National Aeronautics and Space Administration (NASA) Environmental Control and Life Support (ECLS) Capability Roadmap Development for Exploration

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Abstract

NASA is considering a number of future human space exploration mission concepts. Although detailed requirements and vehicle architectures remain mostly undefined, near-term technology investment decisions need to be guided by the anticipated capabilities needed to enable or enhance the mission concepts. This paper describes a roadmap that NASA has formulated to guide the development of Environmental Control and Life Support Systems (ECLSS) capabilities required to enhance the long-term operation of the International Space Station (ISS) and enable beyond-Low Earth Orbit (LEO) human exploration missions. Three generic mission types were defined to serve as a basis for developing a prioritized list of needed capabilities and technologies. Those are 1) a short duration micro gravity mission; 2) a long duration transit microgravity mission; and 3) a long duration surface exploration mission. To organize the effort, ECLSS was categorized into three major functional groups (atmosphere, water, and solid waste management) with each broken down into sub-functions. The ability of existing, flight-proven state-of-the-art (SOA) technologies to meet the functional needs of each of the three mission types was then assessed. When SOA capabilities fell short of meeting the needs, those “gaps” were prioritized in terms of whether or not the corresponding capabilities enable or enhance each of the mission types. The resulting list of enabling and enhancing capability gaps can be used to guide future ECLSS development. A strategy to fulfill those needs over time was then developed in the form of a roadmap. Through execution of this roadmap, the hardware and technologies needed to enable and enhance exploration may be developed in a manner that synergistically benefits the ISS operational capability, supports Multi-Purpose Crew Vehicle (MPCV) development, and sustains long-term technology investments for longer duration missions. This paper summarizes NASA’s ECLSS capability roadmap development process, findings, and recommendations.

BACKGROUND

At present, the National Aeronautics and Space Administration (NASA) has considered a number of future human space exploration mission concepts. Yet, detailed mission requirements and vehicle architectures remain mostly undefined, making technology investment strategies difficult to develop and sustain without a top-level roadmap to serve as a guide.

This paper documents a roadmap for development of Environmental Control and Life Support (ECLS) Systems (ECLSS) capabilities required to enhance the long-term operation of the International Space Station (ISS) as well as enable beyond-Low Earth Orbit (LEO) human exploration missions. Three generic mission types were defined to serve as a basis for developing a prioritized list of needed capabilities and technologies. Those are 1) a short-duration micro gravity mission; 2) a long-duration microgravity mission; and 3) a long-duration surface exploration mission.

To organize the effort, ECLSS was categorized into three major functional groups (management of atmosphere, water, and solid waste) with each broken down into sub-functions. NASA subject matter experts (SMEs) then assessed the ability of existing state-of-the-art (SOA) technologies to meet the functional needs of each of the three mission types. When SOA capabilities were deemed incapable of meeting the needs of one or more mission types, those “gaps” were prioritized according to whether the corresponding capabilities were enabling (essential for mission success) or enhancing (provides an improvement over the SOA) for each of the mission types.

The result was a list of enabling and enhancing capability needs that can be used to guide future ECLSS development, mapped to current projects and

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development efforts attempting to address those needs. A strategy to complete development to fulfill those needs over time was then developed in the form of a roadmap.

APPROACH

Formulation of the strategic ECLSS capability roadmap included the following main efforts:

1. Decomposition of the various functions that are typically performed by ECLSS, down to a level of detail sufficient to assess its adequacy to fulfill future mission needs
2. Definition of three representative exploration mission types, selected to encompass the range of system capabilities likely to be needed to support human exploration objectives
3. Qualitative assessment of the ability of today's state-of-the-art (SOA) ECLSS components and subsystems to meet the needs of the three representative exploration mission types
4. Identification of those instances in which today's SOA capabilities fall short of meeting expected future needs
5. Qualitative prioritization of the capability gaps identified in Step 4 in terms of whether the associated functions enable or enhance the representative mission types.

ECLSS FUNCTIONAL DECOMPOSITION

A tiered functional decomposition of ECLSS was established as the framework to organize subsequent capabilities and gap assessments. The first tier decomposition is shown in Figure 1 and includes Air Management, Water Management, and Solid Waste Management.

Figure 1. ECLSS Top-Level Function Decomposition

Lower level decompositions (to second through fifth level tiers) were defined as needed to adequately capture the collective set of ECLSS functions that are expected to be applicable to the representative exploration missions. Second-level functions under Atmosphere Management include circulation, conditioning, emergency services, monitoring, and pressure management. Water Management includes potable water management, waste water management, and water quality monitoring. Waste Management is decomposed into the functions of managing logistical waste, managing trash, and managing metabolic waste. However, for the purposes of this effort, the capabilities needs for managing logistical wastes (packing foam, cargo transfer bags, stowage equipment, etc) was not assessed.

REPRESENTATIVE MISSION TYPES

In the absence of a definitive portfolio of human space exploration missions from which to discern capability needs, three representative mission types were identified and generically characterized. The selected mission types were chosen to envelope the anticipated range of ECLSS capabilities likely to be required to enable and enhance the wide range of missions that NASA study teams were assessing. At the same time, care was taken to avoid over-defining the three representative mission types so that resulting capability needs were not prematurely focused on too narrow a set of assumptions. The three representative mission types chosen were a short-duration, micro-gravity mission (referred to as Mission 1), a long-duration microgravity mission (Mission 2), and a long-duration surface mission (Mission 3). The assumed characteristics of each of these three mission types, along with examples, are summarized as follows:

<u>Short-duration, microgravity (Mission 1)</u>: These types of missions would include those of up to three to four weeks duration, with cabin pressures ranging from 8 to 14.7 psia. The entire mission would be conducted in micro-gravity. Extravehicular activity (EVA) capabilities would be supported through the use of an airlock or suitport. Some examples of exploration vehicles that would be used in this fashion include the Multi-Purpose Crew Vehicle (MPCV), Multi-Mission Space Exploration Vehicle (MMSEV), Lunar Lander, etc.

<u>Long-duration, microgravity (Mission 2)</u>: These types of missions are those with durations of 6 months or longer and occur entirely in a micro-gravity environment. Vehicle cabin pressures could range from 8 to 14.7 psia. Limited to no resupply capability, coupled with difficult mission abort scenarios, represent unique ECLSS challenges for this class of mission. Some examples of primary vehicles supporting this class of missions include Deep Space Habitats (DSH) and long-duration, deep space transit vehicles.

<u>Long-duration, partial-gravity surface exploration mission (Mission 3)</u>: These types of missions would generally be similar to Mission 2 with regard to duration, atmospheres, limited resupply, and challenging emergency abort scenarios. The most

substantial difference, from an ECLSS perspective, would be that these missions would occur in a partial-gravity environment on the lunar or other planetary body surface.

Note that there is overlap between mission types. For example, a Lunar Lander would likely be operated in both microgravity and surface environments. Also, the distinction between what constitutes "short" and "long" duration was somewhat arbitrary and, as the study concluded, highlighted several capability needs that deserved closer scrutiny of priorities for intermediate-duration missions.

State of the Art Assessment

Once the functional elements of ECLSS were fully defined and representative missions conceived, the ability of today's state of the art (SOA) ECLSS systems and technologies to perform those functions for those missions was assessed. The assessment relied heavily on the judgments of NASA system managers and sustaining engineers with intimate knowledge of the capabilities and shortcomings of existing Space Shuttle and *International Space Station* ECLSS systems and those that are currently in development for the Orion MPCV. The assessment also relied on insights from subject matter experts and analysts that supported on-going NASA exploration study teams and mission architects to ensure that future ECLSS capability needs were being formulated consistent with NASA exploration planning.

Since the capability assessment was being conducted in parallel with on-going exploration studies, definitive mission requirements, constraints, and resource allocations were not available. The capability assessments were therefore, by necessity, qualitative rather than quantitative.

To a large extent, SOA ECLSS components and technologies were judged to be suitable for application in the representative missions that were assessed. Although substantial challenges in applying SOA equipment to future exploration vehicles will occur because of unique factors such as packaging and layout constraints, material and parts obsolescence, mass and power budgets, etc., many of the future ECLSS functions can likely be met with copies of, or carefully-derived versions of, Shuttle, *ISS*, and MPCV equipment.

Capability Gap Assessment

For each of the ECLSS functions in which SOA capabilities were judged by the assessment team as either being unavailable or insufficient to meet the expected needs of one or more of the representative missions, a capability "gap" was identified. These gaps were qualitatively prioritized in terms of importance in order to provide useful information to NASA program managers charged with making investment decisions. A relatively simplified, two-level priority framework was adopted. For each mission type, capability gaps were signified as being either "Enabling" or "Enhancing". Enabling capability gaps were those which the assessment team felt needed to be filled before one or more of the mission types could reasonably be executed. Enhancing gaps, on the other hand, were those that, if filled, would be expected to provide worthwhile benefit to one or more of the mission types but which, if left unfilled, would not likely prevent the missions from being executed. In some cases, particularly when considering mid-duration types of missions, the distinction between Enabling and Enhancing became difficult and highlighted the need for further focused assessments.

Capability gaps identified in each of the three primary ECLSS functional areas are summarized below.

Air Management - Functional capability gaps in the area of air management are shown in Tables 2 and 3.

	Missions			
Capability	ISS	1	2	3
Suit loop fan		X		
Suit loop gas trap		X		
Suit loop pressure regulator		X		
Replacement for Halon & CO_2 for fire suppression	X	X	X	X
Smoke eater		X	X	X
Personal protection equipment filtering mask	X	X	X	X
Robust CO2 sorbent bed	X		X	X
High reliability O2 generation	X		X	X
O2 recharge for EVA	X		X	X
On-board trace contaminant monitor			X	X
Planetary surface dust pre-filter				X
Partial-g flammability testing				X

Table 2. Enabling Atmosphere Management Capability Gaps

	Missions			
Capability	ISS	1	2	3
Quite fans		X	X	X
Common bed core for CO2 removal		X	X	X
High reliability atmosphere major constituent monitoring reliability		X	X	X
Improved fire product sensors		X	X	X
Oxygen sensor accuracy improvements		X	X	X
Higher degree of CO2 reduction beyond Sabatier	X		X	X
Longer life/regenerable particulate filters			X	X
Advanced trace contaminant control catalysts & sorbents			X	X
Lower power water save for CO2 removal	X		X	X
Long life CO2 compressor	X		X	X
Smaller volume interim CO2 storage	X		X	X
Airborne microbial monitor	X		X	X
Fire detection with incidence to false alarms			X	X
Long life heat exchanger coatings				X
Surface dust particulate monitoring				X

Table 3. Enhancing Atmosphere Management Capability Gaps

Air Management Enabling Capability Gaps – As shown in Table 2, 12 gaps in air management capabilities were identified as Enabling in the assessment. These gaps are summarized as follows:

The baseline MPCV design includes a suit loop, which circulates and purifies 100% oxygen for the crew while they are wearing pressure suits. Air is circulated through the suit loop via a fan that also is used to circulate air through the cabin under nominal conditions. No SOA fans currently exist that meet the multiple flow rate and pressure drop operating points, and the 100% oxygen compatibility, that is required in this system architecture. The MPCV also has a suit cooling loop with a need for a venting gas trap to eliminate gas which will inevitably become entrained as a result of umbilical connects/disconnects and nominal leakage. A pressure regulator with a broad range of flow and pressure control capability is also required to support the MPCV's nominal and emergency "feed-the-leak" pressure control scenarios. Budgetary constraints have precluded MCPV program investments in developing the suit loop fan, gas trap, and pressure regulator flight designs, although some limited funding to procure prototypes has been allocated.

Current SOA fire suppressants are either Halon or CO_2-based. Halon is being avoided for future architectures because of U.S. Environmental Protection Agency restrictions and because it reacts in the presence of high-temperature catalysts used in the trace contaminant control assemblies to form toxic byproducts. Carbon dioxide suppressants cannot be used in smaller crew cabin volumes without exceeding dangerous levels. For these reasons, replacing the current SOA fire extinguishers is necessary. The ISS is also interested in a replacement for its CO2-based PFE and has invested some development funds in this area.

Due to the lack of quick, emergency return capability in missions beyond low earth orbit, all exploration vehicles will require some sort of deployable "smoke-eater" atmosphere cleanup device, to avoid the need for depress/repress following a fire or contaminated atmosphere event. For the MPCV, requiring the crew to don suits following such an event will likely expose the crew and suit loop atmosphere revitalization equipment to toxic gases; a much safer option is one in which the crew don contingency masks while the cabin atmosphere is scrubbed to safe levels. While the *ISS* Russian segment currently has a deployable smoke eater, no such device currently exists in the U.S. inventory. SOA sorbents and catalysts, which will remove the targeted contaminants, can likely be selected, but a challenge lies in designing a deployable device utilizing an existing fan that will provide the proper flow, head rise, and residence time.

A contingency mask, which the crew dons in case of a fire or toxic spill, is required and can be common for all inhabited exploration elements. Use of an O_2–fed mask is not acceptable for small vehicles due to O_2 enrichment/flammability concerns. A replacement for the SOA O_2 mask on ISS, adapted from a commercial cartridge filtration mask, is under development, and is an enabling need for all missions.

For CO2 removal, SOA technologies primarily employ zeolite or amine-based sorbent beds. For short-duration missions, recovering humidity or

O_2 is not as critical, and a CO_2 removal technology often used functions based on a pressure, or vacuum, swing regenerated amine sorbent. Currently, the MPCV and Primary Life Support System (PLSS) baselines both assume amine swing beds for this function. The downside of this pressure swing is that without additional systems to recover the H_2O or O_2, these resources are vented into space and lost. In shorter-duration missions, this creates no issue, but in longer-duration missions, recovering these additional resources is more critical. Currently, *ISS* employs a zeolite bed that is regenerated using a combination of pressure and temperature swing, which enables downstream resource recovery via a Sabatier CO_2 reduction subsystem. The zeolite material has been subject to breakdown and dusting issues on *ISS*. Robust, non-dusting sorbents, that are compatible with CO_2 capture, are required to enable reliable, long-duration oxygen recovery.

Oxygen generation is required for long-duration missions. The current *ISS* Oxygen Generator Assembly (OGA) and Elektron assemblies have experienced reliability issues and are complex. In the OGA, the baseline electrolysis cell membrane material naturally leaches fluoride (which has led to equipment corrosion issues) and is being phased out by the supplier and must be replaced for future exploration applications. In addition, OGA reliability improvements can be realized through potential elimination of some of the system complexity inherent in the first-generation OGA design.

The capability to recharge high-pressure oxygen tanks is required to enable EVA during long-duration exploration missions where earth-based resupply is prohibitive. Such a capability might be based on compressing oxygen delivered directly from an oxygen generator or from oxygen separated out of a cabin air atmosphere.

On-board trace contaminant monitoring was identified by the assessment team as an enabling capability gap for long duration missions beyond low earth orbit due to the lack of quick and affordable air sample return to earth-based analysis. A subsequent assessment is currently underway with members of NASA's medical and environmental health communities to revisit the criticality and state of the art of on-board trace contaminant monitoring for human exploration space missions.

Common use of SOA High-Efficiency Particulate Air (HEPA) filters for particulate filtration across all Exploration vehicles is likely. Additional surface dust pre-filtering technology development is an enabling need for surface missions, as HEPA filtration alone will likely not be sufficient.

Limited material flammability testing in partial-gravity has revealed that this environment may be more challenging for fire suppression than in either normal or microgravity, as materials may burn in partial-g at lower O_2 concentrations[1]. Additional testing in partial-g environments is necessary to understand this phenomenon prior to surface missions.

<u>Air Management Enhancing Capability Gaps</u> – As shown in Table 3, 15 gaps in air management capabilities were identified as Enhancing. These gaps are summarized as follows:

Spacecraft cabins have historically had high levels of background acoustics emissions from ECLSS equipment. Cabin and equipment cooling fans often are the dominant sources of these emissions. Development of quiet fans can enhance exploration missions by not only reducing background noise levels and improving communication between crewmembers, but can also reduce the need for mass- and volume-adding acoustic foam insulation and in-line mufflers.

With the wide-ranging suite of spacecraft habitats, and EVA equipment that will potentially be needed to support an integrated human space exploration strategy, potentially substantial development, sustaining, and operational cost savings could be realized by developing a common CO_2 bed component. If feasible, such a bed component could designed and sized to be deployed in building-block fashion in any exploration element, with or without upstream and/or downstream equipment added to capture humidity and/or carbon dioxide for subsequent water and oxygen recovery, respectively.

The atmosphere monitoring function includes major constituents (nitrogen, O_2, CO_2, and water vapor), trace contaminants, and airborne microbial monitoring. The current SOA for major constituents is the mass spec-based *ISS* Major Constituents Analyzer (MCA). This technology is considered sufficient for future vehicles; however, enhancements to improve reliability and O_2 accuracy for tighter control at lower operating pressures would be valuable for future missions.

The MPCV will develop and utilize a simpler mass-spec based instrument that can be used for all exploration elements, although funding for this component is currently deferred. Airborne microbial monitoring may only be needed for long-duration vehicles and possibly those in contact with surfaces for planetary protection. The current SOA for *ISS* uses manual culture samples, which is crew-intensive. Contingency sensors, which detect combustion by-product gases (acid gases) and propulsion toxins (ammonia (NH_3)/hydrazine (N_2H_4)) can enhance the effectiveness of emergency detection and response in all exploration vehicles.

Oxygen recovery from CO_2 is only foreseen as a need for longer-duration mission elements, and can leverage SOA *ISS* Sabatier technology at a minimum, which recovers approximately 50% of the O_2 from CO_2. Development of technologies for additional recovery of O_2 from CO_2 can enhance longer-duration missions, and may even be enabling, depending on the mission architecture's ability to accommodate replenishment of consumables. Long life CO_2 compressors and advanced technologies to reduce the volume of stored CO_2 can also enhance exploration missions by reducing logistics and system volume.

Operational experiences on the *ISS* have demonstrated the propensity for atmosphere particulates, including lint, hair, etc, to accumulate quickly on filters protecting air circulation ducts and equipment ventilation fans. Rapid loading of these filters, combined with the difficulty in reaching them in densely packed equipment bays, contributes to substantial crew time demands for periodic filter cleaning. Technologies to extend filter life or provide a regeneration function can enhance exploration missions by reducing dependence on expendable filter elements and crew time for routine maintenance. Long-life filters can also allow for greater flexibility in packaging equipment volumes if routine maintenance is not required.

Trace contaminant control concepts for exploration elements could utilize Shuttle/ISS SOA sorbents and catalytic oxidation technology as-is, but could be enhanced by improved sorbents that would reduce the size and extend the life of these components.

The capability to reduce the power expended to capture and recover humidity separated from CO_2 could enhance exploration missions. The SOA technique on ISS utilizes silica gel desiccants. Recovery of the adsorbed water from the desiccants requires substantial heat input.

State of the art, obscuration-based smoke detectors, particularly in microgravity and particulate-laden environments, are prone to false alarms. Exploration missions can be enhanced by smoke detectors that are less susceptible to false alarms triggered by particulates that aren't associated with smoke or combustion events.

Condensing heat exchanger hydrophilic coatings, treated to retard the growth of microorganisms on the wetted surfaces, are prone to the loss of effectiveness and to material sloughing. These characteristics can, over long duration missions, reduce the efficiency of cabin thermal control and cause contaminant-induced failures in fluid components located in downstream condensate lines. Durable, long life condensing heat exchanger coatings can enhance the efficiency and reliability of long duration exploration missions.

The unique characteristics and potential health hazards associated with surface dust, such as that found on the Moon, will require diligent controls against introducing such dust into spacecraft and surface habitat cabins. The ability to monitor the airborne concentration of lunar dust particulates within cabin environments can enhance long duration surface missions by providing early warning of elevated particulate levels.

<u>Water Management</u> - Functional capability gaps in the area of water management are shown in Tables 4 and 5.

	Missions			
Capability	ISS	1	2	3
Drink bags, launchable full		X		
Additional water recovery from urine or urine brine	X		X	X
Laundry wastewater recovery			?	X
Reduced water processing expendables			X	X

Table 4. Enabling Water Management Capability Gaps

	Missions			
Capability	ISS	1	2	3
Replacement biocide		X	X	X
Backup urine separator		X	X	
Alternate pretreatment	X		X	X
Reliable urine processing	X		X	X
In-line water monitoring	X		X	X
Biological water monitoring			X	X

Table 5. Enhancing Water Management Capability Gaps

<u>Water Management Enabling Capability Gaps</u> – As shown in Table 4, a total of 4 gaps in water management capabilities were identified as Enabling in the assessment. These gaps are summarized below:

As a cost savings measure, outfitting initial versions of the Orion MPCV without fixed metal bellows storage tanks is being considered. In lieu of tanks, the MPCV program would prefer to launch water required to support crew members during the short duration test flights with drink bags filled with water prior to launch. In addition, post-landing water must be stored in bags and survive landing loads. However, SOA drink bags are certified to be launched dry and filled on-orbit. Drink bags that have the integrity to be launched and landed full is an enabling need for early MPCV missions.

The *ISS* Urine Processor Assembly (UPA) was designed to recover up to 85% of the water from urine. For long duration missions (typically considered to be 6 months or longer) beyond low earth orbit, the additional system mass for recovering more water from urine or urine brine begins to trade favorably. Similarly, longer-duration missions can also benefit from the ability to launder and re-use clothing, provided that the resource (weight, power, and volume) impacts of a laundry system itself and water recovery system did not negate the clothing savings. Because of the magnitude of the potential benefits, the needs to recover additional water from urine and to launder and re-use clothing were both identified by the community as enabling needs for long-duration exploration missions.

Reducing water recovery equipment life cycle mass is considered an enabling need. In this context, equipment life cycle mass includes the initial system mass plus the mass of hardware replaced either due to failure or because the useful service life of the hardware had expired. For reference, the life cycle equipment mass "utilized" and potable water "produced" by the ISS SOA WRS is shown in Figure 1. As shown in the figure, from its initial activation through March 15, 2012, the WRS produced over 21,000 lb of potable water. During that time, the cumulative mass of equipment "utilized" had been 5,461 lb, including the initial system mass of 3,042 lb plus 2,419 lb of additional equipment changed out due to either hardware failures (722 lb) or service life expiration (1697 lb). The mass of potable water produced represented approximately 88% of the overall water content available in crewmember urine and humidity condensate combined.

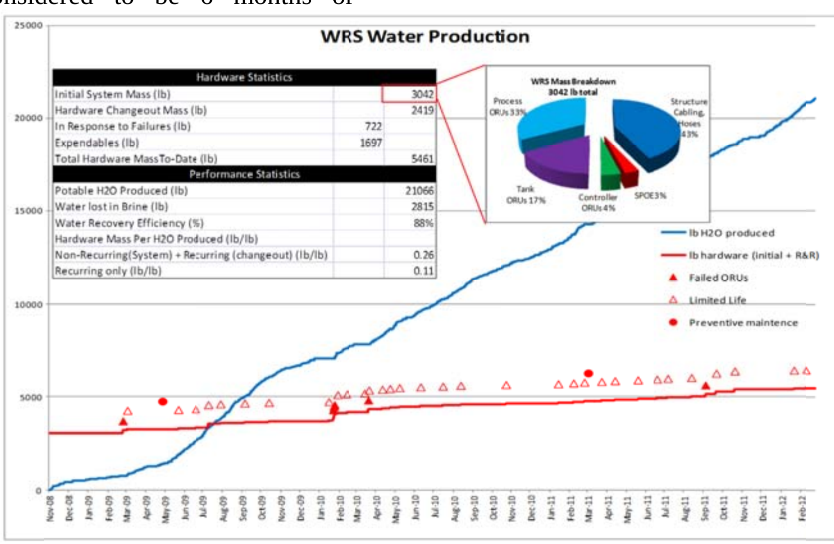

Figure 1. *ISS* Water Recovery System Life Cycle Masses of Equipment Used and Potable Water Produced

Note that the dominating driver in the expendable hardware mass consumed in the *ISS* WRS has been the replacement of UPA Recycle Filter Tank Assemblies (RFTAs). Originally designed to minimize on-orbit crew time and potential exposure to hazardous urine brine, RFTA replacements have exceeded replacements of other failed hardware by about a 2-to-1 ratio (based on mass). The ISS program has developed an Advanced Recycle Filter Tank Assembly (ARFTA) that allows crewmembers to manually transfer brine waste to the Temporary Urine and Brine Stowage System (TUBSS) and the hard-shelled Russian liquid storage containers (EDVs) for manual transfer to logistics modules for eventual disposal, thereby reducing the logistical mass penalty associated with RFTA replacements.

Water Management Enhancing Capability Gaps – As shown in Table 5, 6 gaps in water management capabilities were identified as Enhancing. These gaps are summarized as follows:

The capability to add, monitor, and reduce or eliminate depletion of silver biocide in potable water is an enhancing capability. Although the Russians have the capability to add silver on-line, no such capability has been developed by NASA.

Three enhancing needs were identified relative to managing wastewater. These include developing an alternate urine pretreatment formulation that is non-toxic and mitigates precipitation of calcium sulfate. Precipitation has occurred at lower levels of urine recovery (about 70%) on orbit than on the ground due to higher levels of calcium concentrations in urine from crewmember supplements to offset bone loss. Improving urine processing reliability and its tolerance to precipitation, as well as developing a back-up to a urine spin separator to provide robust redundancy are also enhancing capability gaps.

Two water monitoring capability gaps were determined to be enhancing. An in-line capability to monitor organic and inorganic species in water can enhance exploration missions beyond low earth orbit where the return of water samples to ground-based laboratories for routine checks or contingency troubleshooting will not be possible. Similarly, an on-orbit capability to quantify and identify microorganisms in water samples can also enhance long duration missions by providing the capability to detect and correct contamination events and assess resulting risks to the crew.

Waste Management - Functional capability gaps in the area of solid waste management are shown in Tables 6 and 7.

	Missions			
Capability	ISS	1	2	3
Long term stabilization/ planetary protection			X	X

Table 6. Enabling Waste Management Capability Gaps

	Missions			
Capability	ISS	1	2	3
Wet trash jettison			X	
Trash compaction & dewatering			X	X
Metabolic waste packaging			X	
Odor and trace contaminant control			X	X
Metabolic waste water recovery (if trades show need)			X	X

Table 7. Enhancing Waste Management Capability Gaps

Waste Management Enabling Capability Gaps – As shown in Table 6, one gap in waste management capability was identified as Enabling in the assessment. Long-term (and perhaps indefinite) stabilization of fecal and trash wastes is expected to be required to meet planetary protection requirements for future surface missions.

Waste Management Enhancing Capability Gaps – As shown in Table 7, five gaps in waste management capabilities were identified as Enhancing in the assessment. These include the capabilities to compact, dewater, and jettison wet trash, package metabolic solid waste for the MPCV application, manage odors released from waste management equipment, and recovering water from metabolic solid wastes for missions in which such capability would trade favorably.

Current Status

The findings and recommendations from the assessment team have been presented to NASA program managers responsible for operating the *ISS*, developing the MPCV, planning exploration missions, and developing and maturing technologies to guide budgetary planning and facilitate collaborative investment strategies. It is hoped that this work will also serve as a useful tool for discussing mutual needs and interests with the international space exploration community.

References

1. Ferkul, Paul V., and S. L. Olson, "Zero-Gravity Centrifuge Used for the Evaluation of Material Flammability in Lunar-Gravity", AIAA 2010-6260, 40th International Conference on Environmental Systems, Barcelona, Spain, July 2010.

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Outline

ECLSS is more than an Exploration Element Subsystem…..

It is the infrastructure for expanding human presence in space.

- How we got here
- Roadmapping approach
- Results
- Next Steps

Tight Budget + Exploration Needs = integrated strategic approach for ECLSS capability is a MUST

How We Got Here

- NASA Engineering - Function-based survey of ISS ECLSS (March/April ‘11)
  - What works well; what needs improving
- NASA ECLSS TIM (July ‘11)
  - HQ actions
  - White Paper objective
- Technical community discussions (Aug ‘11)
  - Common functional breakdown
  - Mission scenarios
  - Hardware commonality
  - Atmosphere requirements
- White Paper effort (July-Dec ‘11)
  - Facilitated through Thermal/ECLSS Steering Committee
  - Broad participation of Agency-wide experts
  - Compilation, organization, condensation of results
- Up and Out (Dec-Jan)
  - Presentations to HEOMD, ISS, MPCV, OCT, and AES stakeholders
  - Positive feedback; follow-on budget inputs for specific gaps identified
  - Actions to socialize with industry and international community

Approach

1. Decomposition of the various functions that are typically performed by ECLSS, down to a level of detail sufficient to assess its adequacy to fulfill future mission needs
2. Definition of three representative exploration mission types, selected to encompass the range of system capabilities likely to be needed to support human exploration objectives
3. Qualitative assessment of the ability of today's state-of-the-art (SOA) ECLSS components and subsystems to meet the needs of the three representative exploration mission types
4. Identification of those instances in which today's SOA capabilities fall short of meeting expected future needs
5. Qualitative prioritization of the capability gaps identified in Step 4 in terms of whether the associated functions enable or enhance the representative mission types.
   – ***Enabling*** = Fulfillment of need is essential to achieving missions
   – ***Enhancing*** = Fulfillment of need would offer improvement over SOA, but is not essential

Stakeholder Relationships

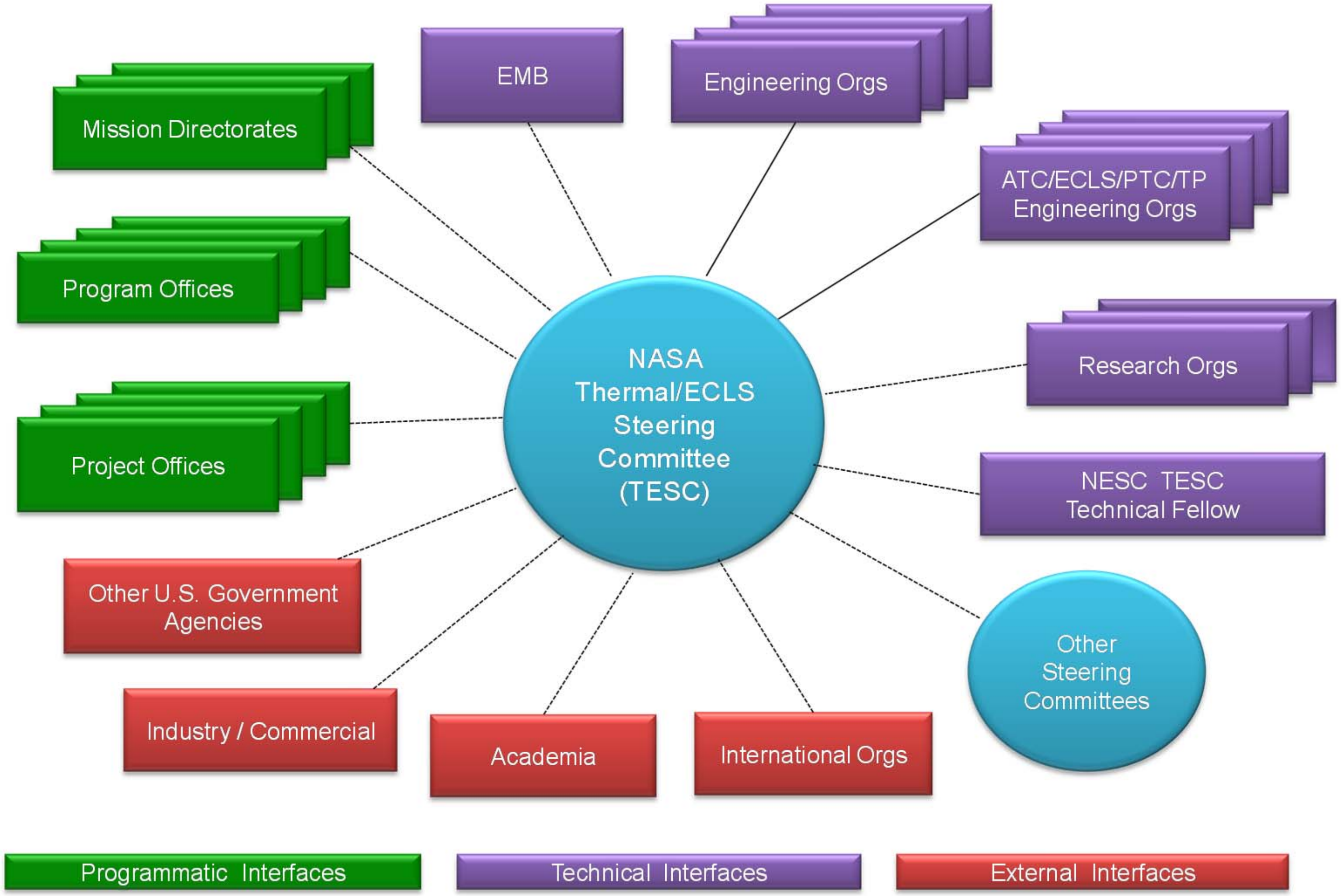


Figure 1

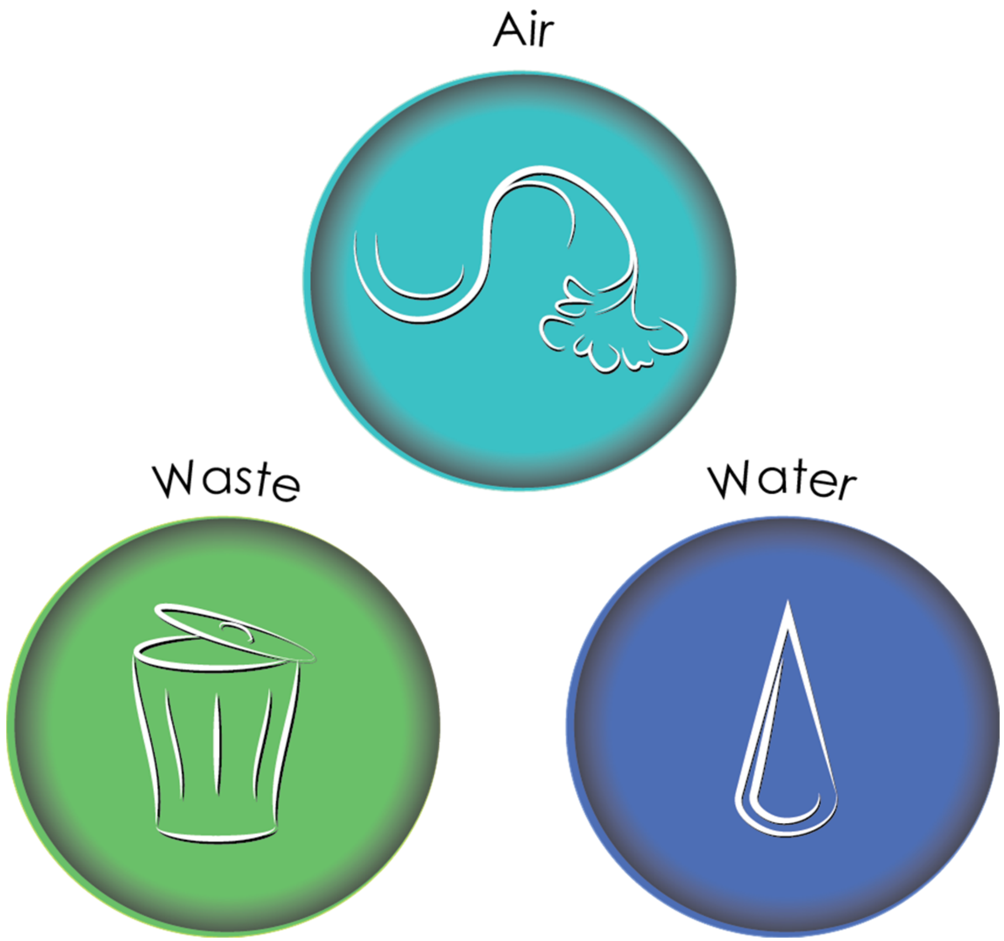
TESC Strategic Relationships

Functional Breakdown

Atmosphere Management
- Circulation
- Conditioning
- Emergency Services
- Monitoring
- Pressure Management

Water Management
- Manage Potable Water
- Manage Waste Water
- Monitoring

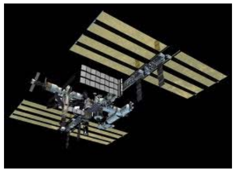
Solid Waste Management
- Manage Logistical Waste
- Manage Trash
- Manage Metabolic Waste



Primary Drivers: 3 ECLSS Mission Types

- ***Reference Mission #1: Short-duration***
  - < 3 - 4 weeks
  - *Examples: MPCV, MMSEV, SEV, Lander*
- Other considerations
  - EVA via an airlock or suitport
  - 8 – 14.7 psia range of cabin pressures (mission & architecture dependent)
  - *MPCV ECLSS proposed as the Point of Departure design for this general scenario*

- ***Reference Mission #2: Long-duration microgravity***
  - > 1 month to years
    - "Derivative increments" can be used to build capability
  - Limited or no resupply available (need for high self sufficiency and reliability)
  - *Examples: ISS, Deep Space Habitat, Man-tended L1/L2 outpost, Long-duration transit vehicle*
- Other considerations
  - EVA via an airlock or suitport
  - *ISS ECLSS proposed as the Point of Departure design for this general scenario*



- ***Reference Mission #3: Long-duration with partial gravity***
  - Similar requirements to the microgravity habitat
  - Evaluate use of advanced or gravity dependent technologies

3 Generic Missions map well into Global Exploration Roadmap and HAT DRM's

Results

Functional Capability Needs – Atmosphere Management - Enabling

Function	Need	Mission				Current Funding
* Blue box denotes enhancing for mid-duration missions (~6 mos)		ISS	1	2	3	
Circulation	**Suit loop fan for MPCV (new, 100% O_2, multiple design points)**		X			Limited MPCV
Temperature Control	**Suit cooling loop gas trap for MPCV (new)**		X			Limited MPCV
Pressure Control	**Suit loop pressure regulator for MPCV (new)**		X			Limited MPCV
Fire Suppression	**Replacement for Halon & CO_2 PFE (small volume, non-toxic)**	X	X	X	X	ISS
Atmosphere Recovery	**Smoke Eater (new, safe atm cleanup)**		X	X	X	AES
Personal Protective Equip	**PPE filtering mask (O_2 mask replacement for small volume O_2 safety)**	X	X	X	X	ISS
CO_2 Removal	**Robust sorbent bed (improvement, solves SOA dusting)**	X		X	X	ISS/AES
O_2 Supply	**OGA reliability improvements**	X		X	X	AES
O_2 Supply	**Oxygen recharge for EVA (new)**	X		X	X	ISS/AES
Monitoring	**On-board trace contaminant monitor (new, SOA ISS flt. expt)**			X	X	ISS/AES
Filtration	**Surface dust pre-filter (new)**				X	AES limited $
Fire Suppression	**Partial-g material flammability testing (new data)**				X	None

Functional Capability Needs – Atmosphere Management - Enhancing

Function	Need	Mission				Current Funding
		ISS	1	2	3	
Circulation	Quiet fan technology (improvement)		X	X	X	None
CO2 Removal	Common bed core/commonality (improvement)		X	X	X	AES
Monitoring	MCA reliability improvements		X	X	X	ISS-MPCV cost share
Monitoring	Fire product sensor improvements		X	X	X	AES
Monitoring	Prop hazard sensor improvements		X	X	X	None
Monitoring	O2 sensor accuracy improvements		X	X	X	None
Resource Recovery	CO2 reduction beyond Sabatier (new capability, possibly enabling depending on trades)	X		X	X	AES
Filtration	Longer life/regen filters (improvement)			X	X	AES limited $
Trace Contaminant Control	Advanced catalysts & sorbents/resource reduction (improve)			X	X	AES
CO2 Removal	Improved water save (lower power)	X		X	X	AES
Resource Recovery	Longer life CO2 compressor (improvement)	X		X	X	AES
Resource Recovery	Smaller interim CO2 storage (improvement)	X		X	X	Other
Monitoring	Airborne microbial monitor (new)	X		X	X	none
Fire Detection	SOA improvements – false alarm, partial-g			X	X	AES
THC	Long duration HX coatings (improvement)				X	none
Monitoring	Surface dust particulate monitor (new)				X	AES

Functional Capability Needs – Water Management

Enhancing for mid-duration missions (~6 mos)

Function	Need	Mission				Current Funding
		ISS	1	2	3	
Water Supply	**Launchable/landable full drink bags**		X			MPCV (FY15)
Urine processing	**Increased water recovery from urine (brine reduction or processing) (enhancing for missions <6 months)**	X		X	X	None
Laundry wastewater collection	**Develop laundry capability (enhancing for missions <6 months)**			?	X	None
Wastewater processing	**Reduce Expendables, accommodate laundry (improvement)**			X	X	AES/OCT
Microbial control	Replacement biocide (silver)		X	X	X	None
Urine collection	Backup to spin separator (new, robust redundancy)		X	X		None
Urine pretreatment	Alternate pretreat (lower tox, no precip)	X		X	X	ISS/AES
Urine processing	Improved reliability, tolerance to precip., calcium monitor	X		X	X	ISS/AES
Water Chemistry Monitoring	In-line capability required – organic and inorganic species	X		X	X	AES
Biological monitoring	Microbial monitor w quant. and ident. (new)			X	X	None

Enabling **Enhancing**

Functional Capability Needs – Solid Waste Management

Function	Need	Mission				Current Funding
		ISS	1	2	3	
Stabilization – trash and fecal	**Long term stabilization/planetary protection (new)**			X	X	AES
Wet trash disposition	Jettison capability (if dumped)			X		None
Wet trash – storage & resource recovery	Compaction & dewatering (new)			X	X	AES
Metabolic waste	Common commode - compact		X	X	X	none
Metabolic waste	Odor, trace contaminant control long duration improvement			X	X	AES partial
Metabolic waste - water recovery	If trades show needed			X	X	None

Enabling **Enhancing**

Next Steps

- Population of a "tracking tool" identifying necessary steps to achieve each need, current funded efforts (NASA, industry, academia, international), budgets.
  - Tool to be used to aid in coordination and communication with stakeholders and projects so that most critical needs and next steps are addressed with limited resources
- Communicate needs with industry, academia, and international ECLSS community to foster cooperation and partnerships.
- Periodically update as Exploration roadmaps, DRMs, and timelines evolve.
- Continue to develop budgets and detailed plans.
- Augment with Environmental Health updates.