolerance of food crops
- Food safety

Life Support & Habitation Systems
Environmental Monitoring

Element Description:

The Environmental Monitoring will develop miniature chemical and biological monitors, leveraging the rapidly progressing technical community. The overarching goal is to assure, within allocated resources, that suitable environmental monitoring systems will be provided for future crewed NASA vehicles and habitats, for both nearer term and longer term missions. Such monitoring systems will be responsive to needs based directly on crew health as well as other vehicle systems.

Sub-Elements	Field Center(s)
Atmosphere Monitoring	GRC, JSC, JPL
Water Monitoring	JSC, JPL
Microbial Monitoring	JPL, MSFC
External Monitoring	JPL
Process Monitoring & Controls	JPL

Issues with current SOA Systems - Logistics

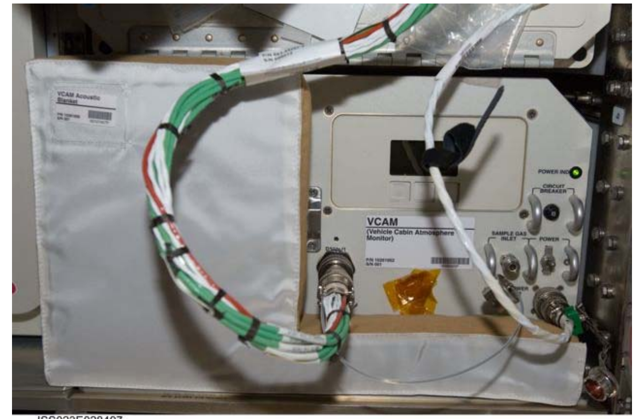
- Dependency on grab samples and sample return to Earth for environmental monitoring, particularly for microbiological and water analysis, and for unknowns
- ISS depends on resupply for many limited life items (e.g. OGS: Limited life hydrogen sensors)

New Requirements/Needs

- Capability to analyze and certify recycled air and water beyond low Earth orbit
- Capability to measure unknowns and recovery following system upsets & anomalies
- Improvements needed in size compared to SOA (90% less mass) and increase in number of analytes
- Advanced monitors:
  - Microbial (targeted species & total cell counts);
  - Water (organic and inorganic constituents);
  - Post-fire cleanup;
  - External contaminants
- In-space calibration and extended sensor life;
- Support for planetary protection

Life Support & Habitation Systems
Environmental Monitoring FY11 Tasks

ENVIRONMENTAL MONITORING - Tasks	
Task Milestone Title: Description	**TRL**
Environmental Monitoring	
Atmosphere Monitoring	
Optical Particle Counter (OPC)	2 to 3
Charge-Based Detector (CBD)	2 to 3
Atmosphere Monitoring Technology	
Tunable Environmental Laser	3
Water Monitoring	
Water Monitoring Technology Evaluation	
Water Sample Input to Mass Spectrometer	
Microbial Monitoring	
Microbial Monitoring	
Microbial Monitoring Technology	
Microbial Monitoring Workshop	n/a



ISS023E028497

Vehicle Cabin Atmosphere Monitor

Water Sampling for Front End of Mass Spectrometer for Water Monitoring

Life Support & Habitation Systems
Fire Protection

Element Description:

The Fire Protection Element will develop and mature technologies that will ensure crew health and safety on exploration missions by reducing the likelihood of a fire or, if one does occur, minimizing the risk to the crew, mission, or system. This is accomplished through the development of hardware, design rules and requirements, and procedures that enhance fire safety in exploration vehicles and habitats by addressing the areas of (1) fire prevention and material flammability, (2) fire signatures and detection, (3) fire detector (gaseous and particulate detector) development, and (4) fire suppression and post-fire response.

Sub-Elements	Field Center(s)
Material Flammability and Ignition	GRC, JSC
Fire Detection	GRC, JPL
Fire Suppression	GRC
Post-Fire Recovery	GRC, JSC

Issues with current SOA Systems

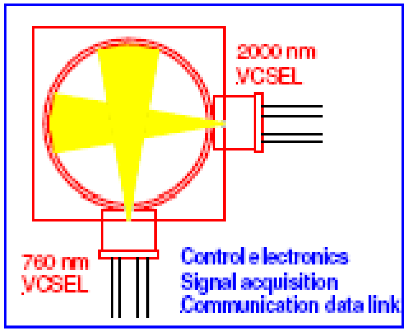
- In Low Earth Orbit (LEO), crews can return to Earth quickly but beyond LEO options for return will be very limited; safe haven or isolation may not be possible due to spacecraft design.
- Crews will not be able to don oxygen masks in high oxygen low pressure spacecraft cabins.
- Logistics Issues - recharge of fire suppression systems is required
- Unknown fire behavior in microgravity

New Requirements

- Integrated fire protection strategy will be required to survive fire events beyond LEO:
  - Accurate definition of the risk from flammable materials in low-g; update usage and controls
  - Early fire detection from distributed sensors
  - Emergency breathing apparatus w/ filter respirator
  - ECLS-compatible and re-chargeable fire extinguisher
  - ECLS-compatible post-fire cleanup
  - Contingency air monitor for relevant chemical markers of post-fire cleanup
- More robust and “green” fire detection, response and recovery
- Vehicle autonomy for recovery from events without loss of mission

Life Support & Habitation Systems
Fire Protection Tasks

FIRE PROTECTION - Tasks	
Task Milestone Title: Description	**TRL**
Fire Protection	
Material Flammability and Ignition	
Flammability Assessments in Spacecraft Atmosphere	n/a
Modeling of NASA-STD-6001B	n/a
Fire Safety Demo Formulation Task	n/a
Testing at White Sands Test Facility (WSTF)	n/a
Fire Detection	
Gaseous Detector Development	
Particulate Detector Development	
Fire Detector Testing	5
Fire Suppression	
Fire Suppression Technology Development	5
Post-Fire Recovery	
Post-fire Monitoring and Response	3

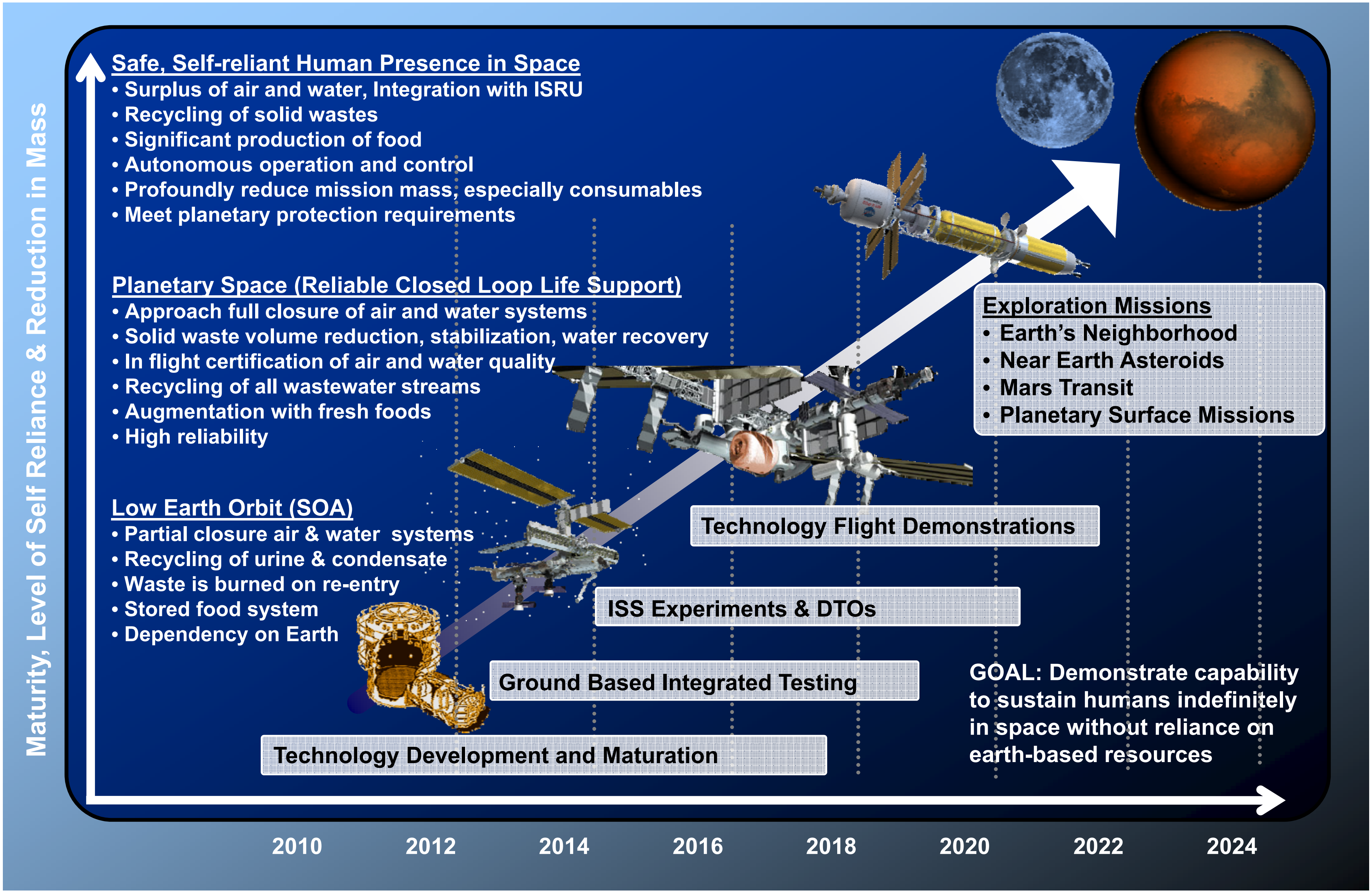


Vista Photonics

Fine Water Mist Extinguisher

Post Fire Test

Life Support & Habitation Systems
Top Level Roadmap



"Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite."

President Barack Obama, April 15, 2010