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Environmental Control and Life Support (ECLS) Integrated Roadmap Development

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Executive Summary

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 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.

The key findings resulting from this effort are summarized by Mission category below.

Mission 1 Needs:

- Ensure adequate funding for Multi-Purpose Crew Vehicle (MPCV) key development items to support crewed flight including the following areas:
    - Suit loop fan, cooling pump, and oxygen (O_2) regulator
    - Sensors and emergency equipment
    - Integrated system ground testing
- Leverage Advanced Exploration Systems (AES) resources to aid in Mission 1 needs
- Continue to leverage International Space Station (ISS) development of fire extinguisher and contingency mask
    - This need is common across all three mission types

Mission 2 Needs:

- Solve key reliability issues:

    - O_2 Generator
    - Regenerative Carbon Dioxide (CO_2) removal with resource recovery
    - Urine processor

- Add capabilities:
    - O_2 recharge for Extra-Vehicular Activities (EVA)
    - Brine processing
    - Improved on-orbit air and water monitoring capability and reliability

- Improve upon existing capabilities:
    - Reduce water processing logistics
    - Obtain additional resource recovery from CO_2
    - Improve upon pre-treats and biocides

- Demonstrate improved reliability and new capabilities
    - Ground testing (e.g., bench-top, component, and/or subsystem levels)
    - Flight tests/demos
    - Culminating in a long-duration, integrated ECLSS ground test prior to full system deployment beyond LEO

Mission 3 Needs: (as funding becomes available)

- Laundry, Long-term waste stabilization

Due to the timeline for completing Missions 1 and 2 within known budget constraints, Mission 3 assessment received less focus in this white paper. However, many of the capabilities required for Mission 3 are simply extensions or augmentations of Mission 2 capabilities.

The ECLSS technical community has developed a general roadmap framework that pursues short-duration operations (which inherently develops and utilizes MPCV ECLSS), pursues long-duration operations (improving, demonstrating and utilizing upgraded ISS ECLSS capabilities), and highlights the common needs for integrated ground and flight testing, regardless of destination. This framework must be tailored as specific mission requirements are developed. Specific requirements such as crew size, mission duration, EVA requirements, or the availability of resupply can (either separately or together) dramatically affect the selection of system designs and technologies.

In the current NASA environment, the most efficient strategy for advancing ECLSS needs is to:

1. Complete the MPCV ECLSS hardware development currently on hold due to budget constraints (termed as wedge work),

2. Perform targeted ISS demonstrations to address reliability issues and add capabilities, and

3. Pursue a rigorous ground testing program.

While proposed Exploration Test Module (ETM) and Deep Space Habitation (DSH) flight demonstrations would provide some ECLSS advancement benefits, they are not considered a necessary component of the ECLSS roadmap. Procurement of additional copies of MPCV and ISS hardware can be utilized to support ETM and DSH demo objectives.

Currently, the ECLSS budget and activities are spread across the ISS, MPCV, AES, and the Office of Chief Technologist (OCT) Game Changing Technology (GCT) programs, which all have common technical goals, but separate unique requirements. With each program individually underfunded, the amalgam of funding is likely still not enough to completely address the critical needs. The strategic plan developed within this paper must be coordinated with stakeholders from these programs to prioritize funding to the most critical needs and integrate plans to support those needs. Once that is completed, budgetary estimates can be developed for the remaining work needed, to support the integrated NASA budget submit in for fiscal year (FY) 13.

The preparation of this whitepaper was guided and supported by the Thermal/ECLSS Steering Committee (TESC), which is made up of technical discipline management representatives from each NASA center and the Jet Propulsion Laboratory (JPL). In addition, two NASA Engineering and Safety Council (NESC) technical fellows act as ad-hoc members of the TESC. ECLSS technical SMEs from each of the centers and the NESC provided significant material and support that culminated in this paper.

Acknowledgements

This paper was supported by the efforts of ECLSS technical experts from across the Agency. Information and material provided by those experts was coordinated into this paper by:

- Jordan Metcalf, JSC
- Robyn Carrasquillo, MSFC
- Laurie Peterson, JSC
- Bob Bagdigian, MSFC
- David Westheimer, JSC

Introduction

Purpose

This white paper documents a roadmap for development of Environmental Control and Life Support (ECLS) Systems (ECLSS) capabilities required to enable beyond-Low Earth Orbit (LEO) Exploration missions. In many cases, the execution of this Exploration-based roadmap will directly benefit International Space Station (ISS) operational capability by resolving known issues and/or improving overall system reliability. In addition, many of the resulting products will be applicable across multiple Exploration elements such as Multi-Purpose Crew Vehicle (MPCV), Multi-Mission Space Exploration Vehicle (MMSEV), ~~Development Support Hardware~~Deep Space Habitat (DSH), and Landers.

Within the ECLS community, this white paper will be a unifying tool that will improve coordination of resources, common hardware, and technologies. It will help to align efforts to focus on the highest priority needs that will produce life support systems for future human exploration missions that will simply “run in the background,” requiring minimal crew interaction.

Scope

This paper defines a strategy to develop ECLSS capabilities that are necessary for Exploration missions, based on those identified in Human Space Flight (HSF) Architecture Team (HAT) studies. The list of necessary capabilities was developed by examining the current state of the art hardware, determining whether it is sufficient to meet projected Exploration mission objectives and if not, what additional development is required. Priority was given to use of existing flight-qualified hardware and/or use of common components in multiple vehicles where possible to reduce overall lifecycle costs.

The strategy also includes technology development efforts encompassed by the ISS, MPCV, Office of Chief Technologist (OCT) and Advanced Exploration Systems (AES) programs, and maps those to the relevant capability needs. Recommendations for additional development, including ground testing and on-orbit ISS demonstrations, are provided to address needs of two fundamental yet different ECLSS objectives: 1) a long-duration habitation vehicle, and 2) a short-duration transit vehicle; both are laid out along projected timelines.

It is important to note that this white paper does not include ECLS-related thermal control strategies. Though thermal control is sometimes combined with ECLSS, it is a uniquely complicated system that requires as much attention to detail as has been paid to ECLS in this paper. The only ECLS-specific temperature control addressed by this ECLS white paper is related to conditioning the air (i.e., a condensing heat exchanger (HX)).

Background

In the spring of 2011, an ISS functionality survey was developed and presented to multiple ECLS SMEs to assess the qualitative understanding of the functionality and reliability of existing ISS ECLS hardware. Information from this survey was utilized as a starting point to identify those ECLSS functions for which existing hardware is or is not expected to be sufficient for anticipated Exploration missions.

In July, 2011, a request came to the ECLSS technical community from the Exploration and Science Mission Directorate (ESMD) Integration Office to prepare this white paper in support of Agency planning activities for Exploration beyond Low Earth Orbit. It was requested that this plan utilize the ISS, planned ETM, or DSH as flight demonstration platforms.

On July 6, 2011, an ECLSS Integration Technical Interchange Meeting (TIM) was held at Johnson Space Center (JSC) to review and discuss ECLSS capabilities in support of Exploration objectives. The meeting was attended by 1) ECLSS technical community members from several centers including JSC, Marshall Space Flight Center (MSFC), Ames Research Center (ARC), and JPL, 2) Headquarters (HQ) representatives (Doug Craig, Chris Moore, Mike Hembree, Jitendra Joshi) and 3) Mike Gernhardt, representing the Space Exploration Vehicle (SEV). Starting with an overview of ECLSS for MPCV, SEV, and DSH, the meeting also included a status of ECLSS capabilities in the existing flight programs (Shuttle & ISS). An objective of the meeting was to prepare for a status with the ISS Program Manager on July 14, 2011, to discuss plans for a portfolio of demonstrations onboard ISS. Technology development (Exploration Technology Development Program (ETDP), OCT and AES plans), ISS Testbed for Analog Research (ISTAR), and other activities were also discussed. A follow-on pair of meetings was planned to 1) create an ECLSS development and demonstration strategy; and 2) to satisfy a HAT action item to a) revisit the proposals of the Exploration Atmospheres Working Group (EAWG) and b) assess the potential use of common ECLSS hardware items across multiple vehicles. Those meetings were held on August 1-2, 2011, and August 3-4, 2011, respectively.

The development and review of this document, related studies and other associated activities are led by the ECLSS swim lane leads and supported by the TESC, formed by NASA's Office of Chief Engineer (OCE) in March 2010. The TESC is one of several technical discipline steering committees formed as part of an Agency-wide effort to help integrate major functions for human spaceflight. The NASA TESC Charter commissioned line management from each center to 'bring engineering leadership together to continually improve the state of the discipline including workforce and facilities. Specifically, the TESC is tasked with 'developing a common vision and strategy' by: a) Promoting discipline-wide collaboration, b) Advancing and maintaining the state of the disciplines ahead of anticipated Agency needs, and c) Advancing current and next generation ECLS technologies. A copy of the TESC Charter is listed in Appendix B for reference.

Appendix B describes the systematic approach used to develop the ECLS Integrated Roadmap. This white paper contains more material than originally requested by ESMD management; however, this information will be used as an on-going reference to help maintain coordination across the ECLS community.

Goals

The specific goals of this strategic roadmap development, all based on ECLS community integration, were three-fold:

1. Determine the appropriate ECLS functions and capabilities for future missions (assuming three generic mission scenarios: a short-duration micro gravity mission (MPCV/SEV-like); a long-duration microgravity mission [ISS-like with low/zero resupply]; and a long-duration partial-gravity (surface) exploration mission).
    a. Utilize existing hardware/technologies where possible to minimize life cycle cost, and schedule while maintaining functionality and increasing corporate experience.
    b. Increase reliability of existing hardware/technologies (i.e., ISS ECLS) to benefit current and future missions.
    c. Reduce crew time for maintenance, sustaining operations and repair of ECLS (e.g., through design for maintenance, in-line instrumentation, internal data logging and periodic reporting).
    d. Develop new technologies as needed to fill identified gaps in reliability and functionality that will be required for future missions.
2. Determine what component-level and integrated ECLS ground configurations could/should be tested.
3. Determine what integrated ECLS flight test configurations could/should be tested (i.e., ISS improvements & demos).

ECLS Stakeholders & Customers

Step 1 of the process involved bringing together the community of ECLS experts and stakeholders across the agency. The ECLS community consists of experts residing at multiple NASA centers working with multiple programs and projects. In many cases, SMEs support multiple projects, which facilitate integration of the ECLS discipline across the agency. Figure 1~~Figure 1~~ depicts where these various experts reside.

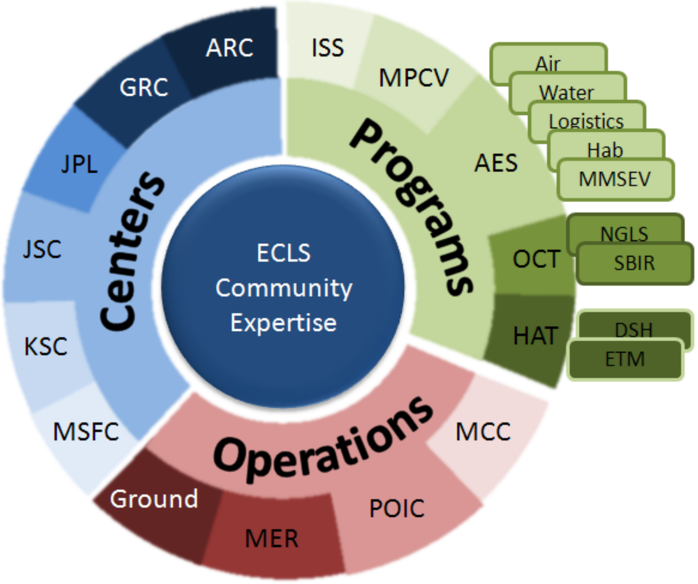


Figure 1. ECLS Stakeholders & Customers

Many of these ECLS SMEs contributed to the creation of this ECLS Integrated Roadmap. The primary contributors are listed in Table 1. These key SMEs include TESC members, project managers for technology development activities in AES and OCT, ISS system management, MPCV system management.

Table 1. ECLS Integrated Roadmap Development Contributing ECLS SMEs

Team Members	Center
John Fischer, Michael Flynn, John Hogan, Mark Kliss*	ARC
Juan Agui, Mojib Hasan, Michael Hicks, John McQuillen, Brian Motil*, Gary Ruff, Bhim Singh, David Urban	Glenn Research Center (GRC)
Jen Keyes	Langley Research Center (LaRC)
Murray Darrach, Bob Gershman, Margie Homer, Darrell Jan*	JPL
Molly Anderson, Richard Barido, Dan Barta, Jim Broyan, John Cover, Jason Dake, Mike Ewert, Don Henninger, John Lewis, Brian Macias, Jordan Metcalf*, Julie Mitchell, Laurie Peterson, Karen Pickering, Branelle Rodriguez, Laura Shaw, Imelda Stambaugh, Jeff Sweterlitsch, Stephanie Walker, Mary Walsh, Dave Williams	JSC
Matt Craycraft*	Kennedy Space Center (KSC)
Morgan Abney, Bob Bagdigian*, Robyn Carrasquillo, Layne Carter, Jim Knox, Jay Perry, Monsi Roman	MSFC
Hank Rotter*	NESC

** Denotes TESC Member*

ECLSS Functional Decomposition

The ECLSS is a complex system of systems that performs many critical functions. The top-level, primary functions performed by the ECLSS, illustrate in Figure 2, are Atmosphere Management (AM), Water Management (WM), and Solid Waste Management (SWM). While defined as separate functions, they are very interdependent and must be properly integrated to maintain balance at the higher ECLSS functional level. The degree of interdependency, and therefore the difficulty, in maintaining that balance increases directly with the degree of resource recovery required of the ECLSS to meet specific mission objectives.

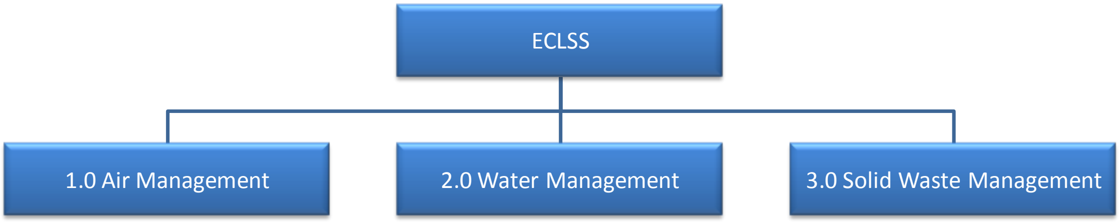


Figure 2. ECLS Top-Level Functional Decomposition

Each of these primary functions include many sub-functions (i.e., CO_2 removal, atmospheric pressure control, smoke detection & fire suppression, potable WM, the “potty”, etc.) A basic decomposition of the three primary ECLSS functions is included later in the sections that address those functions. However, a full decomposition to the component level is included in Appendices C, D, and E for AM, WM, and SWM, respectively.

Short- vs. Long-Duration ECLSS

Generally speaking, ECLSS requirements dictate one of two distinct design approaches: one that supports short-duration missions (up to a few weeks), the other that supports long-duration missions (months to years). The distinction between the two lies in the difference in launch mass and volume required to support the mission duration. The total mass and volume of air and water (and the associated system hardware) required to support crew metabolic needs for short-duration missions is usually less than the mass and volume of just the hardware required to reclaim and reuse those resources.

Open-loop ECLSS designs (similar to Apollo and Shuttle) that operate based on resource consumption and non-use of metabolic waste products are therefore more appropriate for the shorter-duration missions. These designs are also less complex and interdependent, and have been matured to a very high level of reliability vs. usage time. A basic depiction of the open-loop versus closed-loop mass trade is shown in Figure 3. The mass in the Figure represents hardware mass plus total consumables. The thickness of the bars indicates a level of uncertainty associated with each mass estimate. This uncertainty is based on assumptions with respect to technologies or mission requirements.

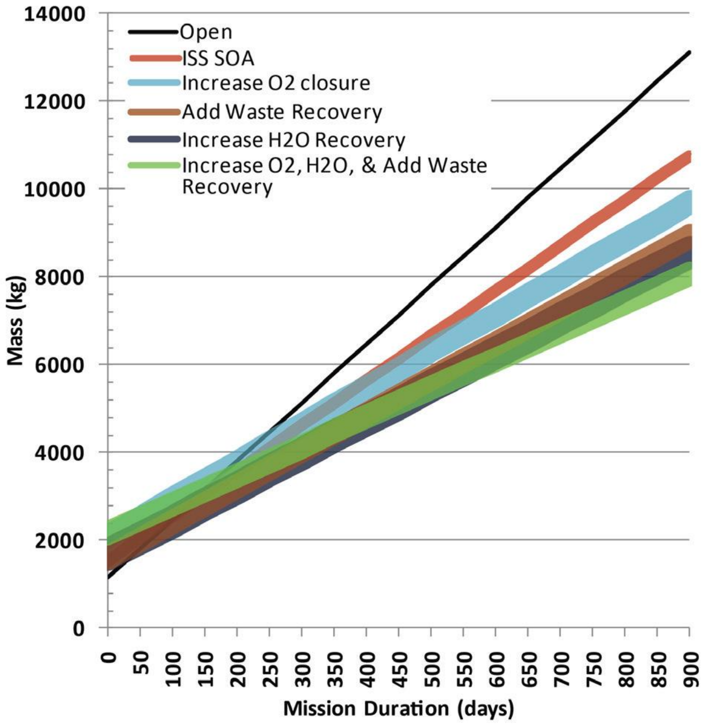


Figure 3. Representative Comparison of Mass Required by Mission Durations

Increased recovery of air and water resources is important in longer-duration missions. As shown in Figure 3, mass and volume of an open-loop ECLSS increases linearly with mission duration, becoming prohibitively large for months-to-years-long missions beyond LEO. The absence of a nearby resupply source also increases mass and volume needs to carry adequate maintenance components and/or contingency supplies that enable self-reliance for crews that are far from home. Another factor to consider besides open versus closed loop ECLS systems is distance from the Earth. As an example, reliability for a mission that is 'close to Earth' may not be as critical as a mission months or years from Earth. Unlike LEO missions where return to Earth can be accomplished in just hours, beyond-LEO missions do not have sympathetic abort scenarios. Thus, the crews' dependence on their ECLS for survival is key. Demonstrating the reliability needed to send crews on long-duration missions beyond LEO requires adequate ground and life testing. This includes ground testing components, subsystems, and highly-coupled subsystems; and fully integrated ECLS system testing with humans in the loop to provide a high-fidelity test environment. This activity is relatively low-cost (compared to flight experiments) and very low-risk because it is possible to stop the test, fix the problem, and restart. Ground testing, especially integrated systems testing with humans in the loop for durations approximating the intended missions, is crucial to identifying and controlling risks. In addition to a rigorous ground test program, targeted flight demonstrations are important for processes considered sensitive to microgravity, and long-duration on-orbit testing can improve confidence that resulting systems are robust before deploying on a long-duration crewed mission far away from Earth. The balance between ground and flight testing is an important factor considered in the integrated ECLS roadmap.

Generic Mission Definitions

Because of the distinction between short- and long-duration missions in the design of ECLS systems for Exploration, and also because detailed mission objectives are still being assessed, three generic mission categories were defined for the development of this roadmap. The community believes these missions will form the basic starting points for specific Exploration missions as they evolve in the future. Characteristics of these representative mission types are listed below.

1. A short-duration, micro-gravity mission (Mission 1)
    a. Examples include: MPCV, MMSEV, Lander, ETM
    b. Duration: 3-4 weeks
    c. EVA via an airlock or suitport
    d. 8-14.7 psia range of cabin pressure depending on specific mission
    e. Assumes MPCV technologies are used as a point of departure
2. A long-duration micro-gravity mission (Mission 2)
    a. Examples include: ISS, DSH, Long-duration transit vehicle
    b. Duration: >1 month to years
    c. EVA via an airlock or suitport
    d. 10.2 psia, 30% O_2 atmosphere
        - (Note: the 10.2 psia/30% O_2 atmosphere is an interim starting point for the long-duration microgravity mission based on conclusions reached by the ECLSS, M&P, and medical representatives at the August 2011 workshop. While 8 psia/34% O_2 is the goal for missions where rapid EVA is an objective, it will require additional material certification, heritage hardware recertification, and limit material choices (with potential resulting mass impacts). This approach must be traded with operational workarounds (such as limiting the 8 psia/34% environment to design of the MMSEV and common components used within it) as Exploration missions and architectures become more defined.
    e. Assumes ISS technologies are used as a point of departure
    f. Limited or no resupply available (need for high self-sufficiency and reliability)
    g. Difficult mission abort scenarios
3. A long-duration, partial-gravity surface exploration mission (Mission 3)
    a. Similar requirements to Mission 2 but must take into account the effects of partial gravity

A fourth, “mid-duration” mission (Mission 4) lasting about six months may be an important distinction to be made in future updates to the strategic roadmap, as not all ECLSS needs for a long-duration mission would be applicable for a mid-duration mission. This refinement will be considered as the definition of Exploration missions matures.

ECLSS Functions and Gap Assessment

The following section provides a detailed functional description and gap assessment for the three major ECLSS functions: AM, WM, and SWM. For each of these functions, each subsection provides 1) a description including current SOA, 2) an assessment whether that SOA is sufficient to meet anticipated Exploration architecture needs, and 3) a review of potential hardware commonality based on the August workshop. Gaps where current SOA does not meet anticipated needs for the three representative missions are highlighted, and also included is a discussion of whether these gaps are currently being addressed through funded development efforts. Gaps are categorized into enabling (the mission cannot be accomplished them) and enhancing (the mission could be accomplished, but improvements to them could reduce resources or provide additional desirable capability).

1.0 Atmosphere Management (AM)

Functional elements of AM include process technologies and equipment components utilized to maintain a habitable atmosphere within a vehicle or habitat. The major AM functions are circulation, conditioning, emergency services, monitoring, and pressure management.

Circulation

The circulation function includes cabin fans, which circulate air within the habitable volume, inter-module ventilation fans, which provide circulation between docked elements, and process-specific fans (e.g., flow air through CO_2-removal beds). Various SOA fans for Shuttle and ISS exist that are sized based on cabin volume, flow rate, and pressure-drop requirements. Cabin ventilation fans for Exploration elements can likely be scaled from heritage ISS or Shuttle designs without requiring new development. MPCV, SEV, MMSEV, and Landers can likely utilize common cabin fans as they all have similar cabin volumes. DSH and Surface Hab may be able to utilize ISS fans or common fans with the short-duration vehicles, depending on total volume/flow needed. Only the MPCV requires a post-landing “snorkel fan,” but this can also be based on heritage technology.

The community identified two development needs. First, an enabling need, the MPCV design requires a unique fan, similar to those used in Apollo, to circulate air through the “suit loop”, which purifies air for the crew while they are wearing suits. This fan also circulates air within the cabin when crewmembers are not in suits. No SOA fans meet the multiple pressure/flow rate design points and 100% O_2 environment necessary when the crewmembers are in suits. A stereo lithography development fan was produced for MPCV before funding for further ECLSS development was deferred, and was recently tested at ambient pressures in an integrated suit loop ground test. Funding for further development of this fan remains on hold until at least FY13.

Second is a desire to reduce fan acoustic emissions through a “quiet fan” technology being addressed with some limited funding at GRC. This is considered an enhancing need since SOA fans, though noisier than desirable, can meet acoustic requirements with appropriate acoustic treatments.

Conditioning

Atmosphere conditioning includes the following functions: atmosphere temperature and humidity control, particulate filtration, CO_2 and trace contaminant removal, and resource recovery from CO_2.

SOA temperature and humidity control equipment has typically included condensing and non-condensing HXs and water separators, although open-loop architecture concepts may utilize sorbents for humidity control with subsequent overboard venting if water savings is not necessary. The MPCV is planning a non-condensing HX for cabin temperature and humidity control via pressure-swing adsorption beds with overboard venting. The SEV, Landers, and Surface Hab can use common condensing HXs and gravity-based water separators, while the MMSEV and DSH can use common condensing HXs and microgravity-compatible spin separators, all based on SOA ISS or Shuttle technology. In addition, the MPCV requires a suit cooling loop for which the pump is considered an enabling development need with funding currently on hold (wedge work). NASA is performing a pump trade study in FY12 to begin to identify candidate technologies. Identified as an enhancing need, a desire also exists to improve the SOA HX coatings, which have been problematic for both ISS and Shuttle.

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. Also, improvements in filtration technologies to extend life or provide a regeneration function are seen as enhancing needs for longer-duration missions. The AES Atmosphere Resource Recovery and Environmental Monitoring (ARREM) project plans to study and test candidate technologies for surface dust pre-filtering and regenerative filters, although the funding allocated to this effort is very limited.

For CO_2 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. Despite the basic constraints with these two technologies, recent activities have extended the capabilities of both sorbents. Through ISS Carbon Dioxide Removal Assembly (CDRA) operations and technology development efforts, many advances have been made with zeolites, including improvements in sorbent performance, system design, and reliability. The CO_2 and Moisture Removal Amine Swing Bed (CAMRAS) flight demonstrator currently on-board ISS is a pressure swing amine-based system that adds components to capture and save water and ullage air, making it more applicable for longer-duration missions. Based on these advances for both candidate sorbents, the ECLSS community sees as a realistic possibility that a single sorbent bed "core" technology be made common across every Exploration vehicle, regardless of mission duration, with additional components for H_2O and CO_2 recovery added as needed around the core. The AES ARREM project will conduct a trade study to explore this concept in more technical detail. In addition, the ISS program is currently pursuing efforts for a more robust sorbent bed retrofit for the current, while AES- and OCT-funded efforts are making additional improvements to CO_2 sorbent and water save technologies.

Resource recovery from CO_2 is only foreseen as a need for longer-duration mission elements (DSH & Surface Hab), 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 is at minimum a mission-enhancing need for longer-duration missions, and may even be enabling, depending on the mission architecture's ability to accommodate replenishment of consumables. Both AES and OCT are funding development work in this area. AES and alternate funding (grants) are addressing a desire to improve CO_2 compressor life and reduce the size of interim CO_2 storage associated with resource recovery from CO_2 are other mission-enhancing needs.

Trace contaminant control concepts for Exploration elements could utilize Shuttle/ISS SOA sorbents and catalytic oxidation technology as-is, or could benefit from improved advanced sorbents that would reduce the size and extend the life of these components (enhancing). The AES program is currently compiling recommendations relative to the best available sorbents and catalysts to potentially retrofit into existing bed designs. Whether the SOA or improved materials are used, the resulting technology can and should be made common across the Exploration architecture.

Emergency Services

Another AM functional element involves emergency services needed to detect, respond to, and recover from cabin atmosphere contamination events caused by thermal decomposition (e.g., fire) or chemical releases. SOA obscuration-based smoke detectors can be utilized across all vehicles, though AES efforts are addressing the desire to eliminate false alarms (enhancing). Surface dust detection for crew protection against these smaller particulates may be required for all Exploration vehicles except MPCV, and is also listed as a mission enhancing need for surface missions.

Current SOA fire suppressants are either Halon or CO_2-based. Halon is being avoided for future architectures because of EPA restrictions and also because it reacts in the presence of high-temperature catalysts used in the Trace Contaminant Control Subassembly (TCCS) to form toxic byproducts. Further, CO_2-based 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 leading development candidate is a water mist portable extinguisher currently in an early development stage and funded by ISS, which could then be utilized by MPCV and all other future elements. The DSH and Surface Hab will also likely require an inert-gas flooding-type system for equipment bays, especially during long dormant periods. Engineering a reliable automated detection/suppression system for uncrewed, dormant elements is an enabling need for longer-duration missions. Finally, 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. Additional testing in partial-g environments is necessary to fully understand this phenomenon prior to surface missions. There is currently no funded work addressing either of these two areas.

A contingency mask, which the crew dons in case of a fire or toxic spill, is required and can be common for all elements. 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. O_2 is not an acceptable contingency mask for small vehicles due to O_2 enrichment/flammability concerns.

All 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 United States (U.S.) inventory. SOA sorbents and catalysts, which will remove the targeted contaminants, can likely be selected, but a challenge lies in designing a device deployed by an existing fan that will provide the proper flow, head rise, and residence time. AES air and fire projects are combining efforts to initiate a study in FY12.

Finally, contingency sensors, which detect combusted gas (acid gas) and propulsion toxins (ammonia (NH_3)/hydrazine (N_2H_4)), are needed for each element; the same sensor design can be used on all vehicles. AES is addressing potential improvements to the ISS SOA Compound Specific Analyzer-Combustion Products (CSACPs) for acid gases, and MPCV has begun to investigate the use of Commercial-Off-The-Shelf (COTS) sensors for NH_3/N_2H_4. Funding for the latter has been put on hold as of FY12.

Monitoring

The monitoring function includes major atmosphere constituents (nitrogen (N_2), O_2, CO_2, water (H_2O) vapor, methane (CH_4)), 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 are valuable for future missions. No funded efforts currently address either of these enhancing needs. The MPCV will develop and utilize a simpler mass-spec based instrument that can be used for all elements, though funding for this component is currently deferred (wedge work).

The current SOA for trace contaminant monitoring on ISS utilizes grab samples for ground analysis. Several experimental instruments for on-orbit monitoring have been flown as flight demos, with some good results. Short-duration Exploration vehicles should not require on-board trace contaminant monitoring. Long-duration vehicles subject to risk of contaminant buildup, such as the DSH and Surface Hab, will require an on-board monitor as an enabling function, and can likely select from instruments demonstrated on ISS. AES is also investigating potential trace contaminant monitors for both air and water. 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 "petri-dish" samples, which is crew-intensive. No funded development currently exists for microbial monitoring.

Pressure Management

Pressure management includes the maintenance of cabin total pressure and O_2 and N_2 partial pressures, including the replenishment of metabolic O_2 consumption and leakage. Also included is the ability to resupply EVA suits with high-pressure O_2. The SOA includes high-pressure tanks, valves, and regulators, as well as positive and negative pressure relief valves. The ISS Regenerative ECLSS includes an O_2 generator to supply O_2 to the cabin via H_2O electrolysis.

Exploration vehicles requiring a suit loop (MPCV, Lander) can utilize common pressure regulation components. Concepts are currently leveraging off PLSS regulators, but need to be sized for the emergency "feed-a-cabin-leak" scenario as well. Funding for this enabling component is currently deferred (wedge work) for MPCV, though a small amount of development budget was approved to purchase a development regulator for integrated suit loop testing in FY12/13.

For cabin pressure control, the MPCV is currently assessing the use of common propulsion system components for cost efficiency. SEV, MMSEV, and Landers may either use MPCV or PLSS components, and DSH and Surface Hab either ISS or MPCV components. No specific enabling or enhancing technology development needs were identified for this particular function.

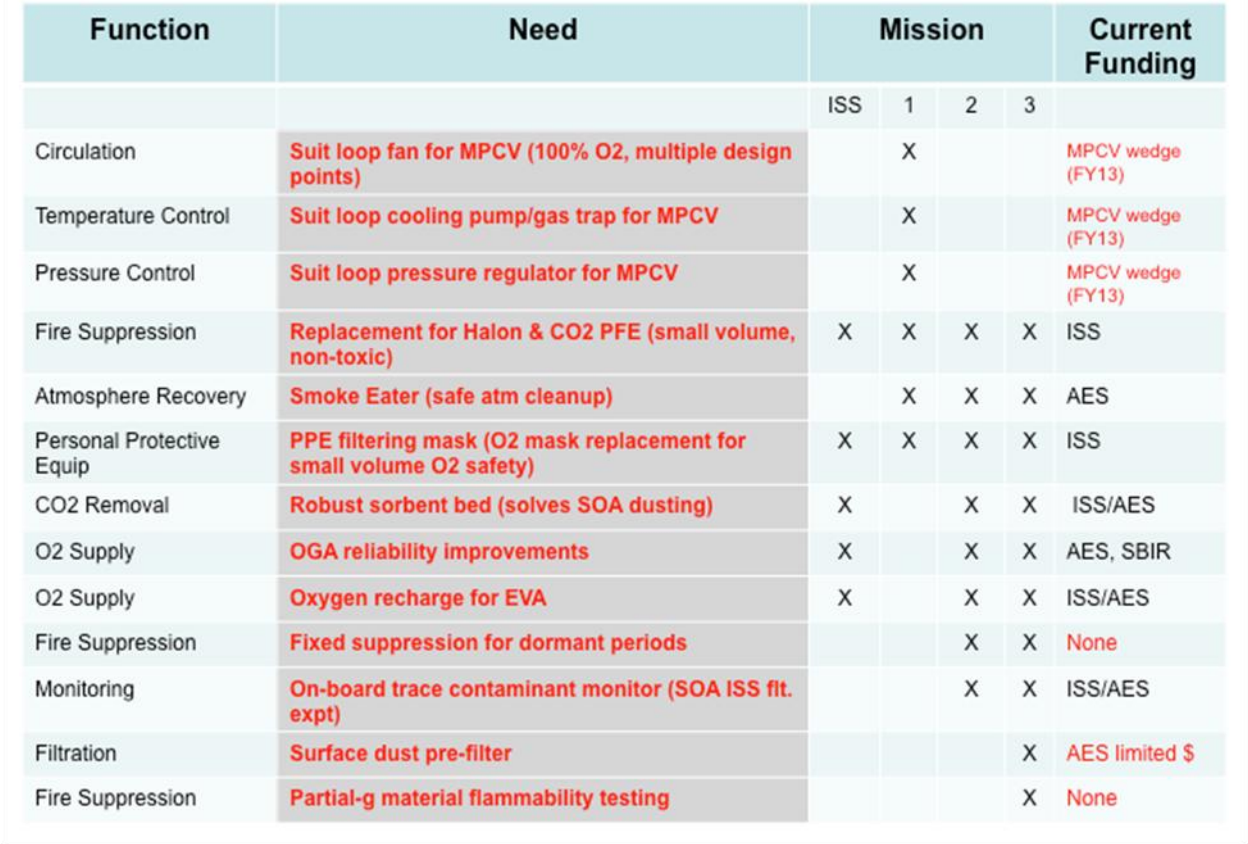
Positive pressure relief valves can be common across all vehicles, depending on to the valve size needed for equipment bay fire suppression. The MPCV is currently pursuing avionics bay flammability testing to eliminate the need for equipment bay fire suppression altogether, in which case a uniquely-sized Positive Pressure Relief Valve (PPRV) would be unnecessary and ISS-heritage PPRV can be used. The need for negative pressure relief is unique to MPCV, and must be water sealing, which prohibits the use of heritage components. A design concept has been selected and is currently funded for the MPCV Exploration Flight Test 1 (EFT-1).

O_2 and N_2 high-pressure storage tanks can be common Composite Overwrapped Pressure Vessels (COPVs) across all elements. DSH and Surface Hab may either use high-pressure tanks or cryogenic technology, depending on architecture trades. High-pressure O_2 recharge is an "enabling need" for long-duration missions, including EVA. The ISS Program is currently funding Cabin Air Separator for EVA Oxygen (CASEO) development, which may serve Exploration architecture needs as well.

O_2 generation is required for long-duration missions and can be based on ISS heritage technology. However, the current ISS Oxygen Generator Assembly (OGA) has experienced reliability issues and is complex, creating an enabling need for improvement for future missions. At a minimum, the current Nafion membrane material is being phased out by the supplier and must be replaced with a new material proven to leach four times less problematic fluoride than the current material, which will reduce corrosion risk. In addition, reliability improvements can be realized through potential elimination of the hydrogen sensor, reexamination of the safety dome, and potential elimination of the nitrogen purge. AES efforts are pursuing these and other ideas.

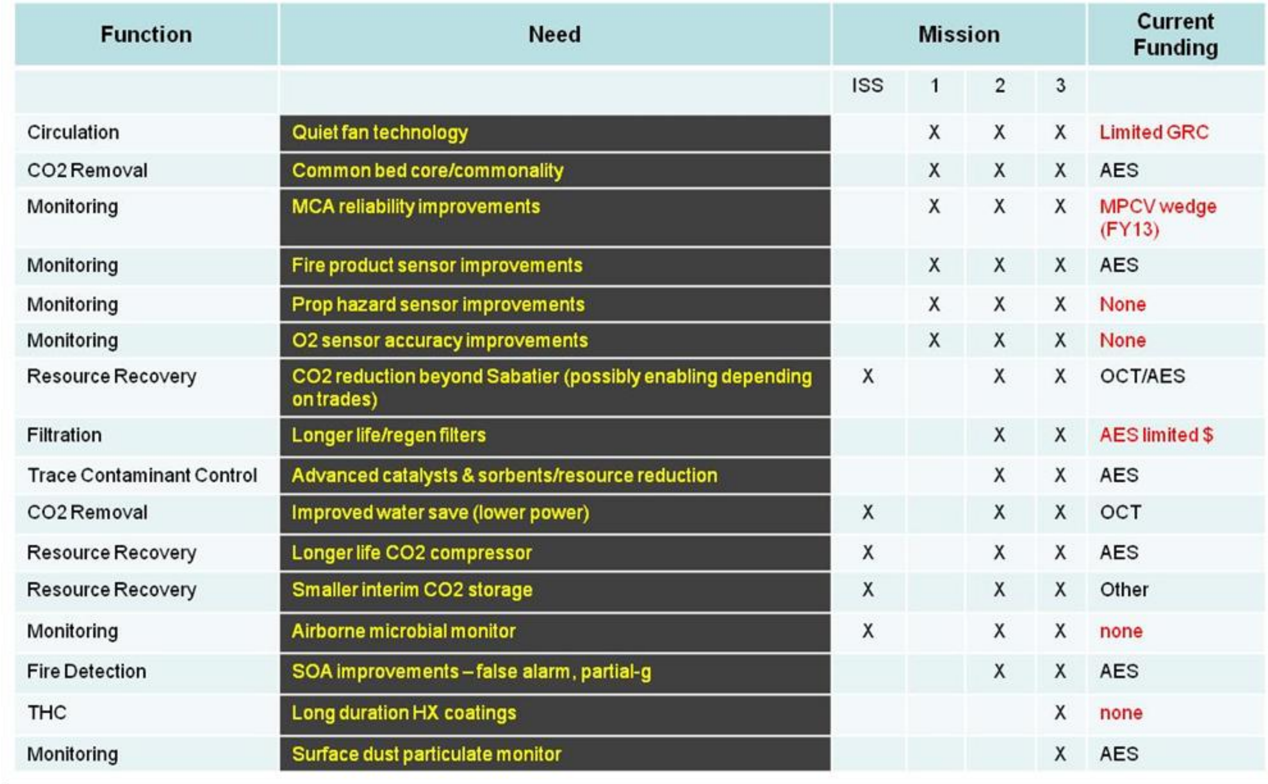
Refer to Appendix C for additional detail on 1) the AM functional decomposition, 2) the ISS survey results mentioned in the background section of this white paper, and 3) the current deliverables for AES, OCT, ISS, and MPCV. Table 2 and Table 3 below summarize the AM functional needs described in this section.

Table 2. AM Enabling Capabilities



Function	Need	Mission				Current Funding
		ISS	1	2	3	
Circulation	Suit loop fan for MPCV (100% O2, multiple design points)		X			MPCV wedge (FY13)
Temperature Control	Suit loop cooling pump/gas trap for MPCV		X			MPCV wedge (FY13)
Pressure Control	Suit loop pressure regulator for MPCV		X			MPCV wedge (FY13)
Fire Suppression	Replacement for Halon & CO2 PFE (small volume, non-toxic)	X	X	X	X	ISS
Atmosphere Recovery	Smoke Eater (safe atm cleanup)		X	X	X	AES
Personal Protective Equip	PPE filtering mask (O2 mask replacement for small volume O2 safety)	X	X	X	X	ISS
CO2 Removal	Robust sorbent bed (solves SOA dusting)	X		X	X	ISS/AES
O2 Supply	OGA reliability improvements	X		X	X	AES, SBIR
O2 Supply	Oxygen recharge for EVA	X		X	X	ISS/AES
Fire Suppression	Fixed suppression for dormant periods			X	X	None
Monitoring	On-board trace contaminant monitor (SOA ISS flt. expt)			X	X	ISS/AES
Filtration	Surface dust pre-filter				X	AES limited $
Fire Suppression	Partial-g material flammability testing				X	None

Table 3. AM Enhancing Capabilities



Function	Need	Mission				Current Funding
		ISS	1	2	3	
Circulation	Quiet fan technology		X	X	X	Limited GRC
CO2 Removal	Common bed core/commonality		X	X	X	AES
Monitoring	MCA reliability improvements		X	X	X	MPCV wedge (FY13)
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 (possibly enabling depending on trades)	X		X	X	OCT/AES
Filtration	Longer life/regen filters			X	X	AES limited $
Trace Contaminant Control	Advanced catalysts & sorbents/resource reduction			X	X	AES
CO2 Removal	Improved water save (lower power)	X		X	X	OCT
Resource Recovery	Longer life CO2 compressor	X		X	X	AES
Resource Recovery	Smaller interim CO2 storage	X		X	X	Other
Monitoring	Airborne microbial monitor	X		X	X	none
Fire Detection	SOA improvements – false alarm, partial-g			X	X	AES
THC	Long duration HX coatings				X	none
Monitoring	Surface dust particulate monitor				X	AES

2.0 Water Management (WM)

Functional elements of WM include process technologies and equipment components employed to provide safe supplies of potable water and to manage wastewater disposal and/or processing within vehicle and habitat environments. The major WM functions are potable WM, waste WM, and water quality monitoring.

Potable WM

Potable WM includes sub-functions of storage, distribution, and microbial control. In microgravity applications, the SOA water storage technique is to use positive-displacement tanks (with internal, movable metal bellows or polymeric bladders) and collapsible polymeric bags (personal drink bags, Contingency Water Containers, for example). In partial-gravity applications, the presence of gravity may be used to eliminate the need for positive-displacement capabilities in water storage tanks. Extended duration missions, particularly into deep space, may benefit by incorporating water storage functionality into the vehicle or habitat structural shell or outfitting equipment in order to take advantage of water's naturally high effectiveness as a radiation barrier to protect crew members. Distributing potable water from storage tanks to usage points is typically done through rigid and flexible lines outfitted with ancillary valves, quick disconnects, and instrumentation. Pumps typically provide the motive force for water distribution. Maintaining adequate microbial control throughout potable water storage and distribution systems is typically achieved by establishing initial system cleanliness, limiting the introduction of viable microorganisms into the storage and distribution system prior to and during missions, maintaining adequate levels of biocides throughout the system, and protecting the system from back-contamination. The SOA biocides used today include iodine and silver used by the U.S. and Russian space programs, respectively. Health risks associated with long-term iodine consumption, coupled with chemical incompatibilities between iodine and silver make a single-biocide system utilizing silver alone the preferred approach for exploration.

The community identified two development needs related to managing potable water. The first, ranked as enabling, is for drink bags that can be launched full of potable water. Historically, drink bags have been launched empty and filled on-orbit with water stored in tanks, and therefore have not had to handle launch loads while full. However, in a cost-savings measure, the MPCV program is considering deleting water storage tanks from the baseline through 2021 flight in favor of launching water needed by the crew in drink bags filled prior to launch. Funding to develop and qualify these drink bags is set aside in MPCV (wedge work) funding beginning in FY13.

The second development need, ranked as enhancing, is for the capability to add, monitor, and reduce or eliminate depletion of silver biocide in potable water. Although the Russians have the capability to add silver on-line, no such capability has been developed within the U.S. program; collaboration with the Russians to obtain such a capability should be considered. No other known funded work is currently underway to develop silver monitoring or prevent its depletion, though the ISS program is funding an effort to assess electrochemical means of disinfecting potable water.

Waste WM

Waste WM includes sub-functions of collection and dispositioning (including disposal, storage, and resource recovery). Wastewaters that may require collection in some form, depending on the vehicle architecture, include cabin humidity condensate, crewmember urine, and waste hygiene and laundry waters. Sources of the humidity released into cabin atmospheres include crew metabolic loads (released through sweat and respiration) and hygiene latent loads. In vehicles in which cabin humidity is not controlled in combination with CO_2 via swing-beds (MPCV uses an amine swing bed that captures CO_2 and water vapor), SOA humidity collection is typically accomplished by flowing cabin air through condensing HXs that are cooled below the cabin dewpoint temperature. In micro-gravity vehicles, SOA urine collection is facilitated by entraining urine in airflow imparted by rotary fan separators. In order to stabilize urine (to prevent urea decomposition to NH_3, solids formation, and microbial growth) it is “pretreated” with chemical additives as it is collected. The SOA urine pre-treat formulation is a solution developed by the Russians containing chromium trioxide and sulfuric acid. Urine is collected from suited crewmembers in Maximum Absorbency Garments (MAGs), which are worn beneath the liquid cooling garment and disposed of after use.

Once collected, waste water is “dispositioned” by either storing it for eventual disposal, venting it overboard, or processing it to recover some fraction of its water content for re-use by the crew. Current SOA techniques for wastewater storage are common with those described above for potable water storage.

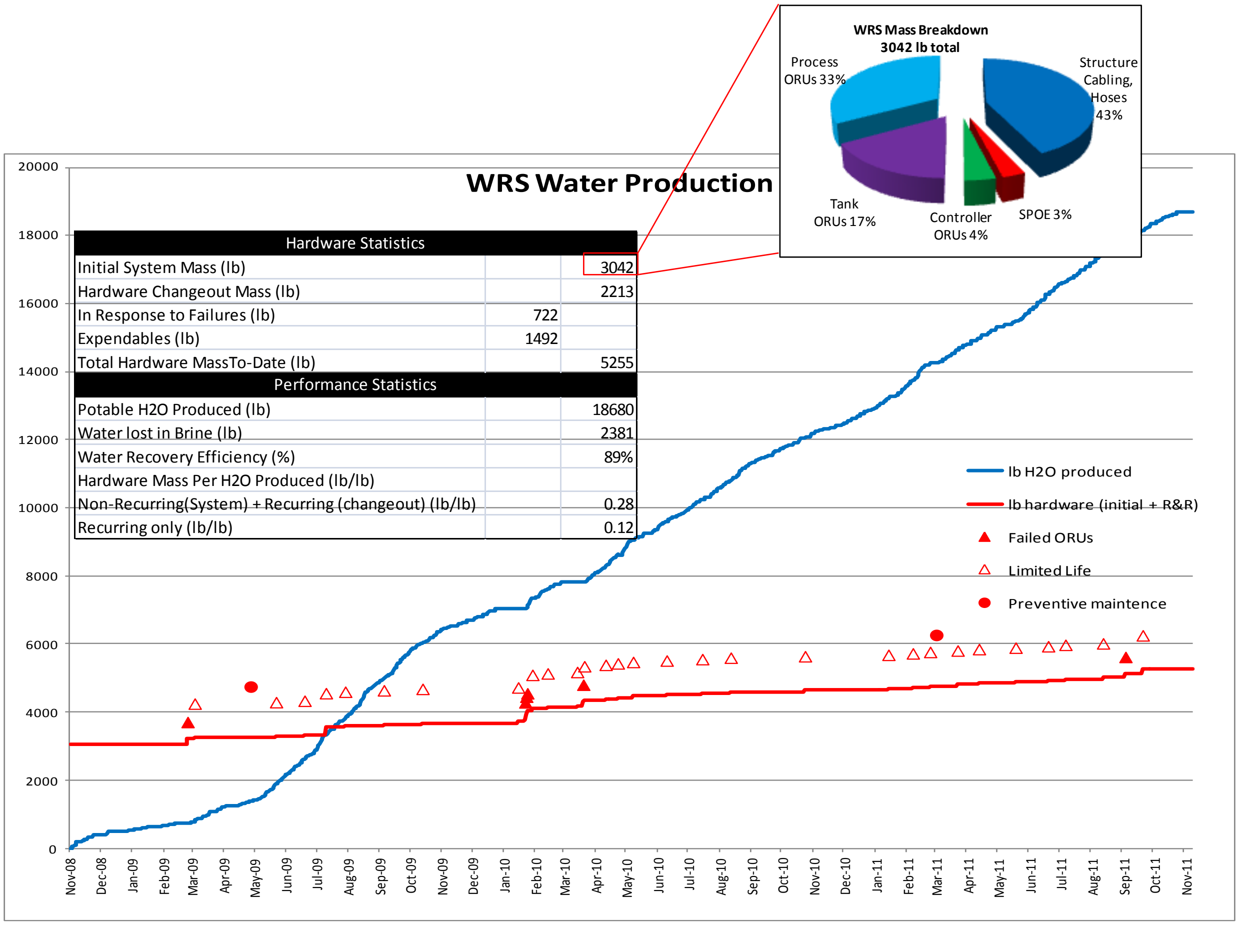
Disposal of wastewater via overboard venting is accomplished through its controlled release through external vent assemblies that are heated to prevent freezing. Vent designs, locations, and operational flow rates are controlled to prevent detrimental propulsive effects on the vehicle or contamination of sensitive external vehicle surfaces (such as solar arrays or radiators). It is anticipated that surface mission architectures will have additional constraints and/or restrictions imposed on wastewater venting due to planetary protection requirements.

Water recovery from wastewater becomes advantageous as mission durations increase. The SOA wastewater recovery capabilities are represented by the ISS Water Recovery System (WRS) (operating in the U.S. On-Orbit Segment) and the Condensate Recovery System (SRV-K) (operating in the Russian On-Orbit Segment). The Water Recovery System contains two separate process assemblies. The Urine Processor Assembly (UPA) is based on Vapor Compression Distillation (VCD) technology. Input to the UPA is pretreated urine delivered automatically from the ISS Waste and Hygiene Compartment or transferred by crewmembers manually from the Russian Segment. Distillate from the UPA is delivered, along with cabin humidity condensate, to the Water Processor Assembly (WPA) where it is treated by a sequence of unit operations including gas/liquid separation (via a centrifugal separator), particulate filtration, adsorption and ion exchange (within integrated "multifiltration" beds), catalytic oxidation (at approximately 275°F), ion exchange polishing, and iodine dosing (via flow through a Microbial Check Valve (MCV) resin first developed for the Shuttle program). The Russian SRV-K uses technologies similar to those used in the WPA, with the exceptions of a proprietary catalytic oxidation process that operates at near ambient temperature and a proprietary means of dosing product water with silver biocide (rather than iodine). The higher allowable total organic carbon content in the Russian potable water quality specification uses an ambient temperature oxidation process viable.

The community identified six development needs related to managing wastewater. Of these, three were considered enabling and three enhancing.

Reducing 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 4. As shown in the figure, from its initial activation through November 14, 2011, the WRS produced 18,680 lb of potable water. During that time, the cumulative mass of equipment "utilized" had been 5,255 lb, including the initial system mass of 3,042 lb plus 2,213 lb of additional equipment changed out due to either hardware failures (722 lb) or service life expiration (1,492 lb). The mass of potable water produced represented approximately 89% of the overall water content available in crewmember urine and humidity condensate combined.

One of the dominating drivers in the expendable hardware mass consumed is 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 RFTA replacement frequency has also been higher than planned due to higher levels of calcium sulfate ($CaSO_4$) in on-orbit pretreated urine (a consequence of dietary supplements taken by the ISS crew to mitigate micro-gravity induced bone loss), causing system failures due to $CaSO_4$ precipitation within the UPA. The ISS program is funding several initiatives to reduce this expendable penalty. An Advanced Recycle Filter Tank Assembly (ARFTA) has been developed and is now in use. Once installed into the UPA, the ARFTA 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. The ISS program has also funded the development of an ion exchange resin cartridge intended to preferentially remove calcium from pretreated urine to reduce the potential for $CaSO_4$ precipitation within the UPA's brine loop. And finally, the ISS program is funding research to investigate alternate pretreatment chemical formulations that reduce or eliminate the addition of sulfate ion as a means of mitigating the formation of $CaSO_4$ precipitate. In a parallel effort, the AES Water Recovery project is funding development of an electrodialysis system to preferentially remove calcium from pretreated urine (as an alternative to the ISS-funded ion exchange resin cartridge approach). Not yet funded, but considered another solution, is the addition of a calcium monitor which would monitor the level of calcium in the urine such that the % recovery of the UPA could be adjusted accordingly and not set conservatively low. This would serve to increase the potential % recovery of water from the ISS UPA.



Hardware Statistics		
Initial System Mass (lb)		3042
Hardware Changeout Mass (lb)		2213
In Response to Failures (lb)	722	
Expendables (lb)	1492	
Total Hardware MassTo-Date (lb)		5255
Performance Statistics		
Potable H2O Produced (lb)		18680
Water lost in Brine (lb)		2381
Water Recovery Efficiency (%)		89%
Hardware Mass Per H2O Produced (lb/lb)		
Non-Recurring(System) + Recurring (changeout) (lb/lb)		0.28
Recurring only (lb/lb)		0.12

Figure 4. ISS SOA Water Recovery System Life Cycle Mass (through 11/14/11)

For longer-duration missions (typically longer than about 6 months), the additional system mass for recovering more water from brine than the current SOA technologies 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 brine and to launder and re-use clothing were both identified by the community as enabling needs for long-duration exploration missions. However, there are no known NASA-funded efforts underway to develop either of these capabilities at this time.

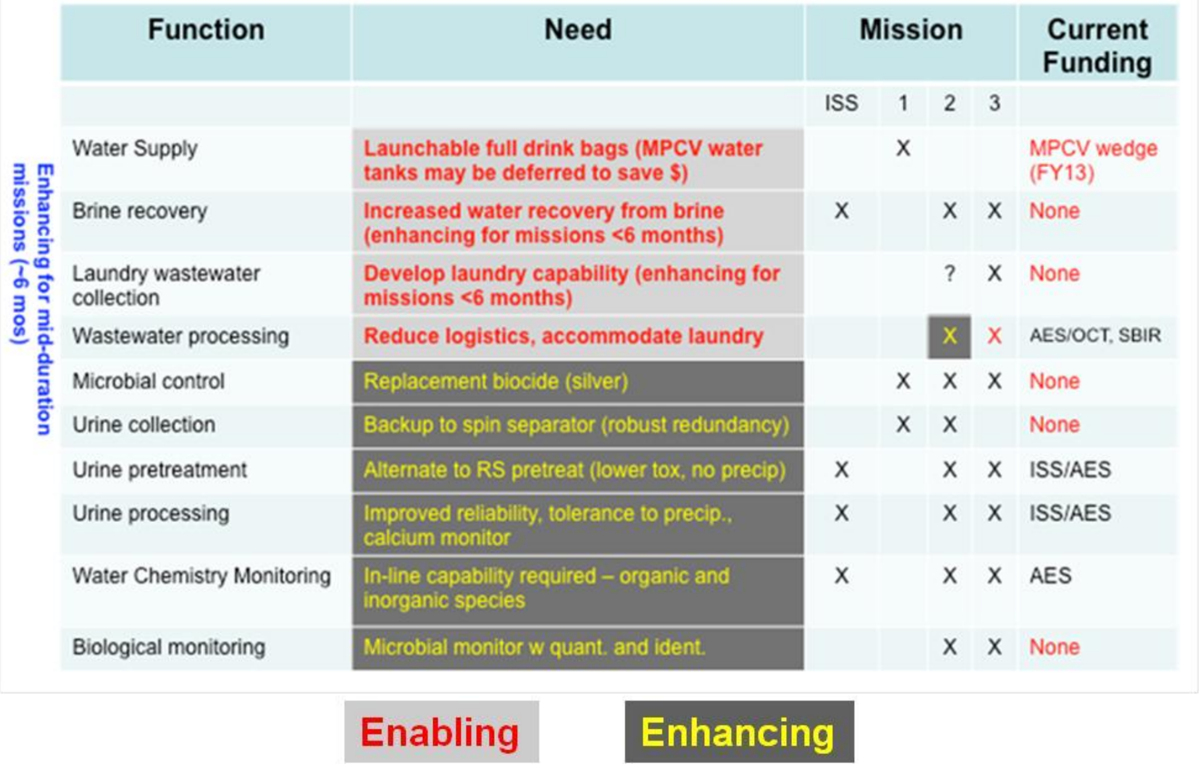
The three enhancing needs that were identified relative to managing waste water include developing an alternate urine pretreatment formulation that is non-toxic (in addition to mitigating precipitation as discussed above), improving urine processing reliability and tolerance to precipitation, and developing a back-up to a urine spin separator to provide robust redundancy. In addition to the ISS- and AES-funded work described above, the AES program is funding maturation of a Cascade Distillation System (CDS) as an alternative to VCD technology currently employed within the ISS UPA. No funding is currently being applied to develop a backup urine separator. The OCT is funding, through the Next Generation Life Support (NGLS) project development of a forward osmosis secondary treatment system.

Water Quality Monitoring

Current SOA water quality monitor relies on in-line measurement of conductivity as a surrogate indicator of WPA operational health and potable water quality. This is supplemented by periodic off-line analyses of total organic carbon in water samples utilizing the on-orbit Total Organic Carbon Analyzer (TOCA). More extensive chemical and microbiological analyses require water samples to be periodically returned to the ground. An in-flight demonstration of an iodine sensor is under development.

The community identified two enhancing development needs related to monitoring water. The first is for an in-line capability to monitor organic and inorganic species in water. The environmental monitoring task within the AES-funded ARREM project is developing a Vehicle Environmental Monitor, with a ground test unit targeted for completion in FY13. A second enhancing need for a capability to quantify and identify micro-organisms in water samples currently has no known NASA funding.

Table 4. WM Enabling & Enhancing Capabilities



Function	Need	Mission				Current Funding
		ISS	1	2	3	
Water Supply	Launchable full drink bags (MPCV water tanks may be deferred to save $)		X			MPCV wedge (FY13)
Brine recovery	Increased water recovery from brine (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 logistics, accommodate laundry			X	X	AES/OCT, SBIR
Microbial control	Replacement biocide (silver)		X	X	X	None
Urine collection	Backup to spin separator (robust redundancy)		X	X		None
Urine pretreatment	Alternate to RS 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.			X	X	None

Enhancing for mid-duration missions (~6 mos)

Enabling

Enhancing

3.0 Solid Waste Management (SWM)

Solid waste may be dry, moist, or wet but in general is free from large volumes of free liquid. Liquid wastes (hygiene waste water, collected condensate water, collected urine, etc) are included within the WM function and not addressed in this section. SWM is functionally divided into three areas: solid trash, solid metabolic waste, and solid logistical trash. SWM is a cross-domain function with solid metabolic waste assigned to the ECLSS domain and solid trash and logistical waste assigned to the Habitation discipline. All three solid waste areas will be described but only the solid metabolic waste is addressed further in this ECLSS white paper.

- Solid trash can be characterized as residual material after crewmember use or action. Examples include: food containers, clothing, wipes, paper, etc.
- Solid metabolic waste can be characterized as material from the crewmember's body. Examples include: fecal, diarrheal, and emesis. Note that metabolic waste collection typically utilizes waste collection subsystem (WCS) hardware common to urine collection (under the WM function).
- Solid logistical waste can be characterized as residual material after launch and stowage that the crew removes on-orbit. Examples include: resupply stowage racks (RSRs), cargo transfer bags (CTBs), packaging foam, and zip lock bags.

For additional detail on the SWM functional decomposition, the ISS survey results mentioned in the background section of this white paper, and the current deliverables for AES, OCT, ISS, and MPCV reference Appendix E.

Opportunities for commonality across the exploration architecture for waste management are as follows.

Manage Metabolic Solid Waste

Metabolic solid waste collection is a function that is strongly driven by the presence or absence of gravity for each mission. The SOA for metabolic SWM is represented by the Shuttle Waste Collection System (WCS) (and its Extended-Duration Orbiter (EDO) derivative), the Russian Soyuz АСУ, and the Russian Service Module АСУ (and its ISS Waste and Hygiene Compartment (WHC) derivative). MPCV is planning to use a Shuttle EDO-derived style commode. MMSEV and DSH plan to be common with MPCV, while SEV, Landers, and Surface Hab may take advantage of partial gravity to employ a simpler "camper style" commode. Because DSH and Surface Hab may need to integrate with a solid waste processing system, consideration should be given to designs that eliminate the need for transfer of the solid waste from the collection canister to the processor. Fecal processing is not planned for any vehicle except potentially the DSH and Surface Hab. The following section describes technology trades and development, as this would be a new ECLSS capability.

The community identified one enabling need relative to metabolic waste management. 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. The AES program is currently funding effort is this area.

Five enhancing needs were identified, including 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. Of these needs, development of the EDO-derived toilet is included in MPCV wedge funding plans for FY13. The AES program is funding studies on compaction and dewatering. The AES Logistics Reduction project is also funding studies to provide trace contaminant (and odor) control for waste management systems.

Table 5. SWM Enabling & Enhancing Capabilities

Function	Need	Mission				Current Funding
		ISS	1	2	3	
Stabilization – trash and fecal	Long term stabilization/planetary protection			X	X	AES
Wet trash disposition	Jettison capability (if dumped)			X		None
Wet trash – storage & resource recovery	Compaction & dewatering †			X	X	AES
Metabolic waste	Packaging (EDO potty)			X		MPCV wedge
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

ECLS Integrated Roadmap Development

Once the specific functional needs for the three missions were identified, more detailed timelines were developed depicting strategies for development and testing necessary to achieve these mission capabilities to support projected Exploration milestones. For Mission 1 (short-duration), the development timeline and strategy centers on MPCV development and first flights are key to demonstrating ECLSS capabilities for MPCV and all short-duration vehicles. While demonstration on an ETM is not considered a necessary milestone, copies of relevant MPCV hardware could certainly be provided to an ETM to support testing with crew for other Exploration objectives given the proper funding. For Mission 2 (long-duration microgravity), the development timeline and strategy centers on utilization of the ISS as the key platform for first demonstrating upgrades and improvements to existing SOA hardware, in conjunction with integrated ground testing. Once successfully demonstrated in these appropriate test environments, hardware would be considered ready for a DSH demo or flight. Timelines for development of Mission 3 capabilities were not addressed at this time.

Figure 5 to Figure 13 all depict the resulting development strategies, organized by mission and enabling vs. enhancing needs. Significant notes are listed following each figure with respect to integrated testing and funding needed. Figure 5 gives illustrative directions of how to read each of the development strategy figures.

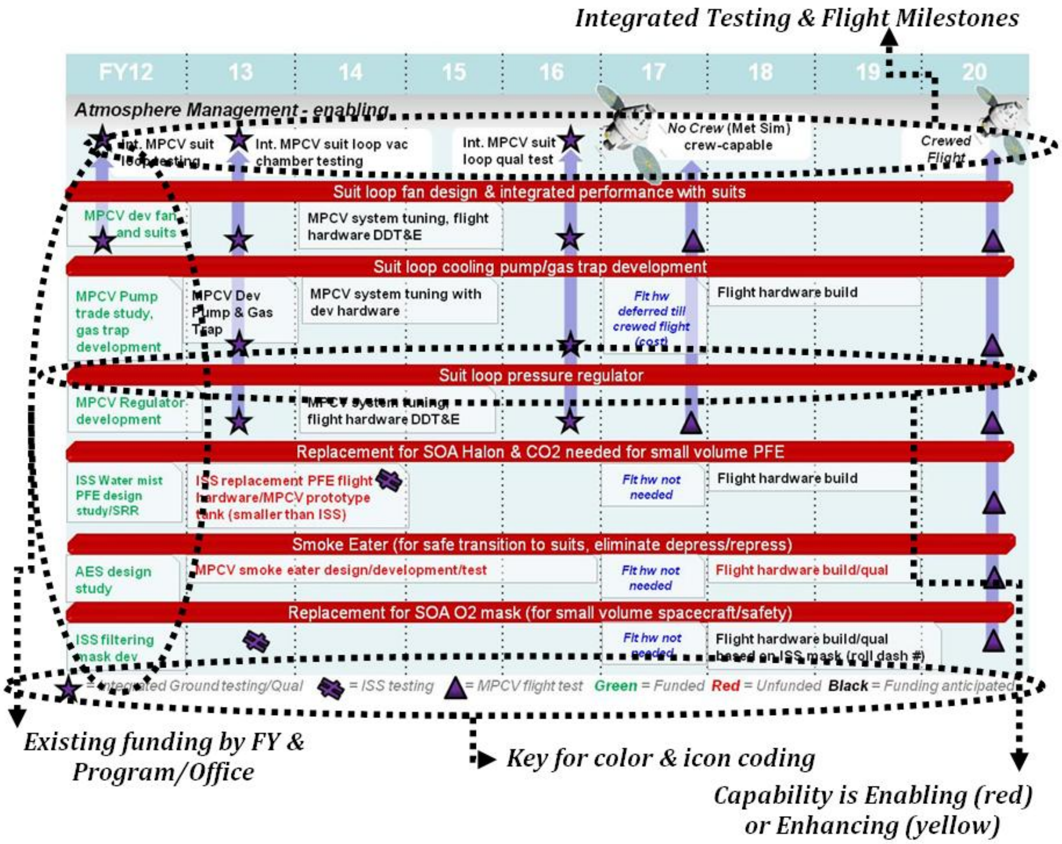


Figure 5. Illustrative Directions for How to Read the Development Strategy

For example, the enabling AM technology 'Suit loop cooling pump/gas trap development' circled above, indicates that existing funding in FY12 is provided by the MPCV Program. For this technology to support the MPCV crew-capable flight in ~2017, ground testing is necessary. The ground tests recommended in this development strategy include a reduced pressure, integrated MPCV suit loop test in FY12 (funded), and an integrated suit loop MPCV vacuum chamber test in FY2013 using a development gas trap and pump (currently unfunded, put included in future program plans). Following MPCV system-level tuning with development hardware (currently unfunded, but expected to be funded) in FY14-15, the qualification hardware will be used in the integrated MPCV Program suit loop qualification test. If the MPCV crew-capable flight is not actually flown with crew aboard, the flight hardware itself can be deferred for cost savings until the currently planned crewed-flight in FY2020. Plans to add crew to the 2017 Engineering Model 1 (EM-1) test will require these activities to be funded.

Mission 1: Short-duration ECLS Development Strategy

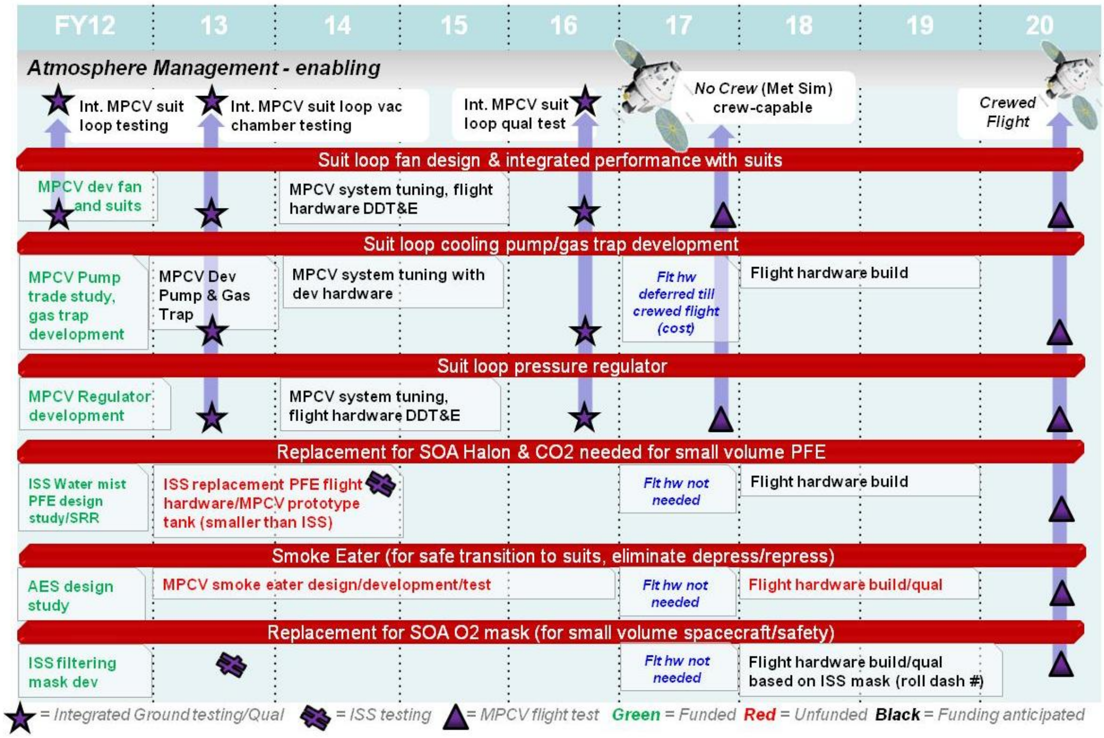


Figure 6. Mission 1: Development Strategy for AM Enabling Capabilities

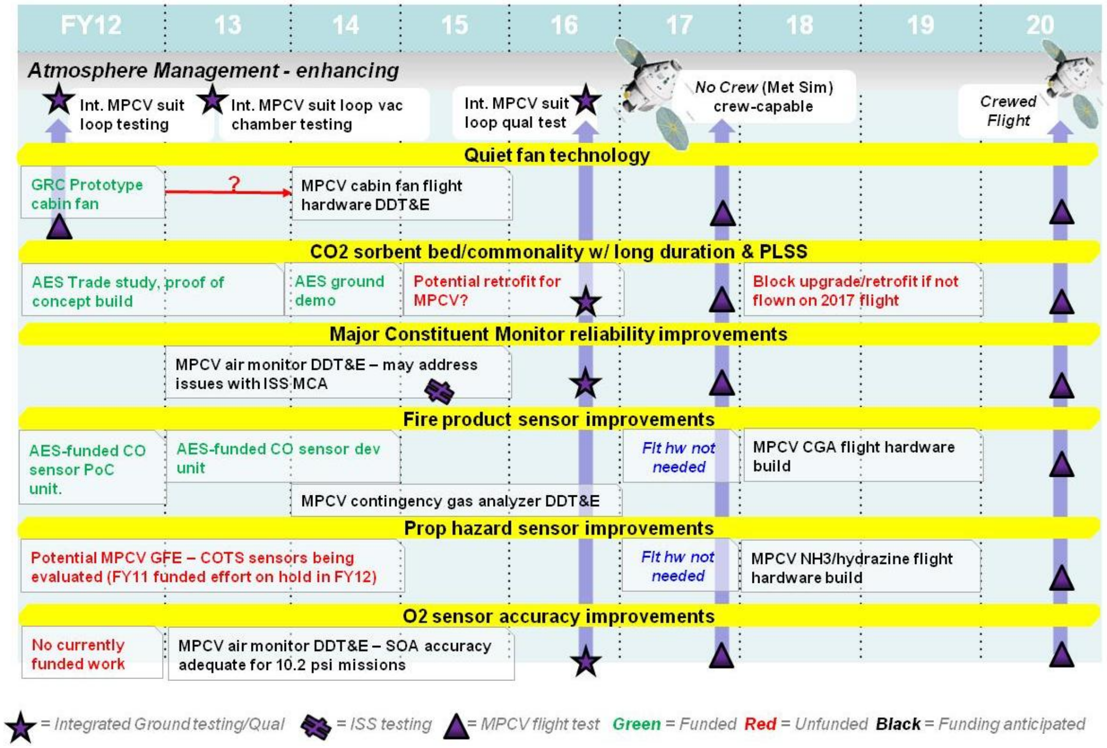


Figure 7. Mission 1: Development Strategy for AM Enhancing Capabilities

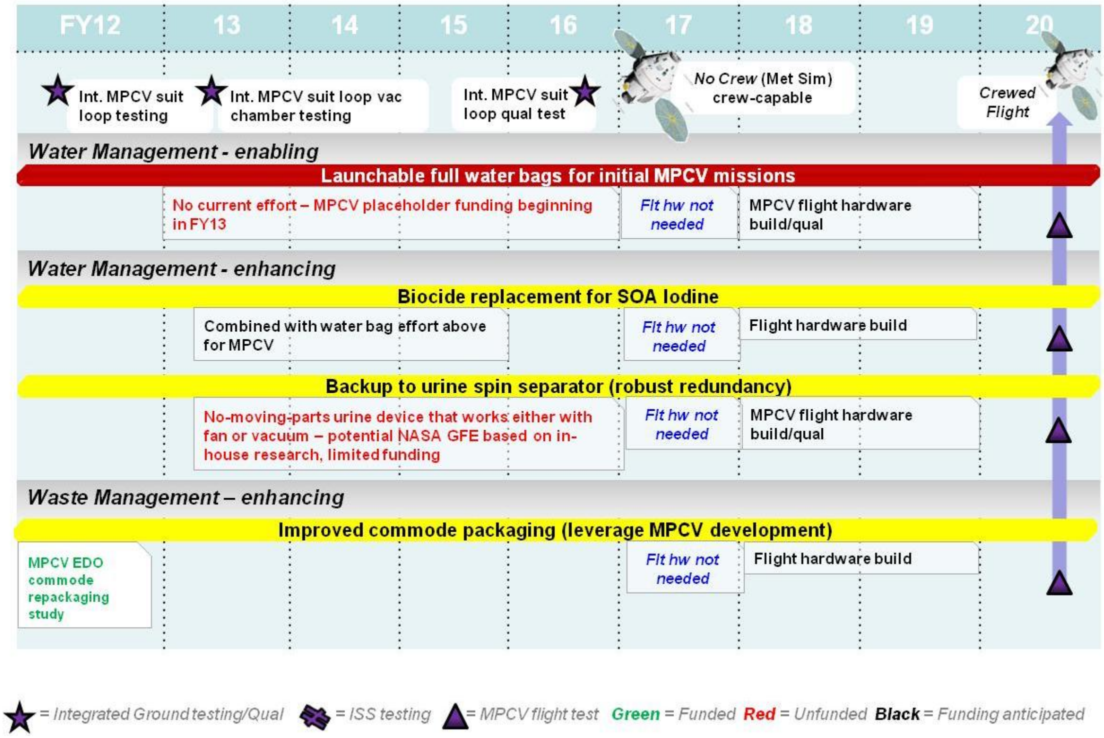


Figure 8. Mission 1: Development Strategy for WM Enabling & Enhancing Capabilities

Mission 2: Long-duration ECLS Development Strategy

Mission 2 roadmaps are based on two major integrated activities. The first is a long-duration ECLSS demonstration. This would be a ground test, including humans, which would be used to demonstrate long-duration performance and reliability of a Mission 2 type system. This test would be required to run for several years. As an example, a Mars mission would require ECLSS hardware to run for approximately three years. Therefore testing should exceed three years of run time at minimum, and planning for four or five years to allow for some changes in the first year and to provide some margin would be prudent. This long-duration testing would demonstrate technologies and systems that would be used in a DSH flight demonstration, the second major integrated activity shown in the 2021-25 timeframe.

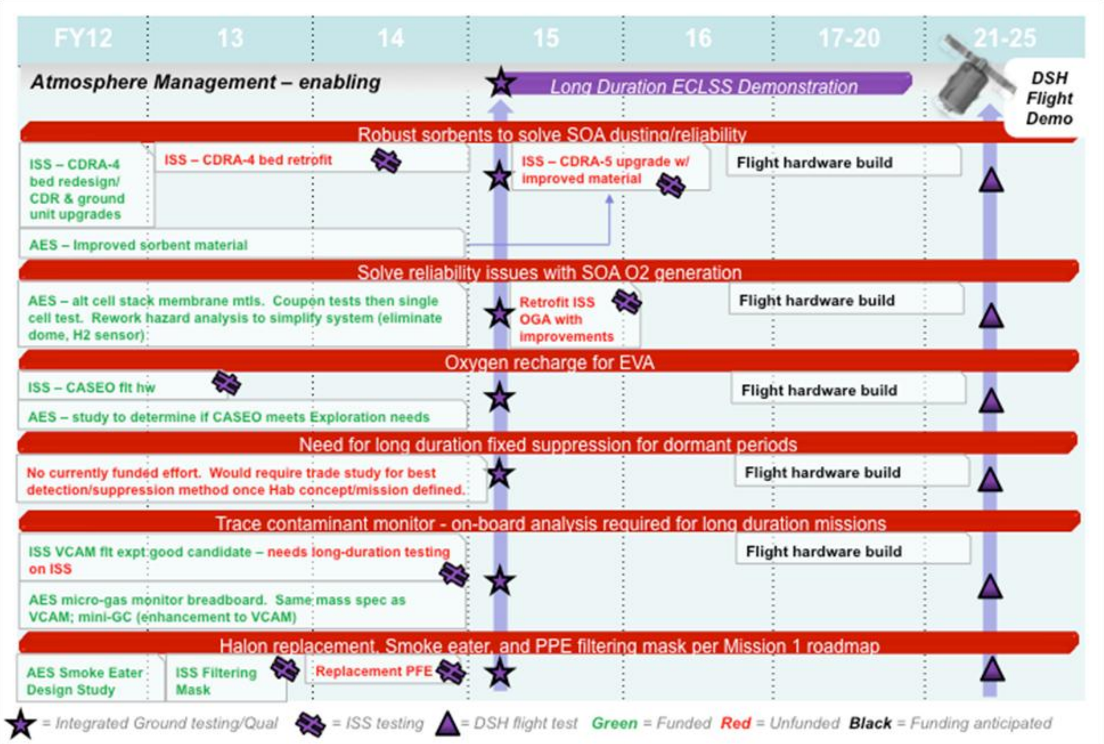


Figure 9. Mission 2: Development Strategy for AM Enabling Capabilities

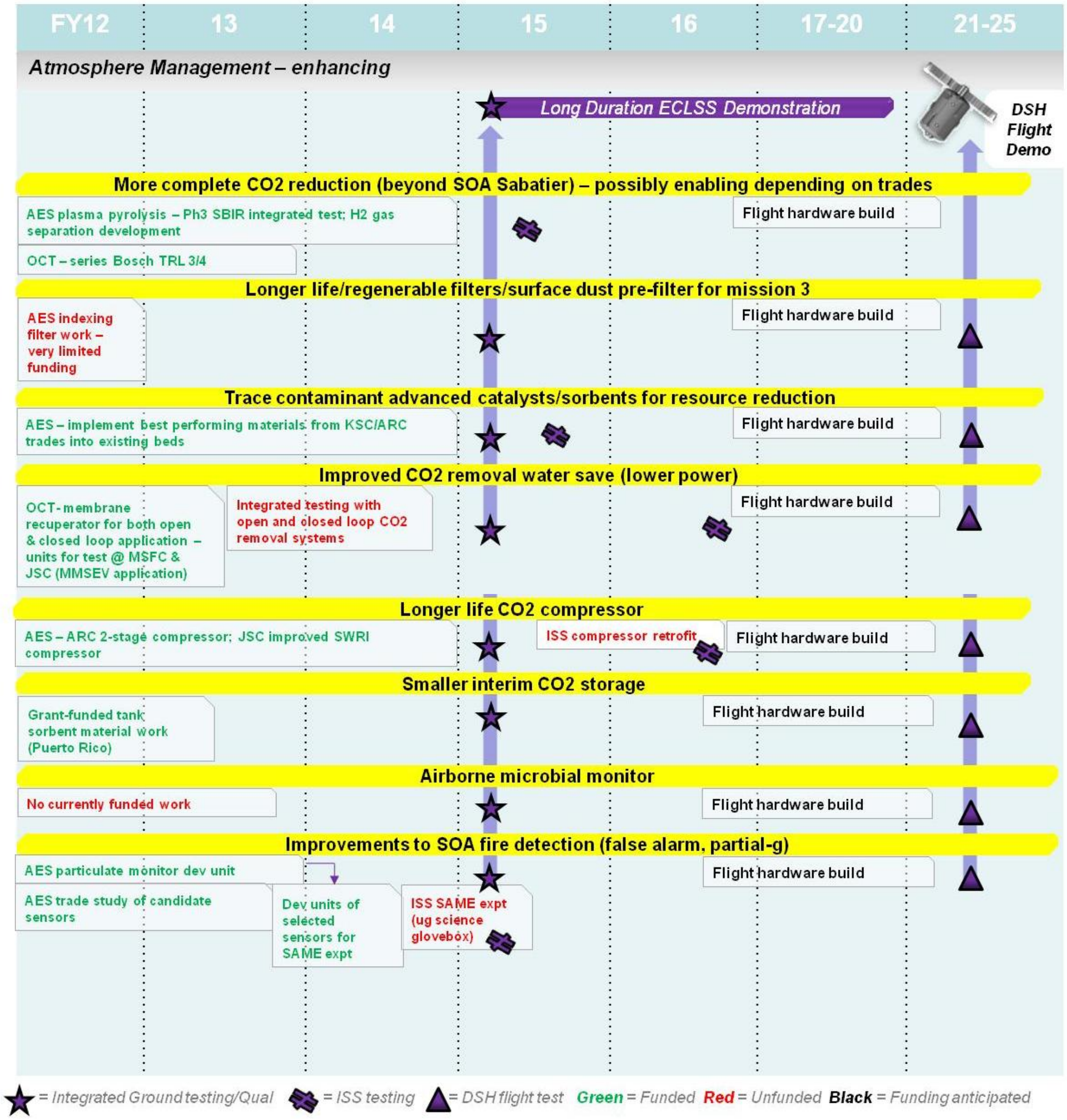


Figure 10. Mission 2: Development Strategy for AM Enhancing Capabilities

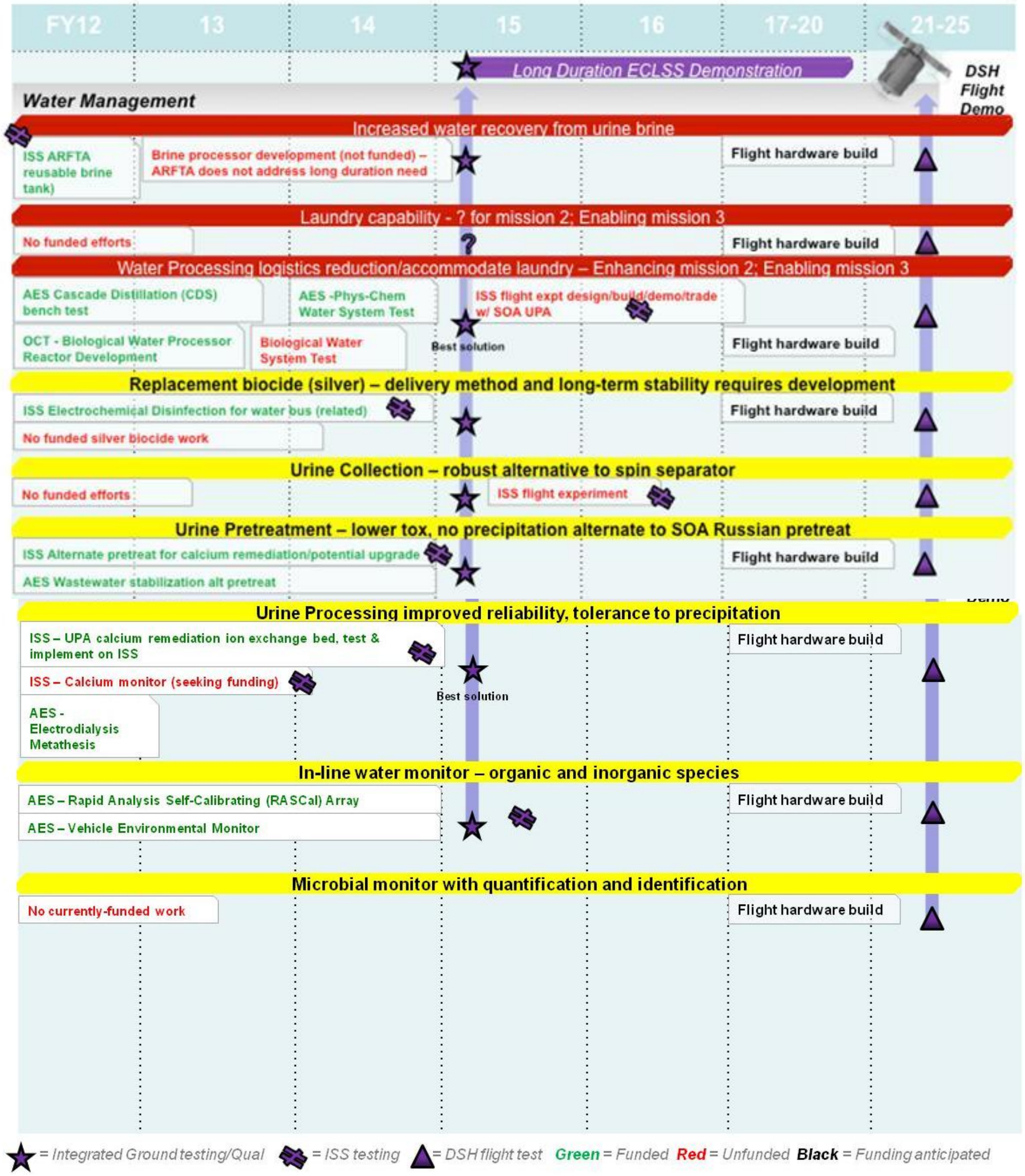


Figure 11. Mission 2: Development Strategy for WM Enabling & Enhancing Capabilities

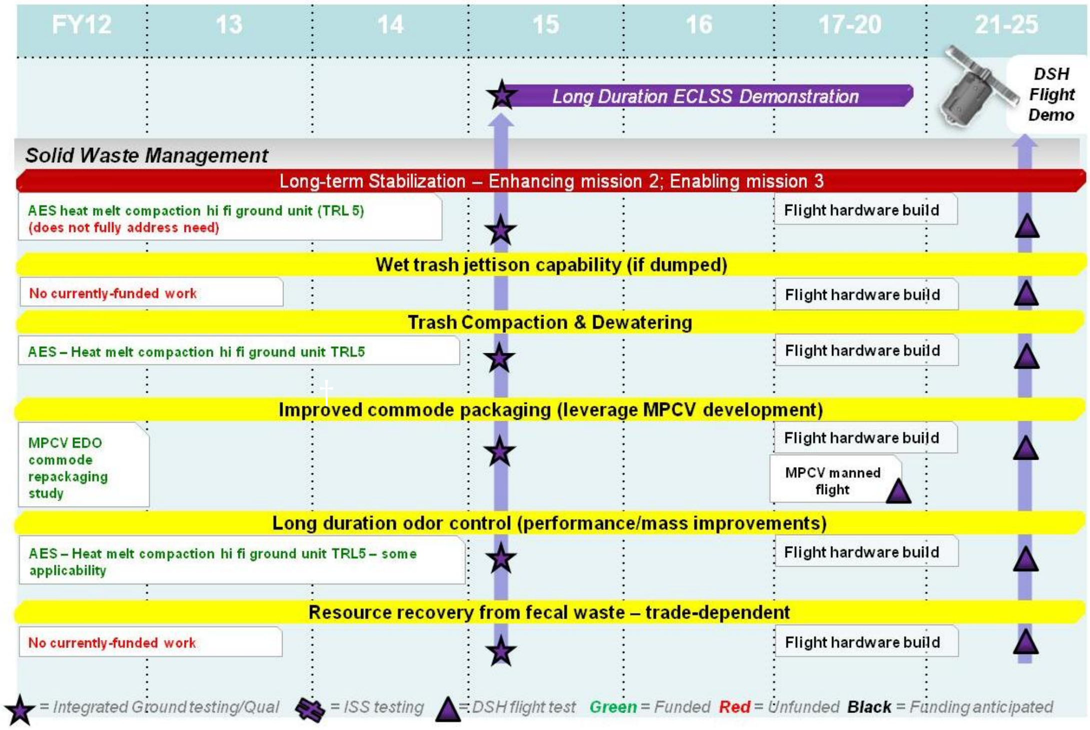


Figure 12. Mission 2: Development Strategy for SWM Enabling & Enhancing Capabilities

ECLS Integrated Roadmap One-Pager

The following figure shows the top level integrated roadmap with respect to major milestones for mission scenario 1: an MPCV flight in 2017 (stretch goal = crewed) or an ETM flight in 2019 (crewed), and mission scenario 2: a DSH flight in the 2021-25 timeframe (stretch goal = crewed). Red highlighting denotes mission enabling technologies (i.e., those technologies that must be developed which would enable this mission to sustain life support for humans), while yellow denotes mission enhancing technologies (i.e., those technologies that would provide benefits to the mission in terms of reduced logistics, improved capability, etc). For details of each of these technology needs, please see Figures 6-14.

As stated earlier, the MPCV ECLSS provide a point of departure architecture for all short-duration (Mission 1) missions, which may need minor changes based on specific mission requirements. The ISS ECLSS, with identified upgrades to resolve known issues, provides the same type of point of departure for long-duration missions (Mission 2).

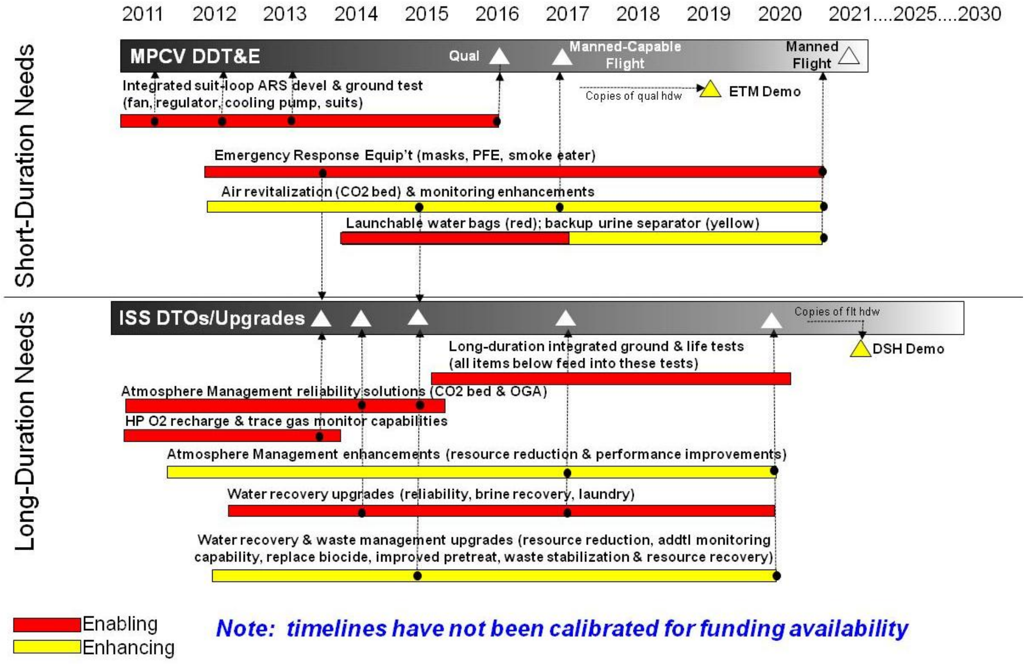


Figure 13. ECLS Integrated Roadmap One-Pager

ECLS Integrated Ground Testing Recommendations

In generic mission scenario 1, a number of integrated ground tests with varying levels of complexity are recommended. Specific to AM, a series of integrated suit loop tests are necessary to enable integrated development of the fan, cooling pump/gas trap, and pressure/regulator for MPCV. Quiet-fan technology, CO_2 sorbent bed commonality with the long-duration needs and PLSS, major constituent monitoring, and O_2 sensor accuracy improvements are also enhancing AM capabilities that can be tested along with the afore mentioned enabling capabilities. The necessary integrated ground tests are: a MPCV suit loop test, an integrated vacuum chamber MPCV suit loop test, and finally an integrated MPCV suit loop qualification test to prove that the MPCV is crew-capable prior to its first uncrewed flight in 2017. No integrated ground testing is planned for generic mission scenario 1 for WM or SWM, as these functions are not highly coupled for the MPCV.

In generic mission scenario 2, long-duration ECLS integrated ground testing (shown in the ~2015-2020 time frame) is required to validate technology improvements which address that the majority of air, water, and SWM enabling and enhancing capabilities. This ground testing is considered essential in the ECLSS development roadmap.

ECLS Flight Testing

ECLS Integrated ISS Flight Testing

Many activities on the roadmap take advantage of and/or require ISS on-orbit testing. Some are currently funded by ISS, while others are recommended for future funding. In the mission scenario 1, ISS is currently sponsoring a Periodic Fitness Evaluation (PFE) replacement design study and requirements review. If the decision is made to continue, development of a flight unit for ISS is desired (but not currently funded) by ~2014. The MPCV plans to leverage this work for a smaller version of the same PFE to support the MPCV crewed flight in ~2020. A replacement SOA O_2 mask is funded and being tested on ISS in ~2014, which will be directly leveraged for MPCV. The reverse is true of the major constituent monitor technology development. ISS may desire to retrofit its SOA MCA with the simpler MPCV air monitor once it is developed by MPCV (funding currently on hold).

For Mission scenario 2, technology development that is targeted for ISS flight includes the CDRA-4 bed modification in 2014, followed by a further-improved CDRA-5 bed in ~2016. Neither of these projects is fully funded as yet, but is considered necessary to demonstrate CO_2 removal reliability improvements. Reliability issues with OGA are being addressed in an AES study, but funding doesn't include a retrofit of the resulting OGA improvements for testing. There is currently one viable trace contaminant monitor flight experiment on board ISS that has undergone some testing; however additional long-duration testing is needed to validate this technology for future mission use. Technologies that recover more O_2 from CO_2 than the SOA ISS Sabatier would benefit from an ISS flight test, as well as improvements to the front-end CO_2 removal water save and compressor components. The SOA trace contaminant sorbents and catalysts could be retrofitted with any improvements to those materials and tested on orbit, and improved fire detectors should undergo testing on ISS before being utilized for long-duration Exploration missions.

Recommended flight tests for water technologies include any alternatives to the SOA water recovery system, biocide and pre-treat changes, in-line water monitors, and no-moving-parts urine collection/separation device. ISS is currently funding flight experiments of UPA calcium remediation projects as outlined earlier.

ECLS MPCV/ETM Testing

The primary flight test strategy for the short-duration ECLSS uses the MPCV crew-capable (but uncrewed) flight in 2017 and crewed flight by 2021. The ground testing previously described specific to mission scenario 1 supports the MPCV flight test and is required for qualification/verification prior to flight. An ETM, assumed to be flown between 2017 and 2021, could be supplied with copies of MPCV ECLSS components for testing ETM-specific objectives; however, the ETM is not considered necessary in this roadmap.

ECLS DSH Testing

Assuming DSH flight demonstration somewhere in the 2021-2025 timeframe, the ECLSS roadmap assumes that the necessary technologies have been proven by extensive integrated ground testing and targeted ISS flight testing. At this point, DSH ECLSS component flight units can be constructed based on lessons learned from these test programs and integrated into the DSH. This strategy reduces risk for ECLSS reliability for DSH missions.

Final Conclusions and Recommendations

This ECLSS white paper documents the roadmap for development of capabilities required to enhance the long-term operation of the ISS as well as enable beyond-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. Additionally, to organize the effort, ECLSS was categorized into three major functional groups (AM, WM, and SWM) with each broken down into sub-functions. The ability of existing SOA technologies to meet the functional needs of each of the three mission types was then assessed by NASA subject matter experts. When SOA capabilities were deemed to fall short of meeting the needs of one or more mission types, those "gaps" were prioritized in terms of whether or not the corresponding capabilities were enabling (essential for mission success) or enhancing (provides an improvement over the SOA) for each of the mission types. The resulting list of enabling and enhancing capability needs is recommended to be used to guide future ECLSS development. Each need was mapped to current projects and development efforts attempting to address development. A strategy to fulfill those needs over time was then outlined in the form of the ECLSS roadmap.

The key findings resulting from this effort are summarized by Mission category below:

Mission 1 Needs:

- Ensure adequate funding for MPCV key development items to support crewed flight including the following:
    - Suit loop fan, cooling pump, and O_2 regulator
    - Sensors and emergency equipment
    - Integrated system ground testing
- Leverage AES resources to aid in Mission 1 needs
- Continue to leverage ISS development of fire extinguisher and contingency mask
    - This need is common across all three mission types

Mission 2 Needs:

- Solve key reliability issues with:
    - O_2 Generator
    - Regenerative CO_2 removal with resource recovery
    - Urine processor
- Add capabilities:
    - O_2 recharge for EVA
    - Brine processing
    - Improved on-orbit air and water monitoring capability and reliability
- Improve existing capabilities:

    - Reduce water processing logistics
    - Additional resource recovery from CO_2
    - Pre-treat and biocide improvements
- Demonstrate improved reliability and new capabilities through an appropriate mix of ground testing (e.g., bench-top, component, and/or subsystem levels) and flight tests/demos, with a long-duration, integrated ECLSS ground test prior to full System deployment beyond LEO.

Mission 3 Needs: (as funding becomes available)

- Laundry, Long-term waste stabilization

The Mission 3 assessment received less focus in this white paper due to the timeline for completing missions 1 and 2 within known budget constraints. However, many of the capabilities required for Mission 3 are extensions or augmentations of Mission 2 capabilities.

The ECLSS technical community has developed a general roadmap framework presented herein that pursues short-duration operations (which inherently develops & utilizes MPCV ECLSS), pursues long-duration operations (improving, demonstrating & utilizing upgraded ISS ECLSS capabilities), and highlights the common needs for integrated ground and flight testing, regardless of destination. This framework will be a living tool which must be tailored as specific mission requirements are developed. Specific requirements such as crew size, mission duration, EVA requirements, or the availability of resupply can (either separately or together) dramatically affect the selection of system designs and technologies.

In the current NASA environment, the most efficient strategy for advancing ECLSS needs is to complete the MPCV ECLSS hardware development currently on hold due to budget constraints, perform targeted ISS demonstrations to address reliability issues and add capabilities, and pursue a rigorous ground testing program. While proposed ETM and DSH flight demonstrations would provide some ECLSS advancement benefits, they are not considered a necessary component of the ECLSS roadmap. Procurement of additional copies of MPCV and ISS hardware can be utilized to support ETM and DSH demo objectives.

Currently, the ECLSS budget and activities are spread across the ISS, MPCV, AES, and the OCT GCT programs, which all have common technical goals, but separate unique requirements. With each program individually underfunded, the amalgam of funding is likely still not enough to completely address the critical needs. The strategic plan developed within this paper must be coordinated with stakeholders from these programs to prioritize funding to the most critical needs and integrate plans to support those needs. Once that is completed, budgetary estimates can be developed for the remaining work needed, to support the integrated NASA budget submit in for fiscal year (FY) 13.

The preparation of this whitepaper was guided and supported by the TESC, which is made up of technical discipline management representatives from each NASA center and JPL. In addition, two NESC technical fellows act as ad-hoc members of the TESC. ECLSS technical subject matter experts from each of the centers and NESC provided significant material and support that culminated in this paper.

The TESC will serve as the principal caretaker of this roadmap and as the advocate of its recommendations to the NASA Directorate and Program/Project Managers that have the authority and resources to contribute to its implementation. The TESC will also capitalize on its membership of line organization managers to communicate the roadmap throughout NASA's ECLSS workforce and industrial partners. The TESC will ensure that the capability needs, gaps, and roadmap are updated as necessary to keep pace with the natural evolution of NASA plans and priorities. Coordination of resources and communication of activities through the TESC will support NASA Directorate and Program/Project Managers' needs to meet their specific objectives while avoiding unnecessary overlaps and addressing unfulfilled gaps. Through the TESC membership, the coordination of appropriate technical and ECLSS project expertise managed at their individual NASA Centers will enable the development of creative solutions, sound cost estimates, and effective implementation plans.

Appendix A: Acronyms and Abbreviations

°F	Degrees Fahrenheit
AES	Advanced Exploration Systems
AM	Atmosphere Management
AQM	Air Quality Monitor
ARC	Ames Research Center
ARFTA	Advanced Recycle Filter Tank Assembly
ARREM	AES Atmosphere Resource Recovery and Environmental Monitoring
ATC	Active Thermal Control
ATCO	Ambient Temperature Catalytic Oxidizer
CAMRAS	CO2 and Moisture Removal Amine Swing Bed
CASEO	Cabin Air Separator for EVA Oxygen
$CaSO_4$	Calcium Sulfate
CDMK	Carbon Dioxide Monitoring Kit
CDRA	Carbon Dioxide Removal Assembly
CDS	Cascade Distillation System
CFD	Computational Fluid Dynamics
CH_4	Methane
CO_2	Carbon Dioxide
COPV	Composite Overwrapped Pressure Vessel
COTS	Commercial-Off-The-Shelf
CSACP	Compound Specific Analyzer - Combustion Products
CTB	Cargo Transfer Bag
CWC	Contingency Water Container
CWCI	Contingency Water Container Iodine
DFRC	Dryden Flight Research Center
dP	Differential Pressure
dP/dT	Pressure Change Rate
DSH	Deep Space Habitat~~ion~~
EAWG	Exploration Atmospheres Working Group
ECLS	Environmental Control and Life Support
ECLSS	Environmental Control and Life Support Systems
EDO	Extended-Duration Orbiter
EDV	Hard-shelled Russian Liquid Storage Containers (Cyrillic)
EHS	Environmental Health System
EMB	Engineering Management Board
EMU	Extra-vehicular Mobility Unit
ESMD	Exploration and Science Mission Directorate
ETDP	Exploration Technology Development Program
ETM	Exploration Test Module
EVA	Extra-Vehicular Activities
FY	Fiscal year
GCT	Game Changing Technology
GFRC	Goddard Flight Research Center
GRC	Glenn Research Center
H_2O	Water
HAT	HSF Architecture Team
HEPA	High-Efficiency Particulate Air
HQ	Headquarters
HSF	Human Space Flight
HX	Heat Exchanger
IMV	Inter-Module Ventilation
IR	Infrared

ISS	International Space Station
ISTAR	ISS Testbed for Analog Research
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
lb	Pound
LEO	Low Earth Orbit
Li_2CO_3	Lithium Carbonate
LiOH	Lithium Hydroxide
MAG	Maximum Absorbency Garment
MCA	Major Constituent Analyzer
MCV	Microbial Check Valve
MMSEV	Multi-Mission Space Exploration Vehicle
MPCV	Multi-Purpose Crew Vehicle
MSFC	Marshall Space Flight Center
N_2	Nitrogen
N_2H_4	Hydrazine
NASA	National Aeronautics and Space Administration
NESC	NASA Engineering and Safety Council
NGLS	Next Generation Life Support
NH_3	Ammonia
O_2	Oxygen
OCE	Office of Chief Engineer
OCT	Office of Chief Technologist
OGA	Oxygen Generator Assembly
PFE	Portable Fire Extinguisher
pH	Potential Hydrogen
PLSS	Primary Life Support System
POU	Point of Use
PPN_2	Partial Pressure Nitrogen
PPO_2	Partial Pressure Oxygen
PPRV	Positive Pressure Relief Valve
psia	pounds per square inch absolute
PTC	Passive Thermal Control
PWR	Payload Water Reservoirs
QD	Quick Disconnect
RFTA	Recycle Filter Tank Assembly
RSR	Resupply Stowage Rack
RTD	Resistive Temperature Device
SEV	Space Exploration Vehicle
SME	Subject matter experts
SOA	State-of-the-Art
SRV-K	Condensate Recovery System (Cyrillic)
SSC	Stennis Space Center
STS	Space Transportation System
SWM	Solid Waste Management
TC	Thermal Control
TCCS	Trace Contaminant Control Subassembly
TESC	Thermal/ECLSS Steering Committee
TIM	Technical Interchange Meeting
TOC	Total Organic Carbon
TOCA	Total Organic Carbon Analyzer
TP	Thermal Protection

TPS	Thermal Protection System
TT&E	Test, Teardown, and Evaluation
TUBBS	Temporary Urine and Brine Stowage System
UPA	Urine Processor Assembly
U.S.	United States
VCAM	Vehicle Cabin Air Monitor
VCD	Vapor Compression Distillation
VV	Visiting Vehicle
WCM	Waste Collection and Management
WCS	Waste Collection Subsystem
WM	Water Management
WHC	Waste and Hygiene Compartment
WPA	Water Processor Assembly
WRS	Water Recovery System

Appendix B: Systematic Approach to creating the ECLSS Roadmap

An enormous amount of work has already been completed by the NASA ECLS community. In large part this is due to the diligence of the team as well as the multiple, non-integrated requests for information from planning teams. The steps used to accomplish the goals in this paper are outlined below. These steps also layout the order of contents for this paper. Each step is meant to increase the level of ECLS community integration to achieve the most effective use of ECLS resources.

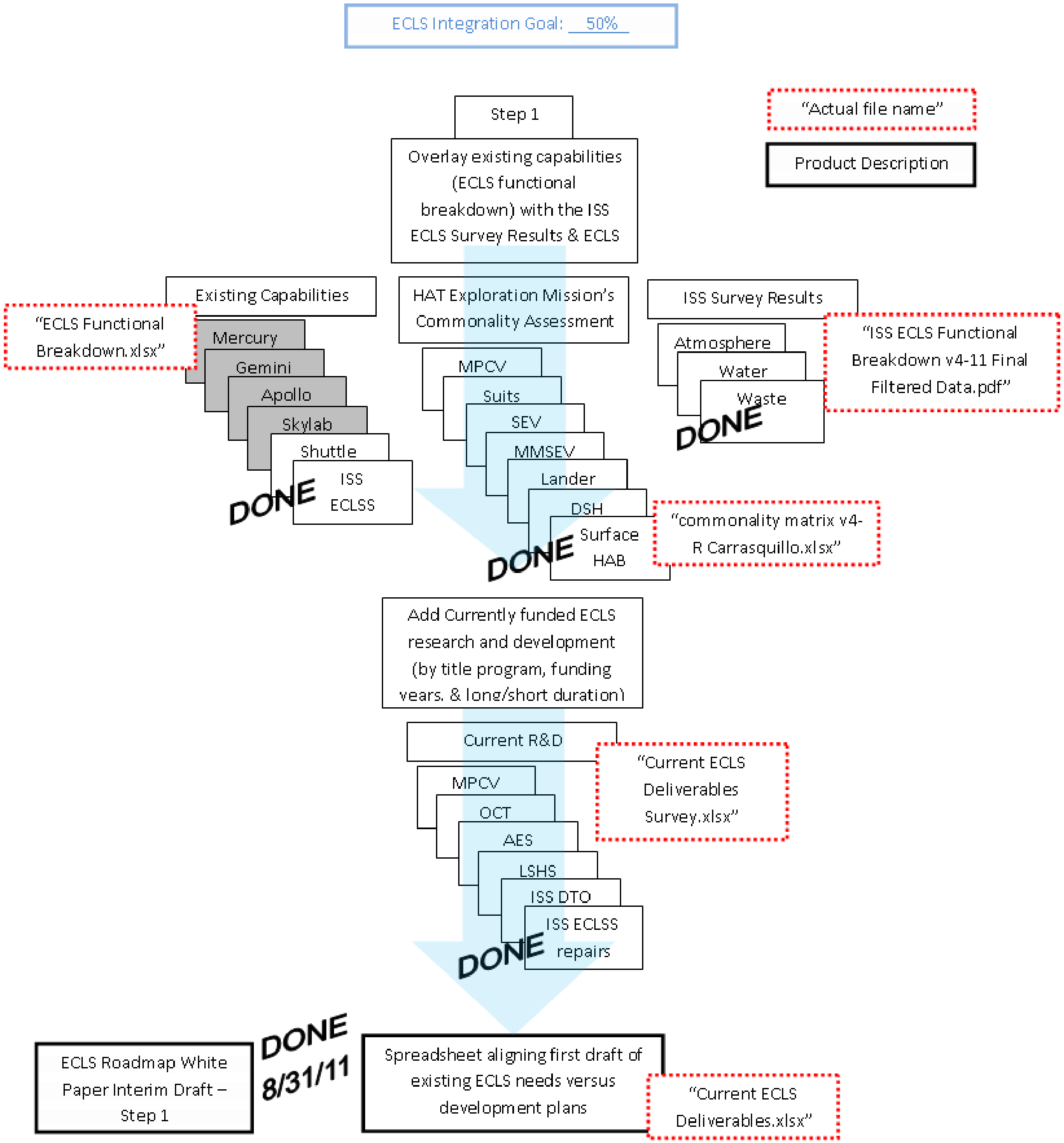
Data already produced to support the multiple planning requests has been compiled to create the results of **Interim Draft – Step 1**. A spreadsheet contains the ECLS functional decomposition and the ISS functionality survey agreed to at the 7/6/11 ECLS TIM, as well as the ECLS commonality assessment completed on 8/4/11, and the list of current work funded by MPCV, AES, OCT, and/or ISS supporting future human space flight missions. The results of these independently generated data sets enable an assessment of alignment (based on what's already been funded) as well as an option for ECLS hardware configuration in support of the ISS Exploration Testing Module (ETM).

At this point, the mass of information hasn't been presented to nor reviewed by the ECLS community as an integrated product. **Interim Draft – Step 2** will include the results of an ECLS community meeting to review of the information, identify and collect any additional information found to be missing, perform a gap assessment, and reach a consensus on an initial plan for an integrated approach to ECLS research, development, and testing needs (both ground and flight) to support future human spaceflight missions. An updated white paper, as well as a prioritized ECLS roadmap spreadsheet will be delivered. By the time Step 2 is complete, the ECLS community will agree on the baseline system for the three major mission categories (short-duration CEV/SEV-like, long-duration microgravity transit [ISS-like with low consumables], and long-duration surface exploration). Gaps will have been identified, as well as what needs to be done in development, ground testing, ISS testing, etc. to get those systems ready.

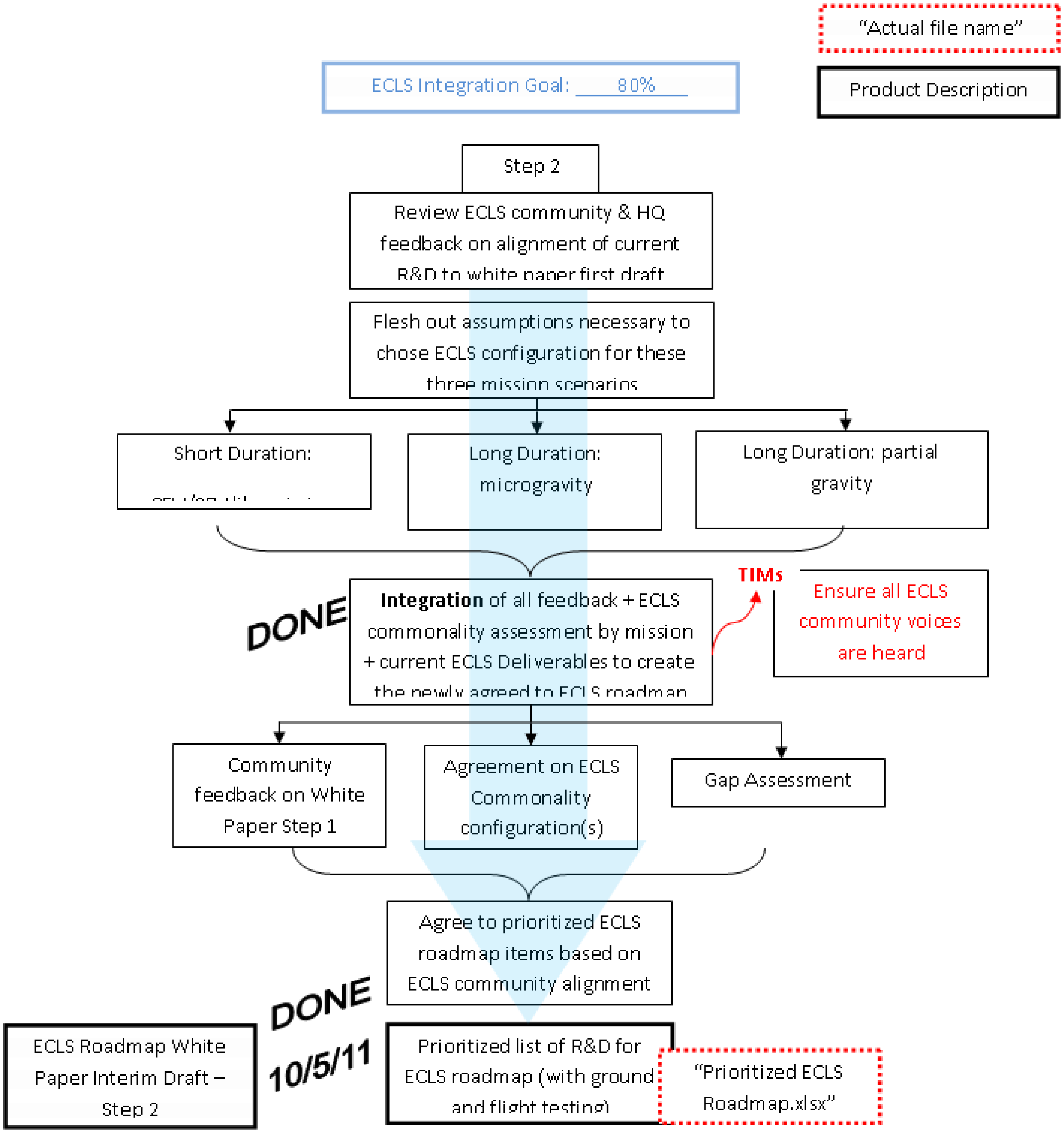
After the ECLS community has narrowed in on the appropriate reference configuration(s) for the future human spaceflight missions, the skeleton of information can be fleshed out. Trade studies, analysis, and TIMs may be used to determine information like mass, volume, cost, schedule, and support required. Additionally, the ECLS community may be add 'tuning features' to the reference ECLS configuration(s) for future missions that accommodate changing requirements. **Final – Step 3** will deliver the final white paper and spreadsheet with recommendations for the ETM. This will be widely circulated through the ECLS customer community for input and buy-in.

Following the review cycle of the final paper, updates will be used to support requests for appropriate funding during the FY13 PPB&E process.

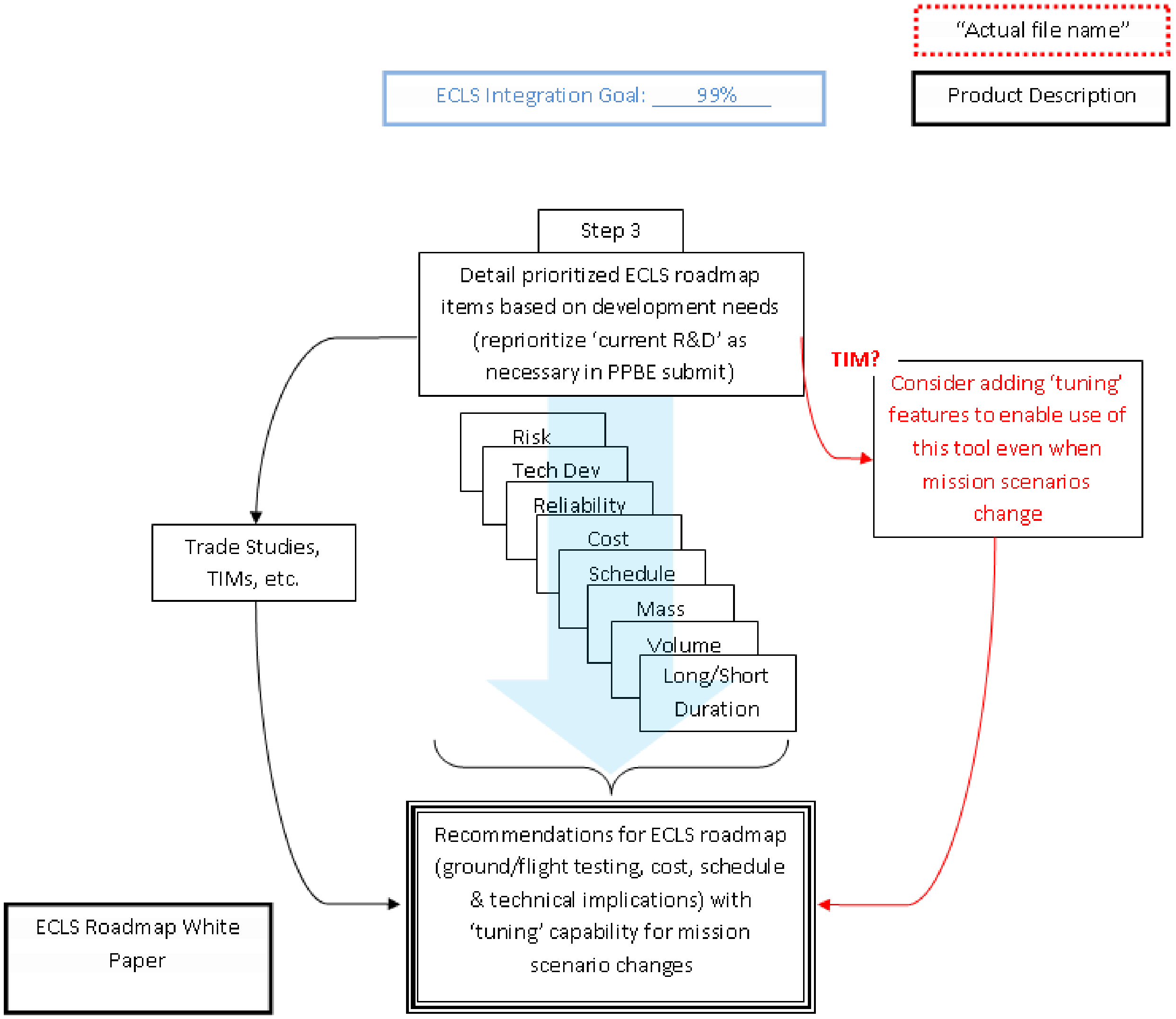
Deliverables of Step 1



Deliverables of Step 2



Deliverables of Step 3



Appendix C: ECLS Steering Committee Charter

National Aeronautics and Space Administration
Headquarters, Office of Chief Engineering

National Aeronautics and Space Administration (NASA) Thermal / Environmental Control and Life Support (ECLS) Steering Committee (TESC)

CHARTER

May 2010

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

NASA Thermal/ECLS Steering Committee Charter

I. Executive Summary

This charter creates the National Aeronautics and Space Administration (NASA) Thermal / Environmental Control and Life Support (ECLS) Steering Committee (TESC), composed of a line management representative from each Center's Active Thermal Control (ATC), ECLS, Passive Thermal Control (PTC), and Thermal Protection (TP) communities, as applicable. This integration effort brings the inter-center ATC/ECLS/PTC/TP engineering leadership together to continually improve the state of the discipline including workforce and facilities. In doing so, the TESC will leverage existing expertise and technologies in industry, academia, and other U.S. Government organizations when possible. The TESC will develop a common vision and strategy associated with the ATC/ECLS/PTC/TP disciplines. Its primary foci are near- and long-term strategies that must be implemented to ensure that relevant Agency resources (workforce, dollars, infrastructure, and advanced initiatives) align with the NASA Mission Directorates and their associated programs and projects. The ultimate goal is to advance the state of the ATC/ECLS/PTC/TP disciplines ahead of program and project needs.

II. Scope

The scope of the TESC includes the ATC/ECLS/PTC/TP elements listed in Tables 1, 2 and 3 below.

Table 1: ATC Elements

Heat collection: HXs and cold plates
Heat transport: single-phase and two-phase pumped loops, heat pipes, heat pumps, boiling, condensation, etc.
Fluid system design and analysis: pumps, accumulators, phase separators, flow through porous media, fluid dynamics, induced vibe, zero-g effects, differential pressure (dP), storage systems, system stability, etc.
Heat sink/rejection: radiators, evaporators, sublimators, phase-change HXs
Payload Refrigeration systems
Ground cooling: ventilation and liquid cooling
Thermal cycle/Thermal vacuum testing: component- and vehicle-level
Integrated thermal system testing: testbeds and vehicle-level
Thermal and fluid analysis and modeling: design, test and flight

Table 2: ECLS Elements

Habitable volume atmosphere quality control: particulate, humidity, trace contaminants/toxicity, CO_2, microbial, temperature, etc.
Habitable volume pressure control" total P, O_2 and N_2, partial P, gas storage and supply systems, solid O_2 generation)
Potable and waste water, constituency, stabilization, storage, and supply: drinking, condensate, hygiene, including shower and laundry, urine, biocides

Human waste and solids collection, stabilization and storage: fecal, urine, odor control, volume reduction, zero-g effects
Air circulation / ventilation: fans, ducting, verification, acoustics
Emergency response: fire suppression, post-fire cleanup, face masks
Environmental monitoring instrumentation: major/trace gases, smoke detection, pressure change rate (dP/dT), particulate, microbial, water quality
Regenerable systems: physical, chemical and biological processes to regenerate O_2, water and wastes
Fluid quality control for flight and ground systems: specification, chemical analysis, etc.
ECLSS design and analysis: Architecture, process modeling, Computational Fluid Dynamics (CFD) analysis, etc.

Table 3: PTC & TP Elements

TP Materials and Systems: reusable Thermal Protection System (TPS), ablatives, barriers, seals, hot structure
PTC: radiators, insulations, isolators, thermal coatings, thermal switches, louvers, paints, PCMs, TECs, heat pipe systems, resistive heaters, cryogenic dewars, thermal interfaces, heaters, sensors, thermostatic control, etc.
TP Materials and Systems: reusable TPS, ablatives, barriers, seals, hot structure
Purge, Vent and Drain Hardware and Systems
Thermal Modeling and Analysis: on-orbit, pre-launch, post-landing, entry, ascent, ablatives, thermal structural (shared with structures), aero-thermal (shared with aero), etc.
Thermal Testing: all thermal testing: thermal vacuum, thermal cycling, radiant, optical property testing, arc jet
Cryogenic Systems

III. Purpose

a. Promote discipline-wide collaboration

- i. Identify opportunities for advancing and aligning the Agency's ATC/ECLS/PTC/TP workforce to develop and maintain core competencies (including rotational assignments, workforce training and development)
- ii. Identify and promote the use of compatible tools and infrastructure to increase overall Agency effectiveness and efficiency of the ATC/ECLS/PTC/TP disciplines
- iii. Coordinate resource planning that positions the ATC/ECLS/PTC/TP disciplines ahead of anticipated program needs

b. Advance and maintain SOA of the disciplines ahead of anticipated Agency needs

- i. Advance tool and infrastructure capabilities to increase overall ATC/ECLS/PTC/TP disciplines effectiveness and efficiency
- ii. Identify gaps and risks in ATC/ECLS/PTC/TP capabilities (knowledge, skills, processes, test beds, facilities, tools, workforce, etc.) and provide solutions/recommendations

    iii. Facilitate, guide, and/or recommend inter- or intra-discipline trades studies to anticipate discipline needs
    iv. Promote knowledge capture and training awareness

c. Advance current and next generation ATC/ECLS/PTC/TP technologies

    i. Evaluate current ATC/ECLS/PTC/TP technology activities and make recommendations to improve/advance critical areas
    ii. Facilitate, guide, and/or recommend inter- or intra-discipline trades studies to advance system architectures supporting the development of roadmaps to meet anticipated Agency needs
    iii. Advocate the implementation of the roadmaps

IV. Strategic Relationships

The TESC is an in-line engineering leadership function endorsed by the Agency's Engineering Management Board (EMB). It will maintain a close symbiotic relationship with the Center Engineering Directorates and the NASA Engineering and Safety Center (NESC) ATC/ECLS/PTC/TP Technical Fellow. The TESC will develop partnerships with other organizations as required to better understand workforce needs, technology roadmaps, skills gaps, risks, and trades from an Agency perspective. These partnerships will be used to develop strategic initiatives that align with our stakeholders' vision and mission. Each TESC member will coordinate committee activities and provide recommendations to the appropriate stakeholders. Primary interfaces are depicted in Figure 14.

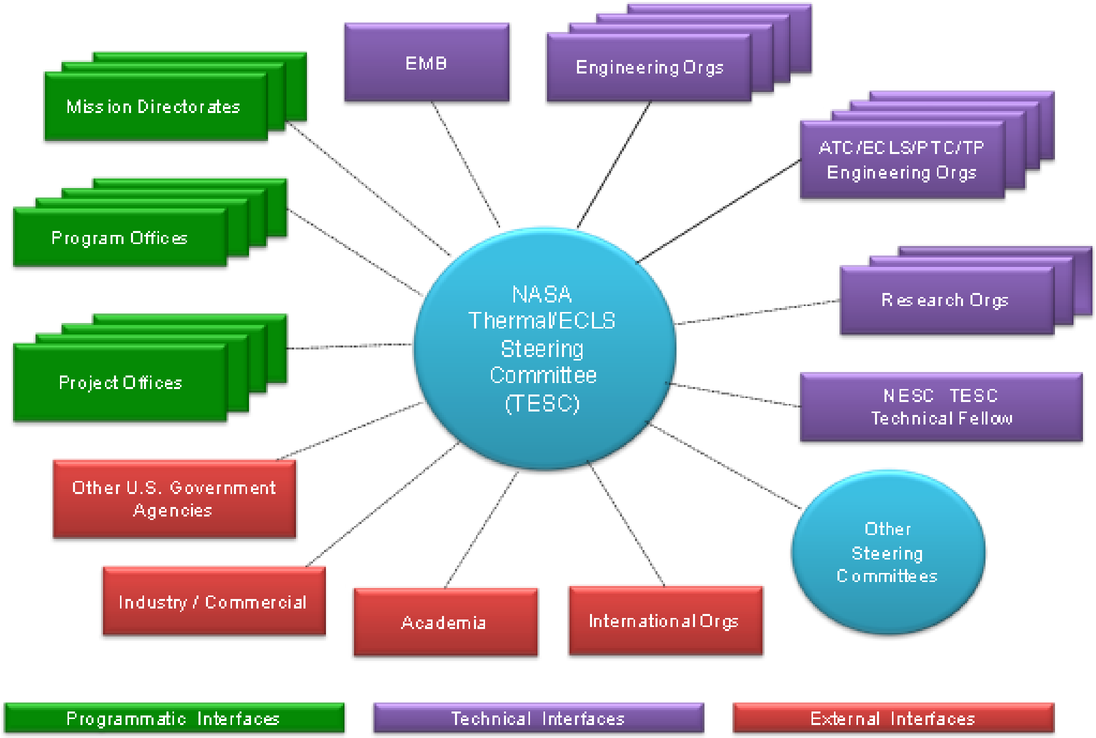


Figure 14. TESC Strategic Relationships

V. Integrated ATC/ECLS/PTC/TP Strategy

Figure 15 depicts a typical products/services flow between the TESC and other organizations.

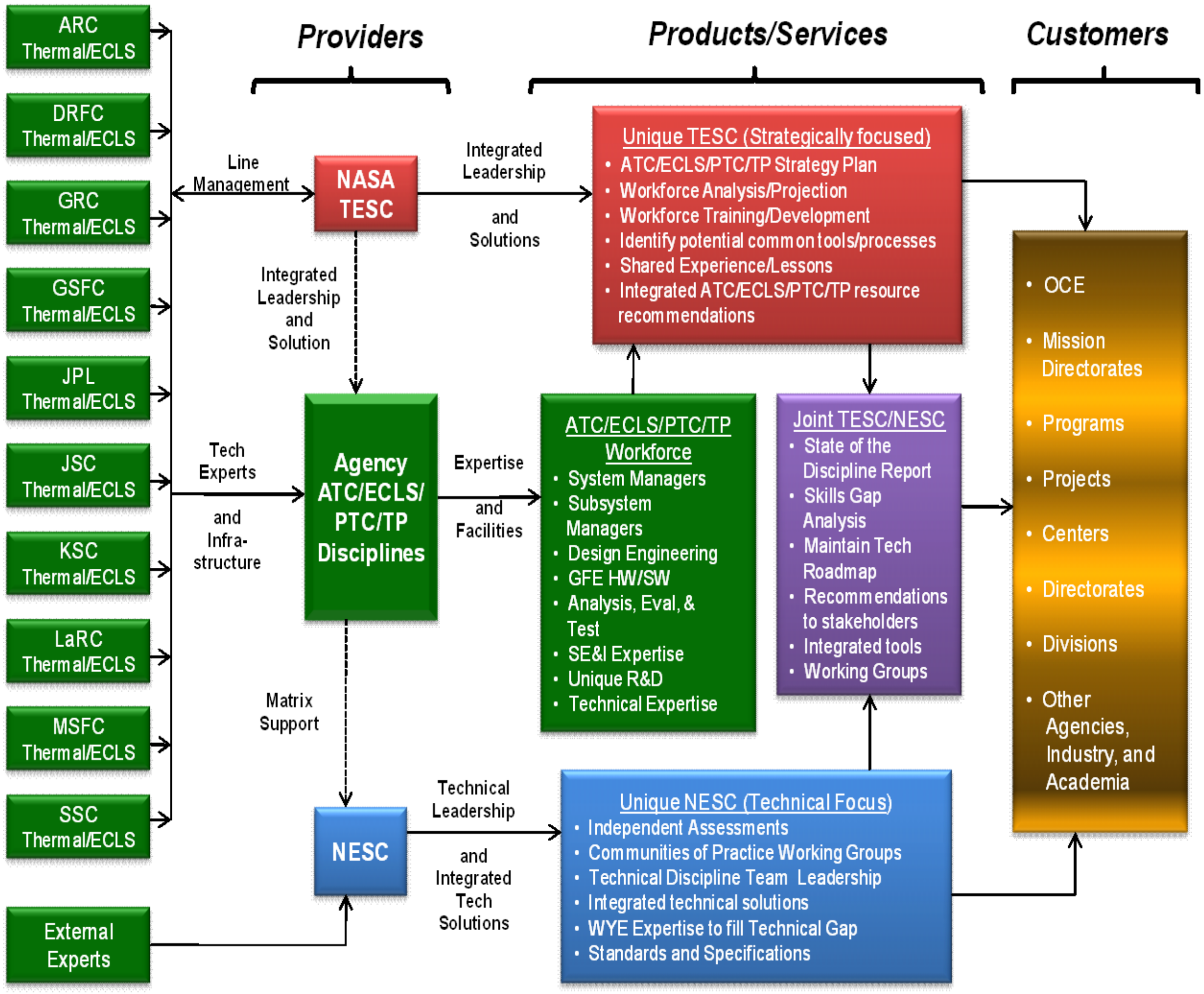


Figure 15. Integrated ATC/ECLS/PTC/TP Strategy

I. Participants

a. One line management representative (of each applicable discipline) from each Center is authorized to represent their Center ATC/ECLS/PTC/TP disciplines/organizations – a center may elect to not actively participate by providing concurrence of the Center's Director of Engineering on the charter and membership.

i. Members

- Ames Research Center (ARC)
- Dryden Flight Research Center (DFRC)
- Glenn Research Center (GRC)
- Goddard Space Flight Center (GSFC)
- Jet Propulsion Laboratory (JPL)
- Johnson Space Center (JSC)

    - Kennedy Space Center (KSC)
    - Langley Research Center (LaRC)
    - Marshall Space Flight Center (MSFC)
    - Stennis Space Center (SSC)

ii. Ad-hoc Member: NASA ATC/ECLS/PTC/TP Technical Fellows

b. Other participants are invited, as required, to support/facilitate team discussions

II. Chair

a. The Committee Chair will be rotated among the represented Centers

b. Responsibilities:

i. Organize and set TESC agenda and meeting locations

ii. Manage and facilitate TESC meetings

iii. Serve as liaison to the EMB as required communicating TESC actions, requests, needs, etc

iv. Provide administrative support to take TESC meeting minutes, track actions, and maintain the PBMA website

III. Meeting Frequency

a. Minimum of quarterly face-to-face meetings

b. Virtual TESC meetings may be called by any member as warranted

Appendix D: AM Detail

Functional Decomposition

Level 1	Level 2	Level 3	Level 4	Level 5	Heritage H/W
1.1 Circulation	1.1.1 Valves				
	1.1.2 Acoustic Control				
	1.1.3 Fans				
	1.1.4 Suit Umbilicals				
	1.1.5 Ducting				
	1.1.6 Debris Exclusion				Inter-Module Ventilation (IMV) Screens
	1.1.7 Diffusers				
1.2 Conditioning	1.2.1 Microbial Control	1.2.1.1 Removal	1.2.1.1.1 Coatings		Conditioning HX
			1.2.1.1.2 Filters		HEPA
		1.2.1.2 Disposal			
	1.2.2 Particulate Control	1.2.2.1 Removal	1.2.2.1.1 Planetary Generated		
			1.2.2.1.2 Cabin Generated		HEPA
		1.2.2.2 Disposal	1.2.2.2.1 Store No Re-use		
	1.2.3 Trace Contaminant Control	1.2.3.1 Removal	1.2.3.1.1 Catalysis	1.2.3.1.1.1 High Temp Reactor	Catalytic Oxidizer
				1.2.3.1.1.2 Mod Temp Reactor	
				1.2.3.1.1.3 Ambient Temperature Reactor	Ambient Temperature Catalytic Oxidizer (ATCO)
			1.2.3.1.2 Absorption		Lithium Carbonate (Li_2CO_3)
					Rusty Gold
					Charcoal

Level 1	Level 2	Level 3	Level 4	Level 5	Heritage H/W
		1.2.3.2 Disposal	1.2.3.2.1 Desorption		
			1.2.3.2.2 Store No Re-use		
	1.2.4 CO_2 Management	1.2.4.1 Removal			Amine Sorbent
					Lithium Hydroxide (LiOH)
					Zeolite Sorbent
		1.2.4.2 Disposition	1.2.4.2.1 Disposal		Vent
			1.2.4.2.2 Store		LiOH
			1.2.4.2.3 Resource Recovery	1.2.4.2.3.1 CO_2 Reduction	Tanks
					Compressor
					Sabatier Reactor
	1.2.5 Humidity Control	1.2.5.1 Removal	1.2.5.1.1 Liquid		Conditioning HX
					Separator
			1.2.5.1.2 Vapor		Silica Gel
					Zeolite Sorbent
					Amine Sorbent
		1.2.5.2 Disposition	1.2.5.2.1 Disposal		Vent
					Tanks
					Bags
			1.2.5.2.2 Store		Silica Gel
			1.2.5.2.3 Resource Recovery		Tanks
					Bags
	1.2.6 Temp Control	1.2.6.1 Removal			Conditioning HX
1.3 Emergency Services	1.3.1 Med O_2				Tanks
	1.3.2 Fire Suppression	1.3.2.1 Fixed			Halon
		1.3.2.2 Portable Extinguisher			Halon
					CO_2
					Water/Foam
		1.3.2.3 Cabin Vent			Depress Valves
	1.3.3 Atmosphere Recovery	1.3.3.1 Sorbent			Fire Cartridge
		1.3.3.2 Catalysis			Fire Cartridge
		1.3.3.3 Filtration			LiOH? (Portable Fire Extinguisher (PFE))
					Fire Cartridge
					Fan Filters

Level 1	Level 2	Level 3	Level 4	Level 5	Heritage H/W
		1.3.3.4 Atmosphere Purge			Vent
	1.3.4 Personal Protective Equipment	1.3.4.1 Filtration Masks			NH_3
		1.3.4.2 Gas Supply Masks			O_2
1.4 Monitoring	1.4.1 Composition Sensing	1.4.1.1 Temp			Thermal Control (TC) / Resistive Temperature Devices (RTDs)
		1.4.1.2 Particulate			
		1.4.1.3 CO_2	1.4.1.3.1 Electro-chemical		Carbon Dioxide Monitoring Kit (CDMK)
			1.4.1.3.2 Infrared (IR)		Space Transportation System (STS)/Extra-vehicular Mobility Unit (EMU)
			1.4.1.3.3 Mass Spec		Air Quality Monitor (AQM)
					Vehicle Cabin Air Monitor (VCAM)
					Major Constituent Analyzer (MCA)
		1.4.1.4 Trace Contaminants			Grab Sample
					VCAM
		1.4.1.5 Water Vapor			MCA
		1.4.1.6 Microbial			Grab Sample
	1.4.2 Emergency Sensing	1.4.2.1 Fire/Smoke	1.4.2.1.1 Laser		ISS Detector
			1.4.2.1.2 Radiation		STS Detector
		1.4.2.2 Acute Hazards (NH_3/Prop/Dust)			Draeger Tubes
					Gold Salt (?)
	1.4.3 Pressure Sensing	1.4.3.1 Partial-Pressure Oxygen (PPO_2)			MCA
		1.4.3.2 Total Pressure			Press Transducer
		1.4.3.3 Leak Detection	1.4.3.3.1 dP/dT		
			1.4.3.3.2 Partial-		MCA

Level 1	Level 2	Level 3	Level 4	Level 5	Heritage H/W
			Pressure Nitrogen (PPN$_2$)		
1.5 Pressure Management	1.5.1 N$_2$ Delivery	1.5.1.1 Payload			Isometric Valves
		1.5.1.2 Habitable Volume			Valves
					Cabin Regulator
	1.5.2 O$_2$ Delivery	1.5.2.1 Medical/Payload			Quick Disconnects (QDs)
					Valves
		1.5.2.2 Habitable Volume			Cabin Regulator
					Valves
		1.5.2.3 EVA	1.5.2.3.1 Suit		
			1.5.2.3.2 PLSS		Mid-pressure Regulators
	1.5.3 O$_2$ Supply	1.5.3.1 O$_2$ Generation	1.5.3.1.1 Liquid Electrolysis		Valves
					Ion Exchange
					SPE Stack
					Separator
					Pumps
					Sensors
			1.5.3.1.2 Chemical		Candles
		1.5.3.2 Cryogenic O$_2$			Tank
					Bottle Regulator
					Heaters
					Valves
		1.5.3.3 Compressed			Bottle Regulator
					Tank
					Valves
	1.5.4 N$_2$ Supply	1.5.4.1 Compressed			Bottle Regulator
					Tank
					Valves
	1.5.5 Cabin Relief	1.5.5.1 Equalization			Valves
		1.5.5.2 Positive Pressure			Valves
		1.5.5.3 Negative Pressure			Valves

Commonality Matrix

Function/ Component	**Shuttle**	**ISS**	**MPCV (Orion)**	**Suits (PLSS)**	**SEV**	**MMSEV**	**Lander**	**DSH**	**Surface Hab**
Atmosphere Management	note: for rotating equip, Shuttle used 115V, 3-phase								
Air Revitalization									
CO2 removal	LiOH; RCRS (amine swing bed)	CDRA (zeolite, water save); ESA ACRS steam desorbed amine proposed flt expt (water save); Silver Oxide (Airlock EVA), Russian Vozdukh (amine, water save).	amine PSA (CO2 vented); deployable LiOH for postlanding (in development)	amine PSA (smaller, shorter cycles)	MPCV or PLSS-size PSA. Must ensure materials good for 8 psi	MPCV or PLSS-size PSA. Must ensure materials good for 8 psi	same as MPCV	Improved ISS CDRA with robust sorbent, changes to up front water save, compressor for CO2 recovery (assumed as LPCOR)	Same as DSH?
	Issues: stowage vol.	Issues: zeolite containment, heater and sensor failures	Possibility to use common amine or zeolite-based bed core (CARE concept) with/without upstream water removal and CO2 recovery components depending on mission trades. Common bed allows reduced mission spares. Design for 8 psi/34% O2.						
Humidity control	CHX/spin sep	CHX/spin sep	amine PSA (H2O vented)	amine PSA (smaller, shorter cycles)	MPCV or PLSS-size PSA. Must ensure materials good for 8 psi	MPCV or PLSS-size PSA. Must ensure materials good for 8 psi	same as MPCV	CHX/spin sep	CHX + partial-g sep
			May trade water save for MPCV evolution	Possibililty for common PSA beds for open-loop applications				Common with ISS or ISS technology	
Trace Contaminant Control	Charcoal/ ATCO	Charcoal/ HTCO; Russian - regenerable Act Carbon/HTCO + ATCO	heritage sorbents (charcoal/ ATCO)	heritage sorbents	heritage sorbents	heritage sorbents	heritage sorbents	ISS as POD	Same as DSH
			Possibility to use advanced sorbents/catalysts common across architecture						
Circulation - fans	none	Dedicated CDRA & TCCS blowers (virtually identical)	New ARS fan in suit loop, 100% O2, range of press/flow, 50 cfm	4.5 cfm, 100% O2	~10-12 cfm needed	~10-12 cfm needed	same as MPCV	Dedicated ARS blowers. Contingency suit support to PLSS	Same as DSH
note: not including diffusers & ducting (vehicle specific)			Common fan between PLSS and SEV shown not to work due to different design points on fan curve. Common fan between MPCV and Lander possible. Common fan between MPCV and SEV may be possible - need to look at design points. Recommend investment in quiet fan technology which could be applied across all fans.						
Resource Recovery from CO2	none	Sabatier with mechanical compressor; Astrium ACRS proposed flt expt uses Sabatier	none due to mission duration	none	none	none	none	Minimum of at least a Sabatier; further reduction depending on mission (CH4 pyrolysis or Bosch). Compressor improvements to either mechanical or may use solid state zeolite compressor instead of mechanical	DSH + ?
								Common Sabatier with ISS?	

Function/ Component	**Shuttle**	**ISS**	**MPCV (Orion)**	**Suits (PLSS)**	**SEV**	**MMSEV**	**Lander**	**DSH**	**Surface Hab**
Atmosphere Management	note: for rotating equip, Shuttle used 115V, 3-phase								
Atmosphere Composition Monitoring									
Major Constituent Monitor	Electrochem O2 sensor, IR CO2 sensor	Major Constituent Analyzer (mass spec); CSA-O2 (portable - electrochem); CO2 monitor kit (CDMK - electrochem); Russian gas analyzer (electrochem); Columbus CO2 analyzer; VCAM expt. (GC-MS)	Atmosphere monitor (mass spec). Redundant CO2 (EMU heritage) and O2 sensors (electrochem)	CO2 sensor (IR), may be O2 sensor on advanced suit	same as MPCV; *consider dissimilar redundancy if EVA contaminates baseline sensor*	same as MPCV; *consider dissimilar redundancy if EVA contaminates baseline sensor*	same as MPCV; *consider dissimilar redundancy if EVA contaminates baseline sensor*	Same as MPCV - may need solution for recalibration due to longer mission	
			Common CO2 sensor?						
Trace Contaminant Monitor	none	Baseline is grab samples with ground analysis. Expts include GC-MS (VCAM), FTIR (ANITA), GC-DMS (AQM); Russian GANK-4M; some COTS (Draeger CMS)	none due to short mission duration	none	none	none	none	Trade space open - on-orbit analysis will likely be needed. Choose from ISS-demo'd instruments.	
Water Vapor	none	MCA - don't rely on accuracy; Russian analyzer may do H2O	part of air monitor	none	same as MPCV	same as MPCV	same as MPCV	Same as MPCV - may need solution for recalibration due to longer mission	
Microbial Monitor (air)	none	microbial air sampler (MAS kit)	none	none	possible planetary protection need	none	possible planetary protection need	Need to be evaluated - technology trade space open	possible planetary protection need

Function/ Component	Shuttle	ISS	MPCV (Orion)	Suits (PLSS)	SEV	MMSEV	Lander	DSH	Surface Hab
Atmosphere Management	note: for rotating equip, Shuttle used 115V, 3-phase								
Ventilation									
Cabin air particulate filtration	OCAC large screen & HEPA filters (?)	HEPA filters	HEPA filters	screens	HEPA filters	HEPA filters	HEPA filters	HEPA filters	HEPA filters
			possibility to use same/heritage HEPA filters						
Airborne microbial filtration	HEPA filters	HEPA filters	HEPA filters	none	HEPA filters	HEPA filters	HEPA filters	HEPA filters	HEPA filters
			possibility to use same/heritage HEPA filters?						
Surface Dust filtration	NA	NA	HEPA filters (may be inadequate for lunar dust)	none	HEPA filters (possible advanced filtration technologies)	HEPA filters (don't know if will need additional filtering depending on mission/exposure)	HEPA filters (possible advanced filtration technologies)	HEPA filters (don't know if will need additional filtering depending on mission/exposure)	HEPA filters (possible advanced filtration technologies)
Cabin ventilaton	2 axial fan package, 4.96-6.14 in H20 head rise, 300-342 cfm; IMU & avionics bay cooling fans	Inlet ORU (300-450 cfm); IMV fan (120 cfm, low head rise); AAA (100 cfm); portable fan assy (100 cfm)	150 cfm cabin fan (scaling from heritage?)	NA	same as MPCV	same as MPCV	same as MPCV	large volume, distributed space, many fans?	
			Inlet ORU too big; AAA too small; IMV not enough head rise					potential to use heritage either ISS or MPCV; recommend adopting quiet fan tech	potential to use heritage either ISS or MPCV; recommend adopting quiet fan tech
Cabin temp control	Air FCA & cabin HX	Condensing HX with bypass; spin sep	condensing (non-slurping) HX (scaling from heritage?). ISS coating (area for improvement?)	Fan/non-condensing HX.	CHX - gravity sep	CHX - spin sep or consider MPCV approach	CHX (gravity sep)	CHX - spin sep (possibililty for ISS or SEV commonality depending on sizing)	CHX - gravity sep
Snorkel fan	NA	NA	unique to MPCV - possible to use ISS IMV fan?	NA	NA	NA	NA	NA	

Function/ Component	Shuttle	ISS	MPCV (Orion)	Suits (PLSS)	SEV	MMSEV	Lander	DSH	Surface Hab
Atmosphere Management	note: for rotating equip, Shuttle used 115V, 3-phase								
Emergency Services									
Smoke detector	Particulate detectors	Obscuration-type	not ISS-heritage. Could be?	none	MPCV?	MPCV?	MPCV	MPCV?	MPCV?
			Advanced technology - CO-based smoke sensor? Possibility to use same across architecture						
Surface dust detector	none	none	none		May need something unique for surface dust	May need something unique for surface dust	May need something unique for surface dust	May need something unique for surface dust	May need something unique for surface dust
Fire Extinguisher	Halon	Portable CO2 for area and equipment bay flooding; water mist under development; Russian water foam PFE	PFE - Water mist under development; av bays N2 flooding (hoping to eliminate with material testing to 40% O2)	none	Similar approach to MPCV	Similar approach to MPCV	PFE only - Water mist under development	PFE - Water mist under development; likely will need flooding-type system for equipment bays, especially with long dormant periods	same as DSH
			Halon prohibited; CO2 doesn't work in small cabins						
Contingency masks	O2 masks	O2 PBA; "rusty gold" mask under development	GFE "rusty gold" under dev - partner with ISS	none	same as MPCV	same as MPCV	same as MPCV	same as MPCV	same as MPCV
			cannot use O2 in small cabin						
Atmosphere Recovery	install charcoal canister in place of LiOH; don masks, purge cabin (last resort),	Russian AFOT (sorbent/catox), PFA add-on kits, use ARS, last resort is depress/repress if cannot clean up	nothing baselined; would like smokeeater based on ISS mask technology (bag of rusty gold); depress/repress if needed	none	same as MPCV; PLSS as backup with depress/repress	same as MPCV; PLSS as backup with depress/repress	smokeater integrated with cabin fan system	smokeater	smokeater
Ammonia/Hydrazine monitor	Gold salt Draeger tubes	Gold salt Draeger tubes	likely GFE - investigating different COTS sensors	none	none needed	same as MPCV	none needed with current prop system	same as MPCV?	none needed
Combustible gas monitor	CSACP	CSACP	initial Block 0 - likely GFE based on new CSACP - partner with ISS; Block 2 integrated with air monitor	none	same as MPCV	same as MPCV	same as MPCV Block 2; airlock dust issues may drive different technology	same as MPCV - ensure long-duration calibration	same as MPCV - ensure long-duration calibration

Function/ Component	**Shuttle**	**ISS**	**MPCV (Orion)**	**Suits (PLSS)**	**SEV**	**MMSEV**	**Lander**	**DSH**	**Surface Hab**
Atmosphere Management	note: for rotating equip, Shuttle used 115V, 3-phase								
Pressure Control									
Suit-loop pressure regulation	NA	NA	New dev - high and low flow - leverages off either PLSS or Orion prop components for commonalilty	3000 step regulator (under development)	NA	NA	Common with MPCV	NA	NA
Cabin pressure equalization	Manual Pressure Equalization Valve (MPEV)	Manual Pressure Equalization Valve (MPEV) - different vendor from Shuttle	Powered and manual EV's	NA	same as MPCV	same as MPCV	same as MPCV	same as MPCV - sizing may be different due to vehicle volumes	same as MPCV - sizing may be different due to vehicle volumes
Cabin pressure regulation	N2O2 control panel (uses cabin pressure regs nominal/emergency)	Pressure Control Assy (PCA) - computer-controlled O2 & N2 intro valves & visiting vehicle gas	Baseline is new valves/regulators; Considering use of common Orion prop components; feed-a-leak requirement	NA	Trading use of PLSS high flow reg vs MPCV system	Trading use of PLSS high flow reg vs MPCV system	Trading use of PLSS high flow reg vs MPCV system	could be ISS-like or MPCV	could be ISS-like or MPCV
	Lesson-learned - difficult to control high flow (PITA)								
Positive pressure relief	PPRV	PPRA	PPRA (common ISS) for OFT1; future missions may be able to use with electronic mods for loads if eliminate av bay fire suppression; if not, will need higher flow PPRV.	suit RV	RV - Common technology but sized for ascent or fire suppression	RV - Common technology but sized for ascent or fire suppression	RV - Common technology but sized for ascent or fire suppression	RV - Common technology but sized for ascent or fire suppression	RV - Common technology but sized for ascent or fire suppression
Negative pressure relief	NPRV	Shuttle-heritage NPRV (for launch only; swapped for IMV valves)	Poppet plus isolation valves - has to be water sealing	none	none	none	none	none	none

Function/ Component	**Shuttle**	**ISS**	**MPCV (Orion)**	**Suits (PLSS)**	**SEV**	**MMSEV**	**Lander**	**DSH**	**Surface Hab**
Atmosphere Management	note: for rotating equip, Shuttle used 115V, 3-phase								
Pressure Control									
Nitrogen storage	3000 psia kevlar COPV	3000 psi COPV	5000 psi COPV	none	Current sizing used 3000 psi COPV but could use MPCV tanks	Current sizing used 3000 psi COPV but could use MPCV tanks	Current sizing used 3000 psi COPV but could use MPCV tanks	Current sizing used 3000 psi COPV but could use MPCV tanks - likely need more	Current sizing used 3000 psi COPV but could use MPCV tanks - likely need more
Oxygen storage	Cryo tanks in fuel cell system	3000 psi COPV	5000 psi COPV - no recharge plans	primary & secondary high press tanks (3000 psi) - not common, small	3600 psi COPV	3600 psi COPV	3600 psi COPV	May use cryo technology or HP tanks (open trade)	May use cryo technology or HP tanks (open trade)
Oxygen generation	none	OGA - solid polymer electrolyte; Astrium ACRS flt expt OGA (liquid KOH); Russian Elektron (KOH), SFOG (candles)	none due to mission duration	none	none	none	none	Use ISS heritage with resolution of reliability issues or alternate technology	Use ISS heritage with resolution of reliability issues or alternate technology
								(CO2 electrolysis)	
O2 recharge (for tanks or EVA)	850 psia from cryo tanks through Airlock	ORCA transfer from Shuttle; new O2 concentrator/compressor in development (CASEO)	none needed	receive	Mechanical Compressor (some parts common with CASEO) and transfer from Surface Hab or PUP, PLSS Recharge	Mechanical Compressor (some parts common with CASEO) and transfer from DSH or PUP, PLSS Recharge	Mechanical Compressor (some parts common with CASEO) PLSS Recharge	Mechanical compressor (some parts commone with CASEO) PLSS Recharge	Mechanical compressor (some parts commone with CASEO) PLSS Recharge

ISS Survey Results

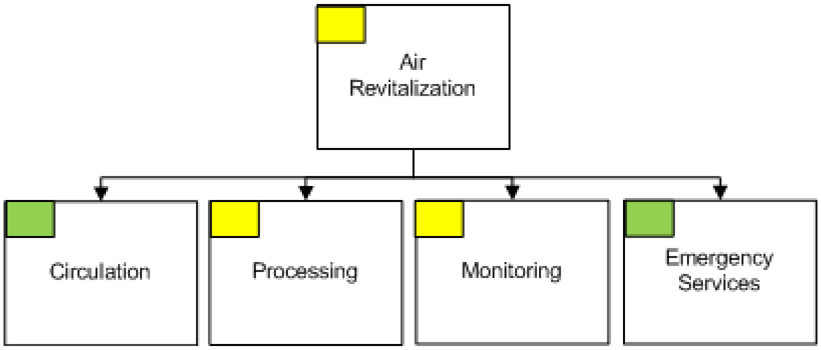
Green: Always – crew intervention required less than once every six months, no ground intervention required

Yellow: Most of the time – crew intervention required less than quarterly, ground intervention required to perform any Test, Teardown, and Evaluation (TT&E) or analysis in support of return to nominal on orbit operations

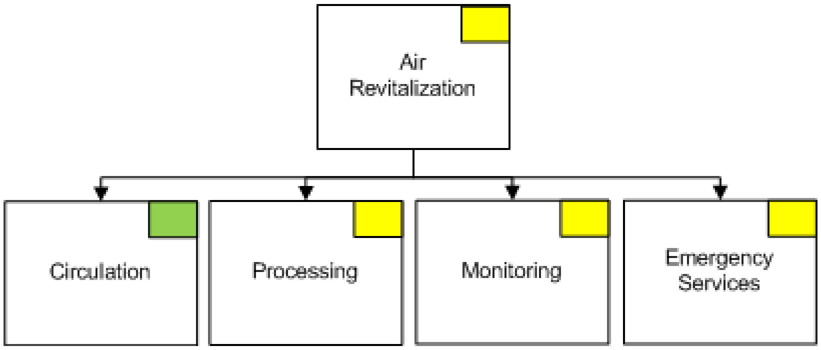
Red: Rarely – frequent crew intervention, frequent ground anomaly resolutions activities and significant logistics support including large up-mass requirements.

Air Revitalization

1. Is this **function** performed *reliably* on a day-to-day basis without crew/ground intervention?



2. Can this function go for 1.5 years with NO ground intervention (resupply, TT&E, etc.) and minimal crew interaction?



Short-Term

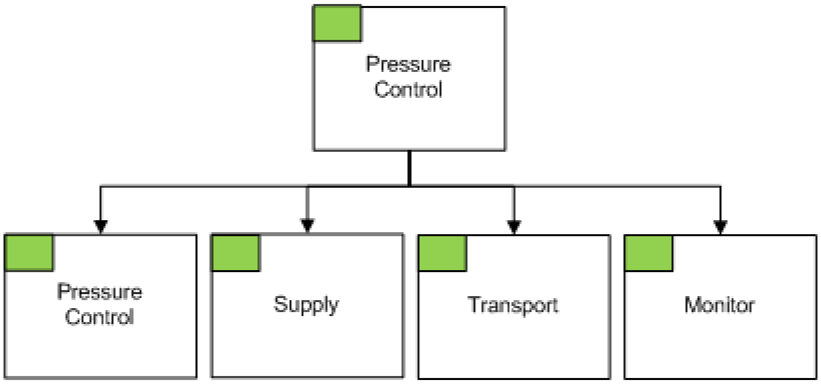
- Works, but generally requires a lot of intervention
- Areas of opportunities:
  - Processing: Filtration, CO_2 removal
  - Monitoring: Air quality/constituents (major and minor)

Long-Term

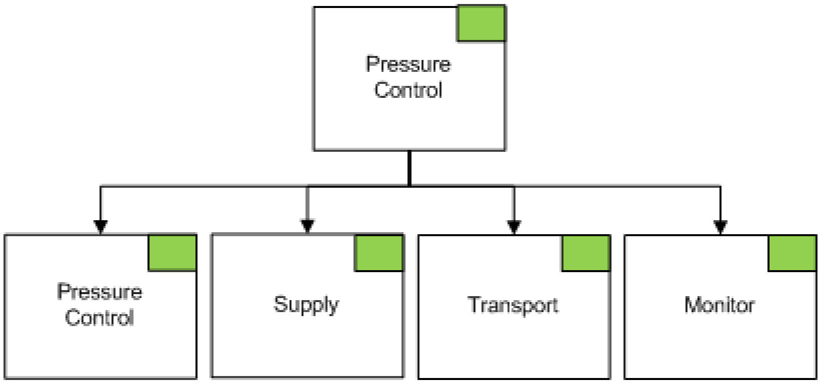
- Same issues exist as for the short-term monitoring; a single solution may address both short- and long-term issues
- Additional focus areas:
  - Processing: CO_2 removal, Filtration
  - Emergency Services

Pressure Control

1. Is this **function** performed *reliably* on a day-to-day basis without crew/ground intervention?



2. Can this function go for 1.5 years with NO ground intervention (resupply, TT&E, etc.) and minimal crew interaction?



Short-Term

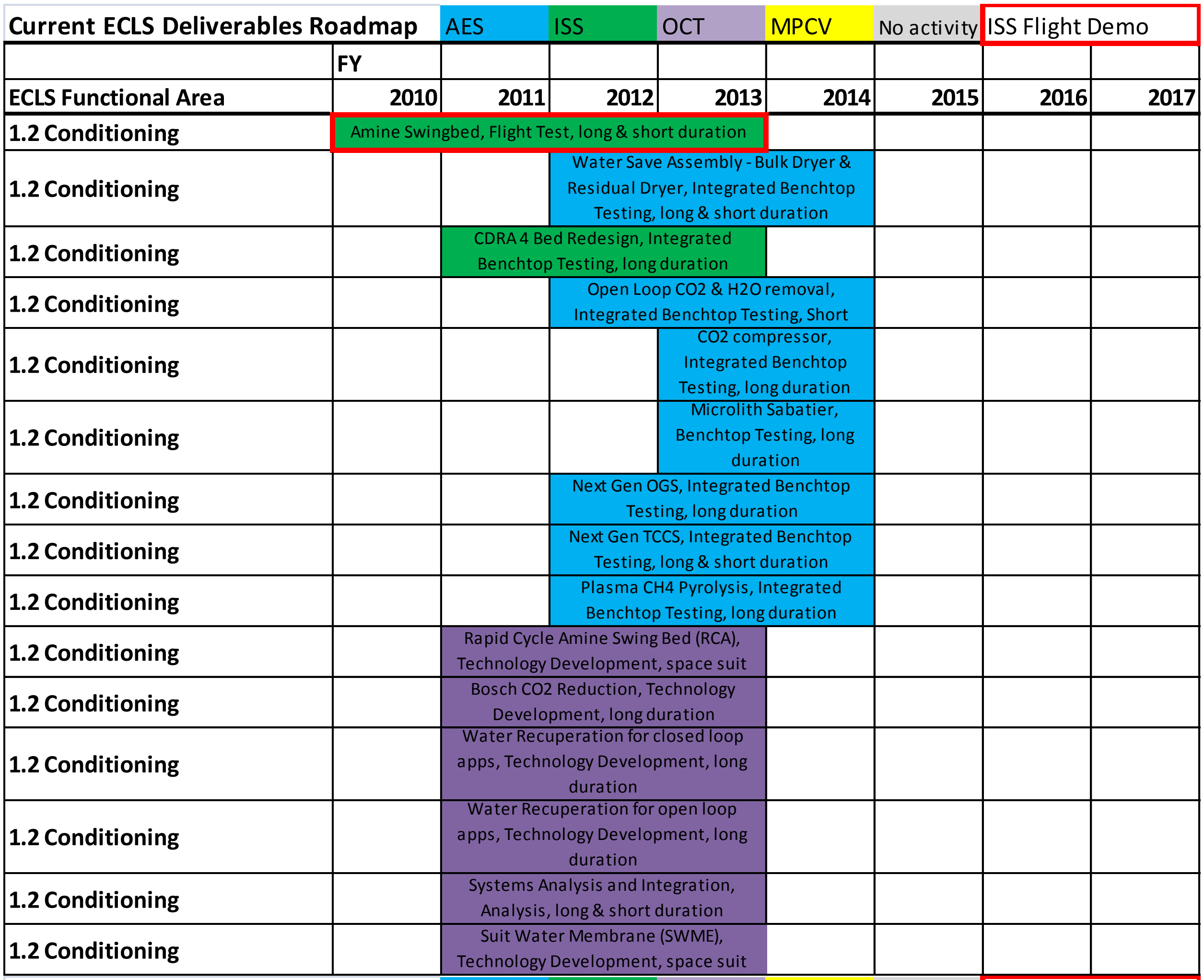
- Overall good for ISS mission needs
- O_2 generation issues are masked by ISS architecture, which provides redundant O_2 supply legs dependent on frequent resupply
  - Removing that redundancy would significantly change the overall ranking for the supply function

Long-Term

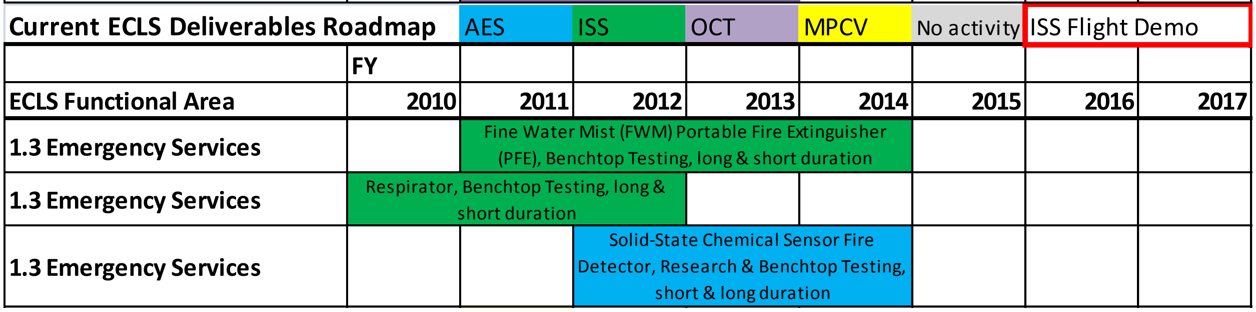
- Focus on O_2 generation
  - Could be addressed through architecture choices like ISS or
  - Technology development in O2 generation

Current Deliverables

Current ECLS Deliverables Roadmap		AES	ISS	OCT	MPCV	No activity	ISS Flight Demo	
	FY							
ECLS Functional Area	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
1.0 Atmosphere Management		BEAM, trade study, long duration						
1.1 Circulation				Fan Dev, Benchtop Testing, short				
1.1 Circulation & 1.2 Conditioning		Ambient Suit Loop Pressure Test, Integrated Ground Testing, short duration						
1.1 Circulation & 1.2 Conditioning				Vacuum Suit Loop Test, Integrated Ground Testing, short duration				
1.1 Circulation & 1.2 Conditioning			Reduced Pressure Suit Loop Test, Integrated Ground Testing, short					



Current ECLS Deliverables Roadmap		AES	ISS	OCT	MPCV	No activity	ISS Flight Demo	
	FY							
ECLS Functional Area	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
1.2 Conditioning	Amine Swingbed, Flight Test, long & short duration							
1.2 Conditioning			Water Save Assembly - Bulk Dryer & Residual Dryer, Integrated Benchtop Testing, long & short duration					
1.2 Conditioning		CDRA 4 Bed Redesign, Integrated Benchtop Testing, long duration						
1.2 Conditioning			Open Loop CO2 & H2O removal, Integrated Benchtop Testing, Short					
1.2 Conditioning				CO2 compressor, Integrated Benchtop Testing, long duration				
1.2 Conditioning				Microlith Sabatier, Benchtop Testing, long duration				
1.2 Conditioning			Next Gen OGS, Integrated Benchtop Testing, long duration					
1.2 Conditioning			Next Gen TCCS, Integrated Benchtop Testing, long & short duration					
1.2 Conditioning			Plasma CH4 Pyrolysis, Integrated Benchtop Testing, long duration					
1.2 Conditioning		Rapid Cycle Amine Swing Bed (RCA), Technology Development, space suit						
1.2 Conditioning		Bosch CO2 Reduction, Technology Development, long duration						
1.2 Conditioning		Water Recuperation for closed loop apps, Technology Development, long duration						
1.2 Conditioning		Water Recuperation for open loop apps, Technology Development, long duration						
1.2 Conditioning		Systems Analysis and Integration, Analysis, long & short duration						
1.2 Conditioning		Suit Water Membrane (SWME), Technology Development, space suit						



Current ECLS Deliverables Roadmap		AES	ISS	OCT	MPCV	No activity	ISS Flight Demo	
	FY							
ECLS Functional Area	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
1.3 Emergency Services		Fine Water Mist (FWM) Portable Fire Extinguisher (PFE), Benchtop Testing, long & short duration						
1.3 Emergency Services	Respirator, Benchtop Testing, long & short duration							
1.3 Emergency Services			Solid-State Chemical Sensor Fire Detector, Research & Benchtop Testing, short & long duration					

<table>
<tr><td colspan="2">Current ECLS Deliverables Roadmap</td><td>AES</td><td>ISS</td><td>OCT</td><td>MPCV</td><td>No activity</td><td colspan="2">ISS Flight Demo</td></tr>
<tr><td></td><td>FY</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>ECLS Functional Area</td><td>2010</td><td>2011</td><td>2012</td><td>2013</td><td>2014</td><td>2015</td><td>2016</td><td>2017</td></tr>
<tr><td>1.4 Monitoring</td><td></td><td>Hydrazine Sensor Dev, Benchtop Testing, short</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1.4 Monitoring</td><td></td><td colspan="3">Micro Gas Monitor, Research & Integrated Benchtop Testing, long & short duration</td><td></td><td></td><td></td><td></td></tr>
<tr><td>1.4 Monitoring</td><td></td><td colspan="3">Rapid Analysis Self-Calibrating (RASCal) Array, Research, long & short duration</td><td></td><td></td><td></td><td></td></tr>
<tr><td>1.4 Monitoring</td><td></td><td colspan="3">Tunable Environmental Laser Spectroscopy, Research & Integrated Benchtop Testing, long & short duration</td><td></td><td></td><td></td><td></td></tr>
<tr><td>1.4 Monitoring</td><td></td><td colspan="3">Vehicle Environmental Monitor (+H2O), Integrated Benchtop Testing, long duration</td><td></td><td></td><td></td><td></td></tr>
<tr><td>1.4 Monitoring</td><td></td><td></td><td colspan="3">Optical Particle Counter (300nm-10microns), Research & Benchtop Testing, long duration</td><td></td><td></td><td></td></tr>
<tr><td>1.4 Monitoring</td><td></td><td></td><td colspan="3">Charge Based Detector (10 - 300 nm), Research & Benchtop Testing, long duration</td><td></td><td></td><td></td></tr>
</table>

Current ECLS Deliverables Roadmap		AES	ISS	OCT	MPCV	No activity	ISS Flight Demo	
	FY							
ECLS Functional Area	2010	2011	2012	2013	2014	2015	2016	2017
1.5 Pressure Mgmt.		Ambient Suit Loop Pressure Test, Integrated Ground Testing, short duration						
1.5 Pressure Mgmt.			High Pressure Electrolysis Cell Stack, Benchtop Testing, long & short duration					
1.5 Pressure Mgmt.		Cabin Air Seperator for EVA O2 (CASEO), Flight Demo, long & short duration						
1.5 Pressure Mgmt.		O2 compression (dates not specified, AES), Benchtop Testing, long duration						
1.5 Pressure Mgmt.	N2/O2 Recharge System (NORS), Benchtop Testing, long & short duration							
1.5 Pressure Mgmt.			Reduced Pressure Suit Loop Test, Integrated Ground Testing, short					
1.5 Pressure Mgmt.			Suit Loop Dev Regulator, Benchtop Testing, short duration					
1.5 Pressure Mgmt.				Vacuum Suit Loop Test, Integrated Ground Testing, short duration				

Appendix E: WM Detail

Functional Decomposition

Level 1	Level 2	Level 3	Level 4	Heritage H/W
2.1 Manage Potable Water	2.1.1 Storage	2.1.1.1 Fixed		Bellows Tank
		2.1.1.2 Portable		Payload Water Reservoirs (PWRs)
				Contingency Water Containers (CWCs)
				Contingency Water Container Iodines (CWCIs)
				Drink Bags

Level 1	Level 2	Level 3	Level 4	Heritage H/W
	2.1.2 Distribution	2.1.2.1 Medical/Payload		Hard Lines
				Valves
				Flex Lines
				QDs
		2.1.2.2 Crew		Hard Lines
				Valves
				Flex Lines
				QDs
		2.1.2.3 EMU		Hard Lines
				Pump?
				Valves
				Flex Lines
				QDs
	2.1.3 Microbial Control			Iodine
				Iodine Removal
				Ionic Silver
				Cold Sterilization
2.2 Manage Waste Water	2.2.1 Collect Wastewater	2.2.1.1 Personal Hygiene		Conditioning HX
		2.2.1.2 Urine		Fan
				Pre-treat
				Funnel/Hose
				Separate
				MAGs
				Odor/Bacteria Filter
		2.2.1.3 Metabolic (Vapor)		Conditioning HX
		2.2.1.4 Laundry		Laundry Line Off MMSEV
	2.2.2 Disposition Wastewater	2.2.2.1 Dump		Filter
				Heaters
				Vent
				Tanks

Level 1	Level 2	Level 3	Level 4	Heritage H/W
		2.2.2.2 Store No Re-use		Tanks
				Bags
		2.2.2.3 Resource Recovery	2.2.2.3.1Waste-water Processing	Filter
				Pump
				Rotary Separator
				Ion Exchange Beds
				Catalytic Reactor
				Iodine Biocide
			2.2.2.3.2 Urine Processing	Vacuum Pump
				Rotary Still
				Pump
				Compressor
				Brine Filter
2.3 Monitor	2.3.1 Chemical	2.3.1.1 Conductivity		Conduct. Transducer
		2.3.1.2 Cation/Anion		CWQMK
		2.3.1.3 Potential Hydrogen (pH)		
		2.3.1.4 Metals		
		2.3.1.5 Total Organic Carbon (TOC)		TOC Analyzer (TOCA)
		2.3.1.6 Organic Characteristics		
	2.3.2 Physical	2.3.2.1 Gas Content		
		2.3.2.2 Particulate		
		2.3.2.3 Dissolved Solids		
		2.3.2.4 Temperature		TCs/RTDs
		2.3.2.5 Quantity		Potent-iometers

Level 1	Level 2	Level 3	Level 4	Heritage H/W
	2.3.3 Biological	2.3.3.1 Speciation	2.3.3.1.1 Bacteria	Environmental Health System (EHS)
			2.3.3.1.2 Fungi	EHS
			2.3.3.1.3 Virus	
		2.3.3.2 Count		EHS

Commonality Matrix

Function/ Component	Shuttle	ISS	MPCV (Orion)	Suits (PLSS)	SEV	MMSEV	Lander	DSH	Surface Hab
Water Management									
Water storage (excluding plumbing)	Five 165 lb capacity, welded metal bellows tanks	metal bellows tanks, EDV, Rodnik, ATV, CWCs, PWRs (EMU)/ICWC.	Launchable full drink bags for initial short mission (dev needed, not funded); metal bellows (same vendor as ISS but welding issues with inconel so may go with SS)	Teflon bag; drink bags	Metal tanks - trade using bellows for commonalilty with ug (wt, vol inefficiences)	Metal bellows tanks	Metal tanks; drink bags	Metal bellows tanks; may trade storage concepts with radiation protection	Metal tanks
		drink bags (share development - needs funding), bellows tanks (using same vendor). Some heritage sizes		drink bags for water transfer? leverage ISS cycle life requirements on bellows				leverage ISS cycle life requirements on bellows	
Microbial Control	Iodine with removal for consumption; POU filter	US: Iodine (MCV) with iodine removal for consumption; Russian: silver biocide; POU filter	Silver biocide with POU filter	silver biocide	silver biocide via tbd method, POU Filter	silver biocide via tbd method, POU Filter	silver biocide via tbd method, POU Filter	silver biocide via tbd method, POU Filter	silver biocide via tbd method, POU Filter
		Iodine not desirable for exploration because it must be removed prior to consumption	Common silver biocide. Issue with long-term storage/silver depletion in metal tanks. Delivery/recharge method with silver requires development.					GEO-servicing mission scenario with DSH "left behind" - how to safe and restart	
Potable water processor (from condensate and other wastewaters)	none	WPA (filtration/ion exchange/adsorption/cat ox); Russian condensate processor	none due to mission duration	none	none	none	none	May require improved (over ISS) processor to reduce expendables, power depending on vehicle resources and resupply capability. Trade space open (ECLSS study to extrapolate ISS tech to exploration DRMs in work)	Same as DSH but could take advantage of gravity
		issues: biomass, resupply penalty, removal of challenging organics	possibility for evolution to include condensate processor					Mixed wastewater to CDS/Distillation (+ electrodialysis?) + VRA/Oxidation + Brine Recovery (as BRIC?) tbd?	

Function/ Component	**Shuttle**	**ISS**	**MPCV (Orion)**	**Suits (PLSS)**	**SEV**	**MMSEV**	**Lander**	**DSH**	**Surface Hab**
Water Management									
Urine Collection	WCS urinal/spin sep/heated overboard vent. UCD's backup.	Russian urinal/phase separator (6-mo life)	Urinal/spin sep/tank/heated overboard vent; static sep backup (exo-LEO, needs dev)	Long-duration waste management device	Gravity-based tank	MPCV-common urinal/spin sep with either vent or portable tank for reprocessing by DSH	same as SEV	Same as MPCV with delivery for processing	
			Shuttle-derived, but sep operation after quiescent periods needs to be addressed (current system fouls)		May look at common urinal/spin sep if trade favorable.				
Urine pretreat	Oxone string of pearls - manual delivery	Russian baseline. Alternate pretreat under development to avoid precipitation	Heritage sulfuric acid/oxone (delivery method TBD, needs dev)	NA	common with MPCV	common with MPCV	common with MPCV	Alternate pretreat (lower tox, no precip)	Alternate pretreat (lower tox, no precip)
			Quiescent periods may require different automated delivery method						
			Could use advanced technology pretreat across architecture. Block upgrade MPCV if possible.						
Urine processing	none	ISS UPA (vapor compression distillation)	none due to mission duration	none	none	none	none	Desire improved-reliability urine processing with brine recovery. mixed in with Water Processor above	
		issues: precipitation, no brine processing						Could use ISS technology depending on mission resupply capability	
Water Quality Monitoring - chemical	samples before and after mission; conductivity sensor on fuel cell supply	TOCA & samples; conductivity sensor in WPA; biocide monitor demo in development (CSPE)	none	none	sampling - analyze in Hab	sampling - analyze in Hab	none	ISS technology may not work long-duration. Need in-line monitor for both inorganic and organic species (technology TBD).	
								Could be front-end sampler that could use air monitor for analysis.	
Water Microbial monitoring	none	HPC, samples to ground	none	none	sampling - analyze in Hab	sampling - analyze in Hab	none	Need for quantification and identification in-situ (more capability than ISS).	Need for quantification and identification in-situ (more capability than ISS).

Function/ Component	**Shuttle**	**ISS**	**MPCV (Orion)**	**Suits (PLSS)**	**SEV**	**MMSEV**	**Lander**	**DSH**	**Surface Hab**
Water Management									
Water storage (excluding plumbing)	Five 165 lb capacity, welded metal bellows tanks	metal bellows tanks, EDV, Rodnik, ATV, CWCs, PWRs (EMU)/ICWC.	Launchable full drink bags for initial short mission (dev needed, not funded); metal bellows (same vendor as ISS but welding issues with inconel so may go with SS)	Teflon bag; drink bags	Metal tanks - trade using bellows for commonalilty with ug (wt, vol inefficiences)	Metal bellows tanks	Metal tanks; drink bags	Metal bellows tanks; may trade storage concepts with radiation protection	Metal tanks
		drink bags (share development - needs funding), bellows tanks (using same vendor). Some heritage sizes		drink bags for water transfer? leverage ISS cycle life requirements on bellows				leverage ISS cycle life requirements on bellows	
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		Iodine not desirable for exploration because it must be removed prior to consumption	Common silver biocide. Issue with long-term storage/silver depletion in metal tanks. Delivery/recharge method with silver requires development.					GEO-servicing mission scenario with DSH "left behind" - how to safe and restart	
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		issues: biomass, resupply penalty, removal of challenging organics	possibility for evolution to include condensate processor					Mixed wastewater to CDS/Distillation (+ electrodialysis?) + VRA/Oxidation + Brine Recovery (as BRIC?) tbd?	

Function/ Component	**Shuttle**	**ISS**	**MPCV (Orion)**	**Suits (PLSS)**	**SEV**	**MMSEV**	**Lander**	**DSH**	**Surface Hab**
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			Quiescent periods may require different automated delivery method						
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Urine processing	none	ISS UPA (vapor compression distillation)	none due to mission duration	none	none	none	none	Desire improved-reliability urine processing with brine recovery. mixed in with Water Processor above	
		issues: precipitation, no brine processing						Could use ISS technology depending on mission resupply capability	
Water Quality Monitoring - chemical	samples before and after mission; conductivity sensor on fuel cell supply	TOCA & samples; conductivity sensor in WPA; biocide monitor demo in development (CSPE)	none	none	sampling - analyze in Hab	sampling - analyze in Hab	none	ISS technology may not work long-duration. Need in-line monitor for both inorganic and organic species (technology TBD).	
								Could be front-end sampler that could use air monitor for analysis.	
Water Microbial monitoring	none	HPC, samples to ground	none	none	sampling - analyze in Hab	sampling - analyze in Hab	none	Need for quantification and identification in-situ (more capability than ISS).	Need for quantification and identification in-situ (more capability than ISS).

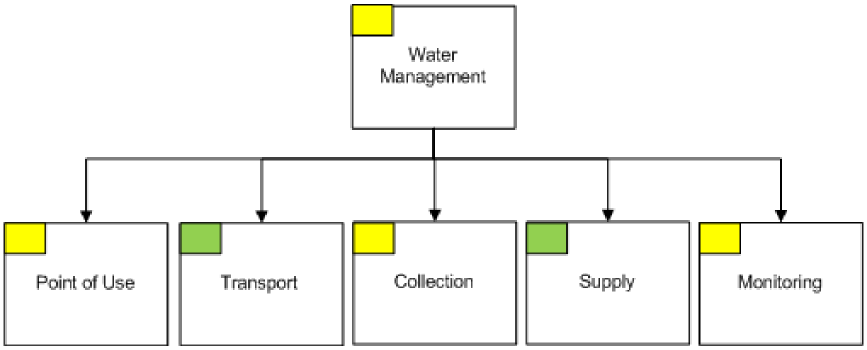
ISS Survey Results

Green : Always – crew intervention required less than once every six months, no ground intervention required

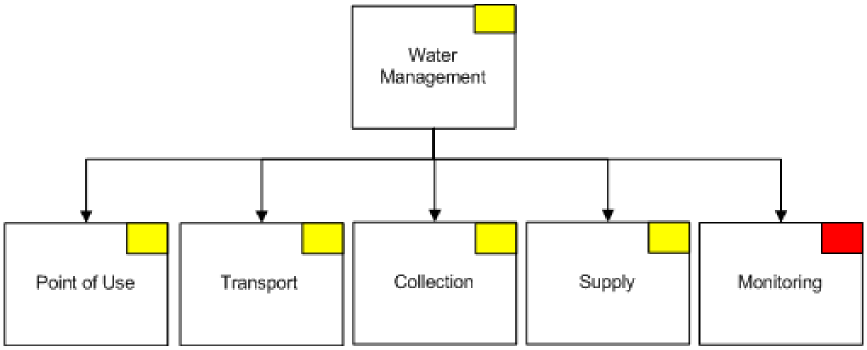
Yellow : Most of the time – crew intervention required less than quarterly, ground intervention required to perform any TT&E or analysis in support of return to nominal on orbit operations

Red : Rarely – frequent crew intervention, frequent ground anomaly resolutions activities and significant logistics support including large up-mass requirements.

1. Is this **<u>function</u>** performed *reliably* on a day-to-day basis without crew/ground intervention?



2. Can this function go for 1.5 years with NO ground intervention (resupply, TT&E etc) and minimal crew interaction?



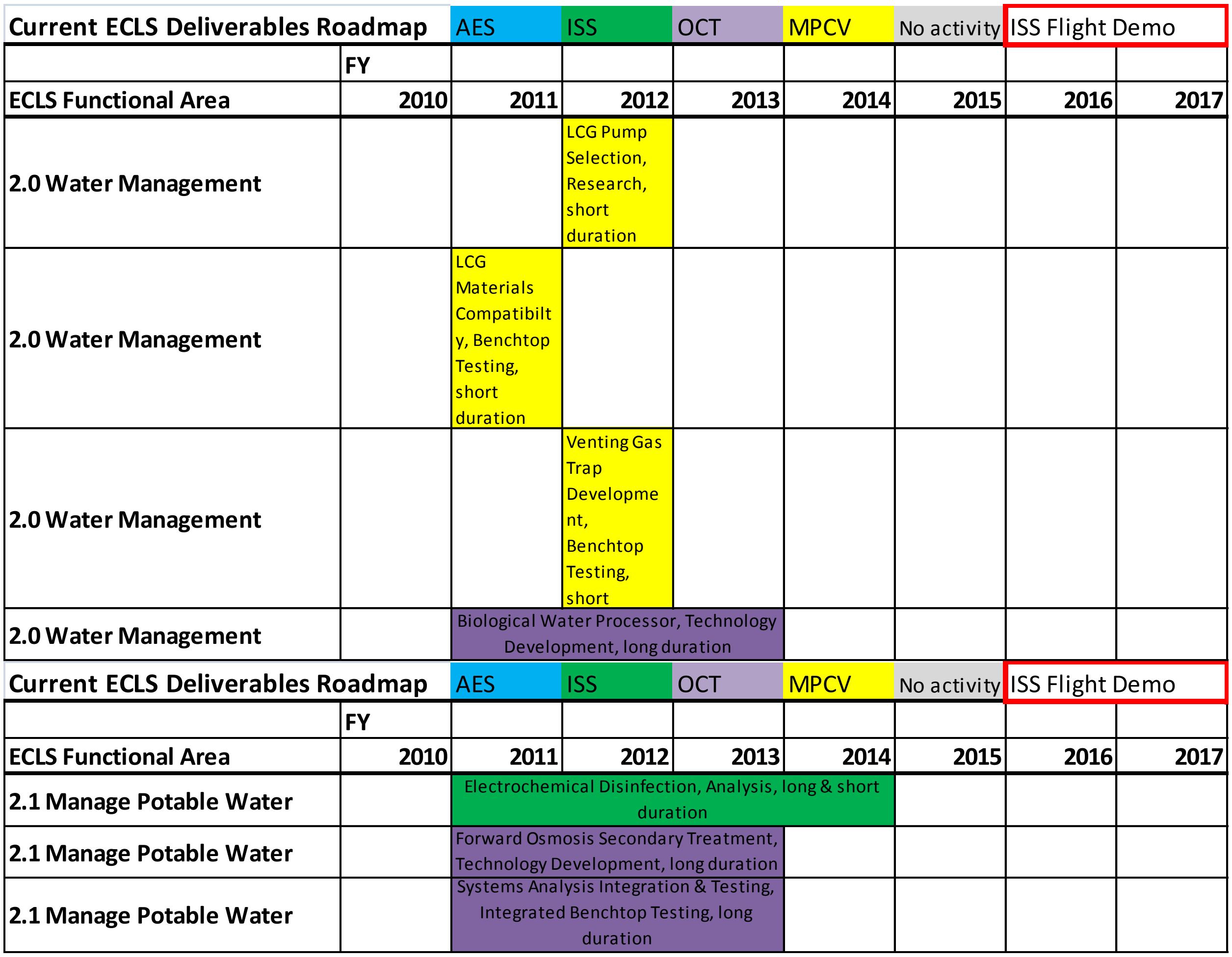
Short-Term

- Works, but generally requires a lot of intervention
- Areas of opportunities:
  - Point of Use (POU)
  - Collection (HXs and separators)
  - Monitoring

Long-Term

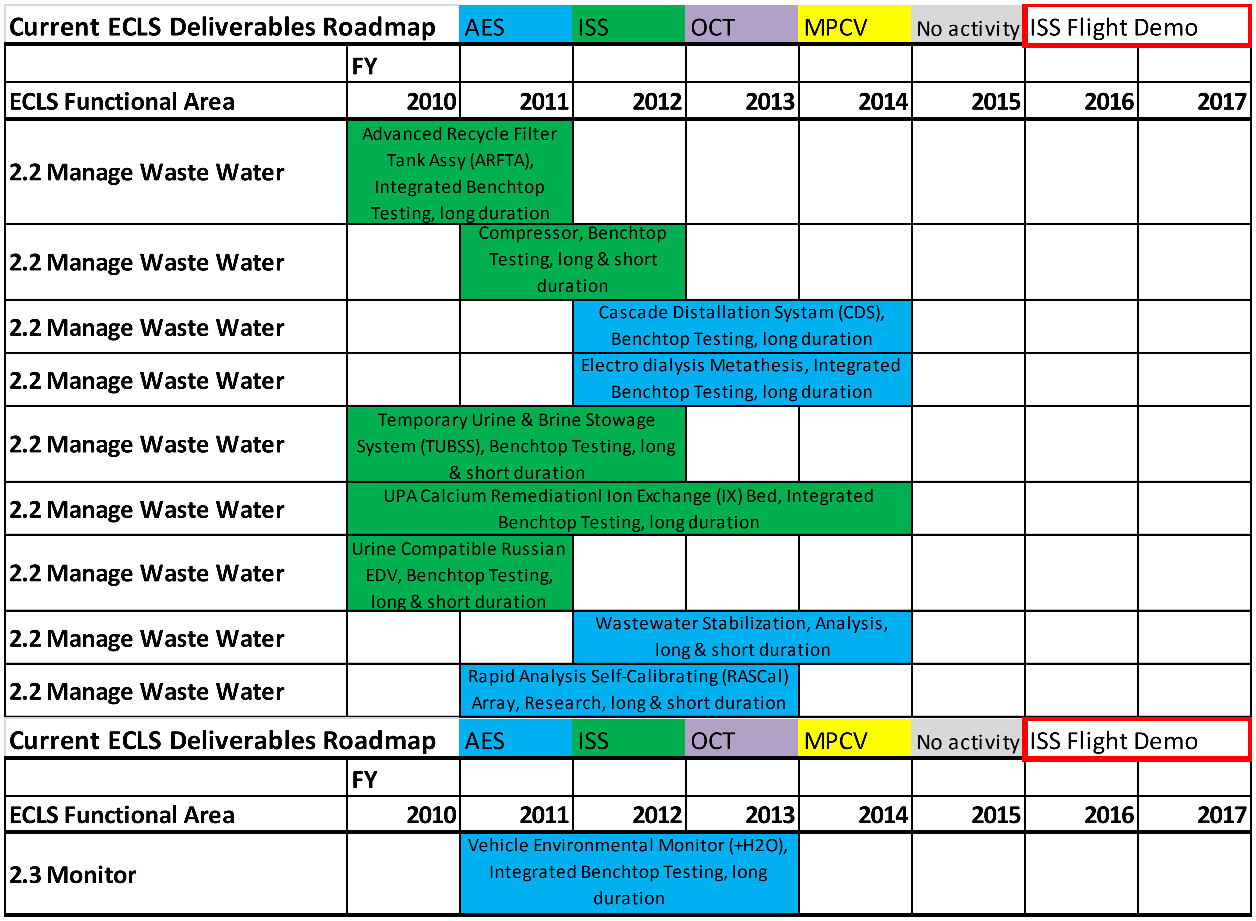
- Area of focus:
    - Monitoring
        - Exo-LEO missions will require on orbit monitoring capability which does not currently exist
    - Supply
        - Long term storage stability
- Same issues exist long term for POU and Collection
    - Single solution may address both short and long term issues

Current Deliverables



Current ECLS Deliverables Roadmap		AES	ISS	OCT	MPCV	No activity	ISS Flight Demo	
	FY							
ECLS Functional Area	2010	2011	2012	2013	2014	2015	2016	2017
2.0 Water Management			LCG Pump Selection, Research, short duration					
2.0 Water Management		LCG Materials Compatibilty, Benchtop Testing, short duration						
2.0 Water Management			Venting Gas Trap Development, Benchtop Testing, short					
2.0 Water Management		Biological Water Processor, Technology Development, long duration						

Current ECLS Deliverables Roadmap		AES	ISS	OCT	MPCV	No activity	ISS Flight Demo	
	FY							
ECLS Functional Area	2010	2011	2012	2013	2014	2015	2016	2017
2.1 Manage Potable Water		Electrochemical Disinfection, Analysis, long & short duration						
2.1 Manage Potable Water		Forward Osmosis Secondary Treatment, Technology Development, long duration						
2.1 Manage Potable Water		Systems Analysis Integration & Testing, Integrated Benchtop Testing, long duration						



Current ECLS Deliverables Roadmap		🟦 AES	🟩 ISS	🟪 OCT	🟨 MPCV	⬜ No activity	🟥 ISS Flight Demo	
	FY							
ECLS Functional Area	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
2.2 Manage Waste Water	🟩 Advanced Recycle Filter Tank Assy (ARFTA), Integrated Benchtop Testing, long duration	🟩						
2.2 Manage Waste Water		🟩 Compressor, Benchtop Testing, long & short duration	🟩					
2.2 Manage Waste Water			🟦 Cascade Distallation System (CDS), Benchtop Testing, long duration	🟦	🟦			
2.2 Manage Waste Water			🟦 Electro dialysis Metathesis, Integrated Benchtop Testing, long duration	🟦	🟦			
2.2 Manage Waste Water	🟩 Temporary Urine & Brine Stowage System (TUBSS), Benchtop Testing, long & short duration	🟩	🟩					
2.2 Manage Waste Water	🟩 UPA Calcium Remediationl Ion Exchange (IX) Bed, Integrated Benchtop Testing, long duration	🟩	🟩	🟩	🟩			
2.2 Manage Waste Water	🟩 Urine Compatible Russian EDV, Benchtop Testing, long & short duration	🟩						
2.2 Manage Waste Water			🟦 Wastewater Stabilization, Analysis, long & short duration	🟦	🟦			
2.2 Manage Waste Water		🟦 Rapid Analysis Self-Calibrating (RASCal) Array, Research, long & short duration	🟦	🟦				

Current ECLS Deliverables Roadmap		🟦 AES	🟩 ISS	🟪 OCT	🟨 MPCV	⬜ No activity	🟥 ISS Flight Demo	
	FY							
ECLS Functional Area	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
2.3 Monitor		🟦 Vehicle Environmental Monitor (+H2O), Integrated Benchtop Testing, long duration	🟦	🟦				

Appendix F: SWM Detail

Functional Decomposition

Level 1	Level 2	Level 3	Level 4	Heritage H/W
3.1 Manage Logistical Waste (i.e., Structure)	3.1.1 Collect			
	3.1.2 Disposition	3.1.2.1 Dump		
		3.1.2.2 Store as-is		
		3.1.2.3 Compact		
		3.1.2.4 Repurpose		
3.2 Manage Trash (Consumables (i.e., wipes, towels))	3.2.1 Collect			
	3.2.2 Disposition	3.2.2.1 Dump		
		3.2.2.2 Store	3.2.2.2.1 Odor Control	
			3.2.2.2.2 Compaction	
			3.2.2.2.3 Stabilization	
		3.2.2.3 Resource Recovery		
3.3 Manage Metabolic Waste (Potty)	3.3.1 Collect	3.3.1.1 Crew Interface		Fan
				Restraints
				Seat
		3.3.1.2 Contain		Fixed Tank
				Removable Tank
				Fecal Bags
				MAGs
		3.3.1.3 Odor Control		Fan

Level 1	Level 2	Level 3	Level 4	Heritage H/W
				Odor/Bacteria Filter
	3.3.2 Disposition	3.3.2.1 Visiting Vehicle (VV)		Bags
		3.3.2.2 Store	3.3.2.2.1 Odor Control	Odor/Bacteria Filter
				Vent to Vacuum
			3.3.2.2.2 Compaction	Manual
				Mechanical
			3.3.2.2.3 Stabilization	Germicide
				Vent to Vacuum
		3.3.2.3 Resource Recovery		

Commonality Matrix

Function/ Component	**Shuttle**	**ISS**	**MPCV (Orion)**	**Suits (PLSS)**	**SEV**	**MMSEV**	**Lander**	**DSH**	**Surface Hab**
Solid Waste Management									
Fecal Waste Collection/ storage	WCS/EDO commode	Russian potty	Shuttle EDO-derived	In-suit waste management	Camper-style gravity potty with bags; stowage TBD	same as MPCV	same as SEV	Same as MPCV; possible need to integrate with solid waste processing for resource recovery	same as SEV but with possible need to integrate with solid waste processing; also need to consider long term storage/planetary protection
Fecal Waste processing (stabilize, dry, compact, recover water)	none	none	none	none	none	none	none	TBD depending on need for resource recovery trades	TBD depending on need for resource recovery trades
								If DSH wishes to process, should consider container design to retrofit into other vehicle commodes to eliminate waste handling	
Trash collection/ storage	Positive airflow wet trash compartment	Assorted trash bags; disposal in visiting vehicles	Assorted trash bags - could transfer to Lander or DSH	NA	Assorted trash bags - consider planetary protection	Assorted trash bags	Assorted trash bags	Compaction	Compaction - consider planetary protection
Trash processing								Compaction and dewatering (heat melt)	Compaction and dewatering (heat melt); possibility of mineralization

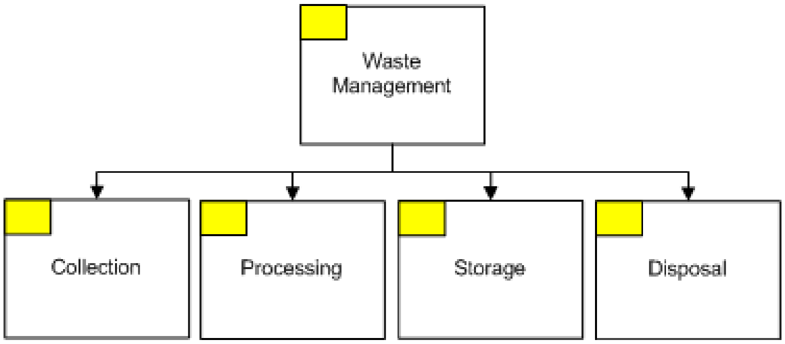
ISS Survey Results

Green: Always – crew intervention required less than once every six months, no ground intervention required

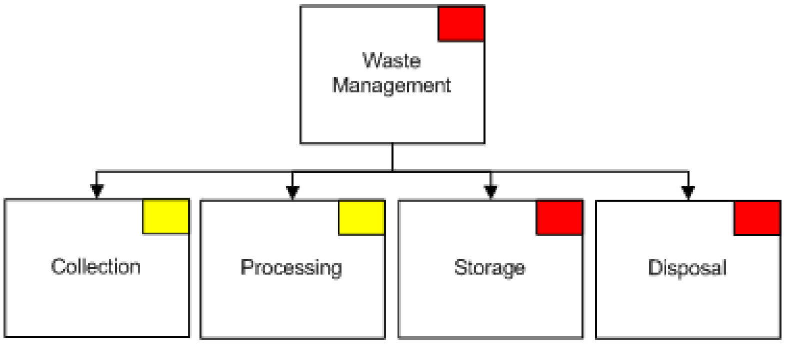
Yellow: Most of the time – crew intervention required less than quarterly, ground intervention required to perform any TT&E or analysis in support of return to nominal on orbit operations

Red: Rarely – frequent crew intervention, frequent ground anomaly resolutions activities and significant logistics support including large up-mass requirements.

1. Is this **function** performed *reliably* on a day-to-day basis without crew/ground intervention?



2. Can this function go for 1.5 years with NO ground intervention (resupply, TT&E, etc.) and minimal crew interaction?



Short Term

- Works, but generally requires significant intervention and resupply

Long Term

- This is an area where a GCT could significantly impact the overall rating of this system
  - Key area of focus may be stabilization and storage, which affects processing, storage, and disposal

Appendix G: ISS ECLS Functionality Survey Results

This roadmap effort was initiated in February 2011 to obtain a qualitative assessment of the current ISS ECLSS hardware's capability to support beyond-LEO Exploration missions, to address the question, "Why can't we just use the ISS ECLSS for Exploration?" The team believed an operational team survey would provide qualitative system vulnerabilities information when assessing the existing system in long-duration operations scenarios, without the nearby "supply chain" from Earth. This would then inform technology development planning to align those activities to address current-day issues for both near-term and long-term capability benefits.

System Engineering experts worked with the ISS system manager and deputy system manager to define an agreed-upon functional (not hardware) decomposition of the current ISS ECLS systems, including all areas generally considered ECLS hardware. Using that functional decomposition, the team created a survey with three questions.

1. Is this **function** performed *reliably* on a day-to-day basis without crew/ground intervention?
2. Can this function go for 1.5 years with NO ground intervention (resupply, TT&E, etc.) and minimal crew interaction?

Questions 1 and 2 were ranked using green, yellow or red based on the following:

- **Green**: Always – crew intervention required less than once every six months, no ground intervention required
- **Yellow**: Most of the time – crew intervention required less than quarterly, ground intervention required to perform any TT&E or analysis in support of return to nominal on orbit operations
- **Red**: Rarely – frequent crew intervention, frequent ground anomaly resolutions activities and significant logistics support including large up-mass requirements.

3. For any functions ranked red in Question 2, what additional functions would be required to get to green? Are there any:
    - Functions not currently incorporated on ISS that will be necessary to support a mission of up to 1.5 years with NO ground intervention; and why?
    - Areas where technology is entirely lacking, meaning no functionality exists.
    - Areas where technology advancement is necessary to enable a more efficient (generally mass) architecture solution.

The survey was administered to three different groups of people in three different sessions:

Group 1 – JSC ISS system management team (15 members)

Group 2 – JSC advanced projects team and other ECLSS System Engineers (10 members)

Group 3 – MSFC ISS and advanced projects team (8 members)

Each member was asked to rank ALL functions regardless of expertise. Answers were linked to the individual and his/her area of responsibility. Each group of answers was then filtered and ranked. In all cases, more than one response was needed to be considered a valid filter.

Final Assessment Results suggest areas of emphasis in the following priority.

1. SWM – details in Appendix F
2. WM – details in Appendix E
3. Air Revitalization – details in Appendix D
4. Pressure Control – details in Appendix D

Additional Findings

- Architecture can drive significant changes in the health assessment of the function. It also drives redundancy and complexity choices.
    - Architecture is driven by the mission parameters.
    - Technology development cannot be decoupled from architecture.
- Understanding interfunctional relationships is important.
    - Updates at lower-level functional areas can make or break other functional areas.
- Knowing where multiple areas can be improved with key technology choices is essential for an efficient technology development program (one that can make real impacts to system robustness).

The survey questions assume an awareness of operational issues. As the survey group expanded over time, the team observed that the farther an individual is removed from exposure to flight operations, the fewer questions they answered. This indicates a significant communication gap between the operational teams and advanced development teams.