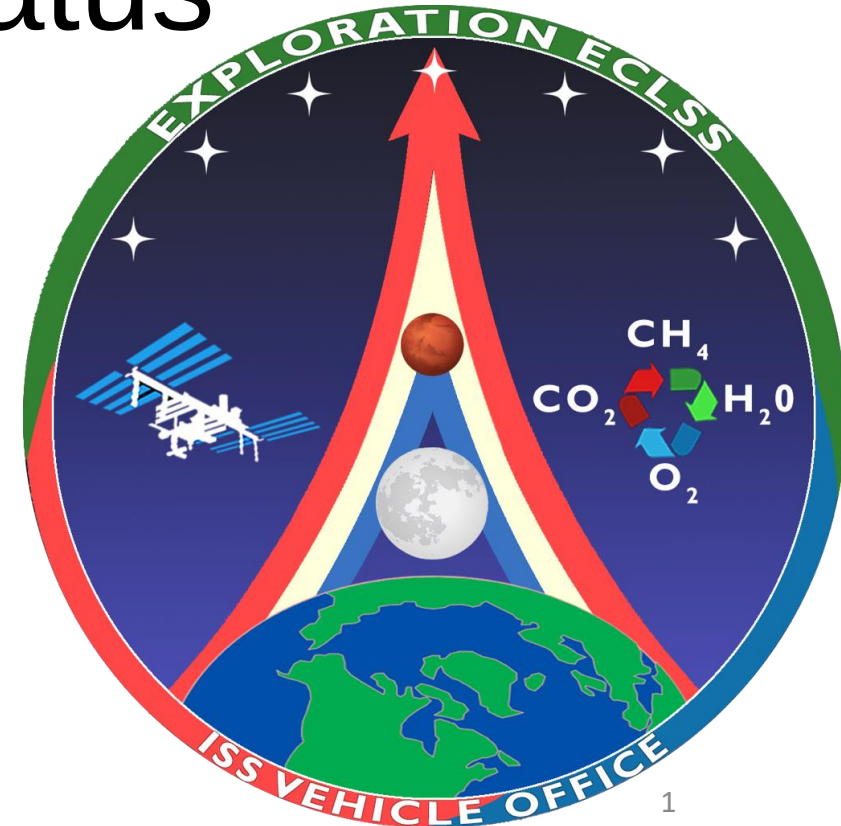
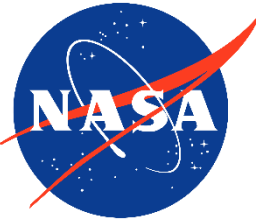


International Space Station (ISS) as a Testbed For Exploration ECLSS – 2024 Status

Paper #ICES-2024-316

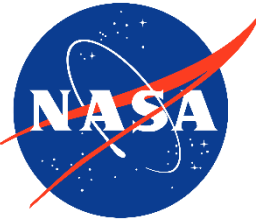
Alesha Ridley, Chris Brown, John Garr,
Lynda Gavin, Dave Hornyak, Adam Korona, Kate Toon (NASA)
Paul Caradec, Allen Williams (Leidos Innovations Corporation)





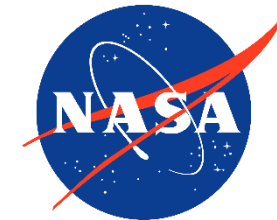
Introduction

- To develop a robust ECLSS portfolio for exploration, NASA is executing an effort to demonstrate exploration-class ECLSS on the ISS
 - New capabilities are being developed and will be installed for long-term demonstration
 - Existing systems are being upgraded based on lessons learned
- Objective is to characterize performance and reliability over long duration in a fully integrated and fully relevant environment
- ISS is unique and essential as a testbed for ECLS-type systems
 - Multi-phase flow in microgravity
 - Relevant constituents in crew waste streams during exposure to microgravity
 - Closed environment spacecraft
 - Fully integrated ECLS system supporting actual crewmembers
- Therefore, ISS is the location for NASA's exploration-class ECLSS testbed
- This presentation describes the overall effort, its integration into the ISS vehicle, and its progress
 - Updates will be provided each year as progress is made
- New special topic section added – anticipate yearly updates
- Effort funded by the Mars Capability Office (MCO) at NASA Headquarters, managed by Marlon Cox, and championed by ECLS System Capability Leadership Team leader Jim Broyan

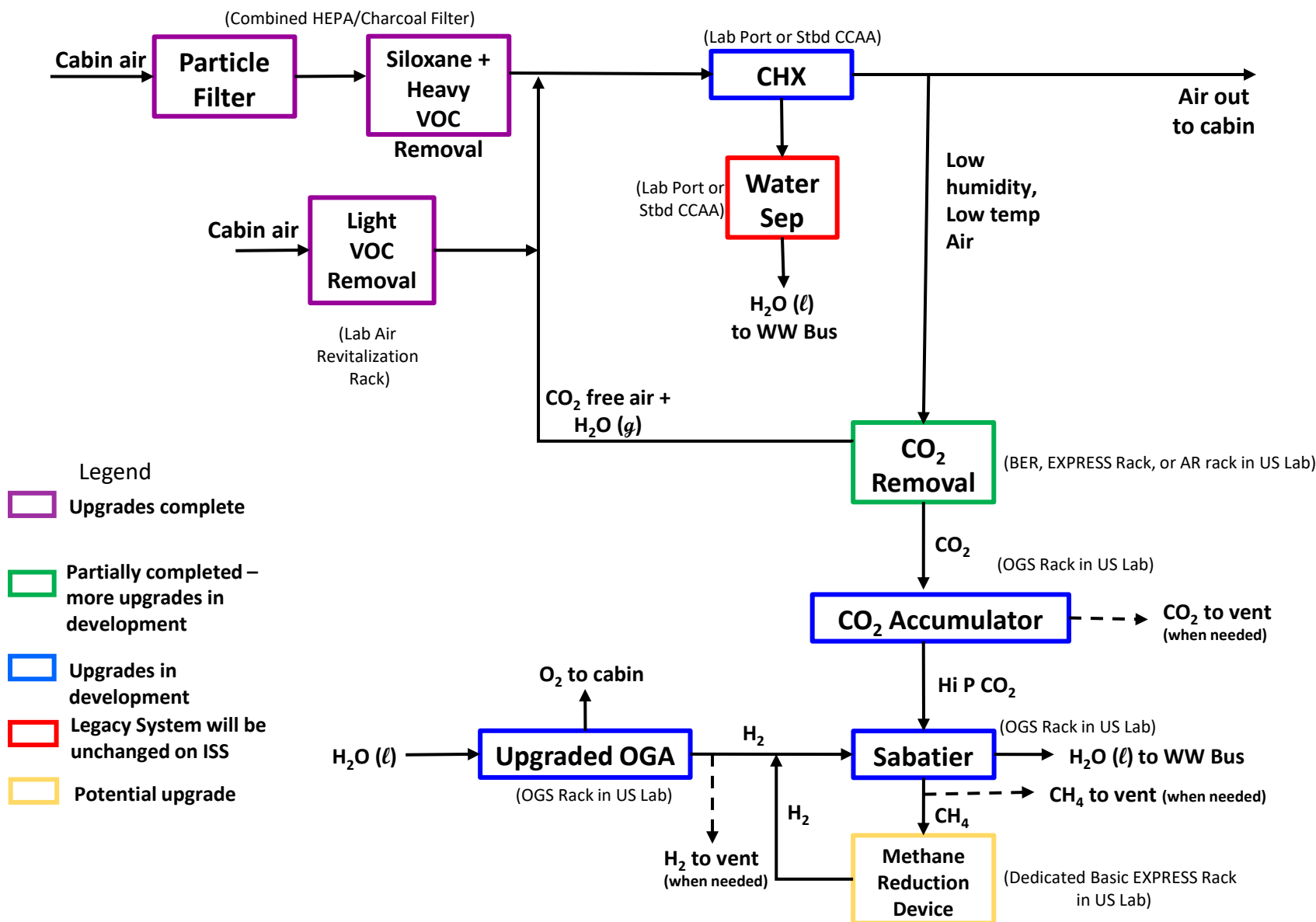


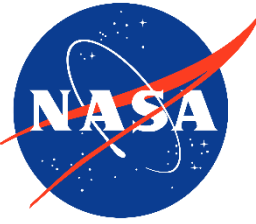
ISS Demonstration Approach

- Develop a testbed that mimics Mars Transit Habitat ECLSS as much as possible
 - ISS architecture presents limitations such as rack layout, 120VDC power, MIL-STD-1553 command and data handling systems, varying crew size
 - New capabilities are in development to increase the usefulness of ISS as a testbed
 - Objective is to mature performance and reliability predictions of the core system components (e.g., Urine Processor Assembly (UPA) Distillation Assembly or Oxygen Generation Assembly (OGA) Cell Stack) and enable repackaging/layout of the systems when actual mission profiles and spacecraft designs are established
- For ease of integration into ISS, overall system is divided into two strings:
 - Air String
 - Water String
- Environmental Monitors are installed as their functions dictate, such as water monitoring devices inline with the Water Processor Assembly (WPA)



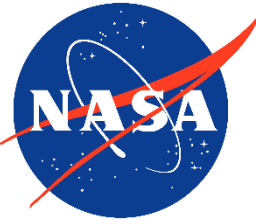
Air String Schematic





Air String Architecture

- **Condensing Heat Exchanger (CHX) and Water Separator** – control humidity and temp of vehicle's atmosphere and collect condensate for future processing
- **Trace Contaminant Control System (TCCS)** – removes chemical contaminants generated by crew, vehicle systems and surfaces, payloads, cargo, etc. from vehicle atmosphere
- **Carbon Dioxide Removal (CO₂) System** – scrubs crew metabolic CO₂, spacesuit CO₂ scrubbing regeneration products, and payload-produced CO₂ from vehicle atmosphere
- **CO₂ Reduction System** – recovers oxygen (O₂) from CO₂ through reaction with hydrogen (H₂) to produce water and byproducts
- **O₂ Generation System** – electrolyzes potable water, generating streams of gaseous O₂ for crew breathing and gaseous H₂ for use in the CO₂ reduction system



Air String Updates

- **Condensing Heat Exchanger (CHX)**

- ISS Legacy CHX will be upgraded to incorporate a modified hydrophilic coating with improved properties for microbial control, siloxane resistance, and overall lifetime
- Goal to enable longer periods between CHX dryouts or eliminate need altogether
- Build will make use of additive manufacturing – reduces time, complexity, and cost of future builds
- Project team had to work through resolution of leaks detected after QMP3 build – failure investigation team concluded that there are no issues with powder contamination, and that from a performance standpoint a similar level of un-fused powder would be acceptable in-flight print. Proceeding with qual build.
- Design TIM #2 held 7/12
- Schedule being assessed – NASA may accept risk and start processing CHX for flight while qual testing occurs in parallel

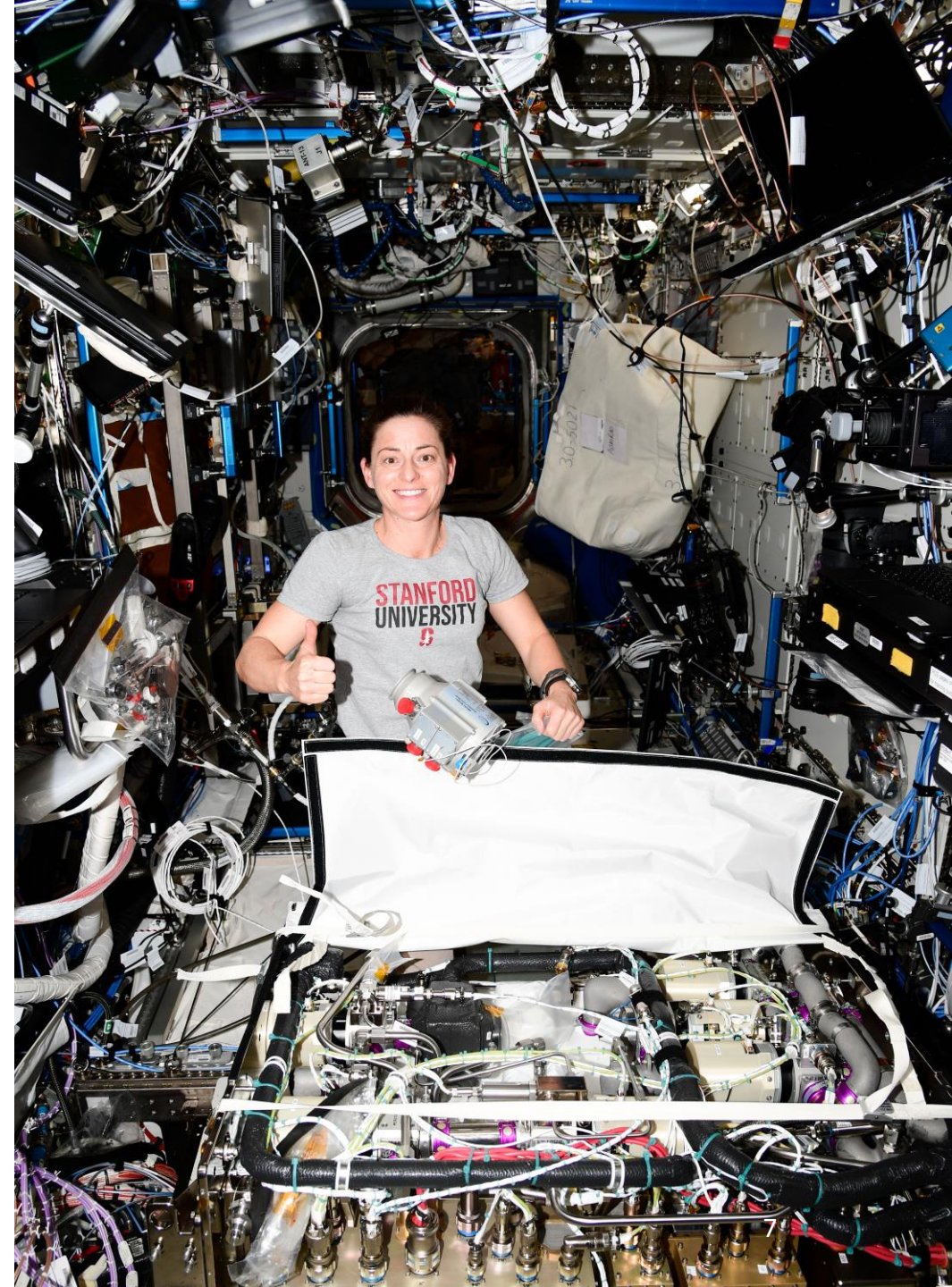
- **Water Separator – will remain with current state-of-the-art (SOA) rotary separator that pairs well with hydrophilic CHX**

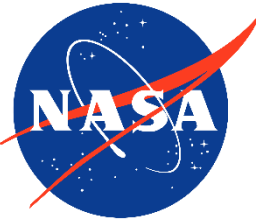
- **TCCS – legacy system is considered SOA**

- Additional filtering (charcoal) added to the inlet of the CHX to remove volatile siloxanes from cabin atmosphere
- On-orbit filters were replaced in August/23
 - Charcoal filters were return for evaluation, testing expected to be complete fall 2024.

Air String Updates (cont'd)

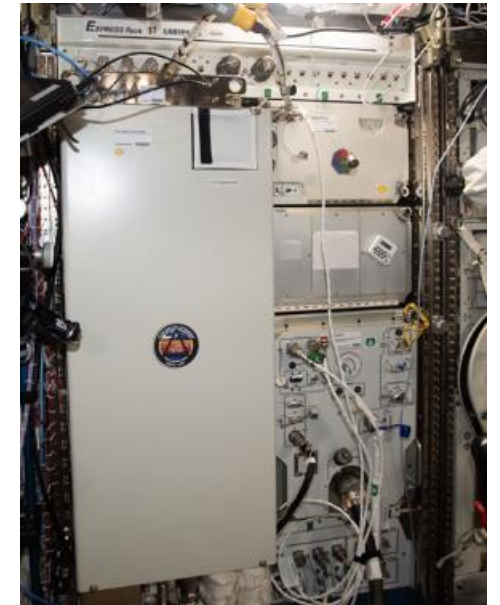
- **Carbon Dioxide Removal (CO₂) System**
 - **Thermal Amine Scrubber (TAS)** was recovered in January 2024 following a controller drawer R&R.
 - It was inoperable for just over a year (Oct 2022-Jan 2024)
 - TAS continues to be operated primarily in 2-crew mode (increased to 4-crew mode during direct crew handover periods)
 - Spare components are on-orbit; no additional spares are being procured at this time.
 - **Four Bed CO₂ Scrubber (FBCO₂)** began operating Aug 2021 – 2.5 years cumulative runtime
 - Software update in work to correct some nuisance issues with new blower and reduce flight control team overhead – Estimated Completion Date (ECD) fall 2023
 - Initiated a study with Calnetix looking at ways to improve blower performance; report expected XX/XX.
 - May feed into a blower upgrade project
 - Depress pump failed 6/29 and planned to be replaced week of 7/8 with on-orbit spare
 - Hardware to support integrated air string demo will be complete fall 2024
- **CO₂ Reduction System - Sabatier 2.0**
 - Sabatier 2.0 project cancellation was determined to be mutually beneficial – flight demo on ISS will not be pursued



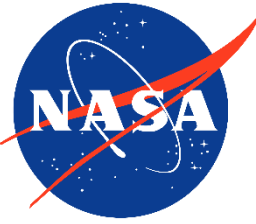


Air String Updates (cont'd)

- **O₂ Generation System – Advanced Oxygen Generation Assembly (AOGA)**
 - Utilize current industry standard cell stack design features, redesign for maintainability, and enable recirculation loop flush to protect downstream systems (like Sabatier) and enable dormancy
 - Change from a single sealed dome that houses the cell stack and Rotary Separator Accumulator (RSA) to two, maintainable domes
 - Delta CDR completed July 2023
 - Development testing still in work – completed testing successfully on new pressure sensors to confirm fracture control requirements
 - Working through results of chemical challenge testing now
 - Cell stack assembly will begin by the end of July
- H₂ Sensor Tech Demo was relocated to Oxygen Generation System (OGS) Rack upon relocation to the Lab in Aug 2022
 - 1 of 4 sensors is failed – others are demonstrating good performance
 - Upward drift initially observed has now leveled off, indicating stability



H2ST installed on OGS Rack in Lab



Air String Integration Approach

- **Location**

- All components of the air string will be demonstrated in the US Laboratory module

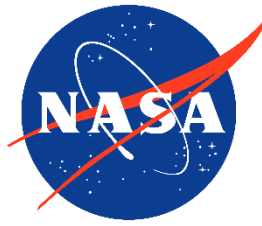
- **Final configuration TBD based on recent decision to not fly Sabatier 2.0**

- A flight demonstration of Honeywell's Carbon Dioxide Removal Ionic Liquids (CDRILS) and a Precision Combustion Incorporated (PCI) Sabatier is being considered

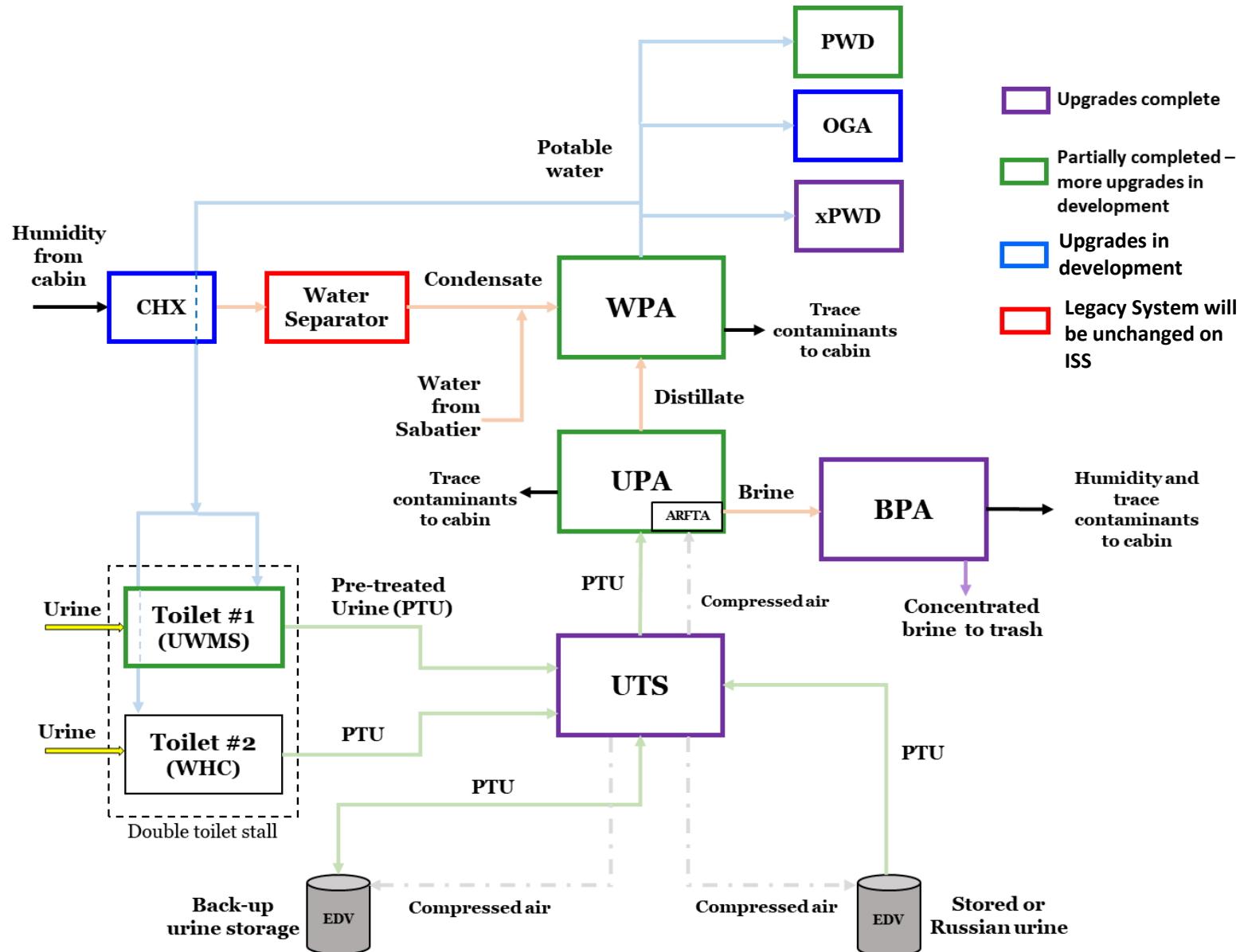
- **Background levels of Freon R-218 (refrigerant used on the Russian Segment), and the fact that FBCO₂ collects R-218 and passes it downstream, have complicated an integrated air string demo**

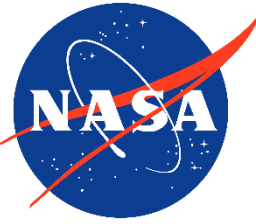
- It is very likely that many catalysts are poisoned by R-218

- **While future spacecraft may not use R-218 specifically, the presence of other types of refrigerants should not be ignored, particularly given use of commercial contracts**



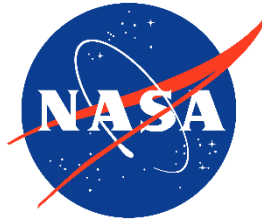
Water String Diagram





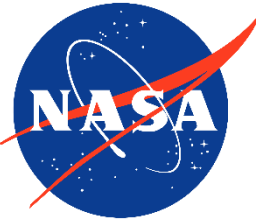
Water String Architecture

- **Human Metabolic Waste Management System (Toilet)** – collects human solid waste for disposal and stabilize liquid human waste (urine and flush water) for processing
- **Urine Processing System** – recovers usable water from liquid human waste
- **Water Processing System** – processes and polishes waste water (processed urine, condensate, CO₂ Reduction System produced water) into potable water for crew consumption, hygiene, O₂ generation, spacesuit cooling, and payload use
- **Brine Processing System** – recovers usable water from the brine generated by the Urine Processing System
- **Potable Water Dispensing System** – meters and distributes potable water from the potable water bus to the crew for food/drink consumption and hygiene water
- **Total Organic Carbon Analyzer** – ensures safety of potable water for crew consumption and provides insight into water processor performance
- **Exploration Potable Water Dispenser** – provides potable water to the crew for consumption and food hydration



Water String Updates

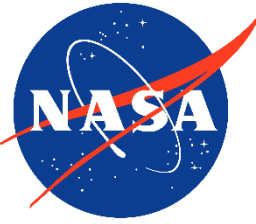
- **Human Metabolic Waste Management System [Universal Waste Management System (UWMS) or Toilet]**
 - Barriers to use on ISS
 - Acoustics – Dual Fan Separator redesign in work
 - Pretreat escape – operational mitigations were agreed-to but root cause yet to be identified and Odor Bacterial Filter redesign in work
 - Dose pump failure – check valve redesign in work to switch from a PEEK plastic body to titanium
 - Activation attempt in June (new dose pump of existing design and redesigned MSFC conductivity sensor with bubble diverter) was unsuccessful. Troubleshooting has been delayed due to higher priority issues on ISS and preservation of urine collection resources).
- **Urine Processing System**
 - Urine Processor Assembly (UPA) is being upgraded to correct design weaknesses and improve maintainability
 - Upgraded Distillation Assembly (DA) installed on ISS in 2020 – system has exceeded legacy hardware operational life (165% as of June 2023)
 - DA eliminated several failure modes including belt slippage and fluid leak path through bearings
 - Purge Pump and Separator Assembly (PPSA) - Purge pump redesign to be smaller, more efficient, maintainable at a lower level and potentially more reliable
 - PPSA operated for ~2 months before failing. TT&E has determined that a valve failure was the cause. Redesign options being traded for final implementation.
 - UPA has also experienced multiple legacy Pressure Control and Pump Assembly (PCPA) failures - the component PPSA was designed to replace - which have led to reduced processing in order to bridge gaps between spares



Water String Updates

- **Urine Processing System (cont'd)**

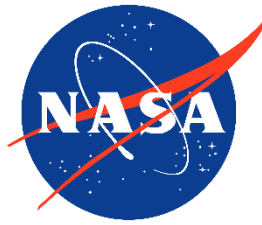
- Joint team: MSFC, JSC and ARC continue to work toward ground demonstration of autonomous operations for Exploration
 - Initial test: autonomous UPA Brine offload and backfill of unconcentrated urine – planned for Dec 2023
- **Brine Conductivity** – Concentration monitored by conductivity sensor vs. test/analysis data could improve insight into concentration – reduce risk of precipitation within UPA and allow system to respond in real-time to conditions within system
 - Sensor development was accelerated for use with UWMS in near-term, following UWMS long-term solution it can be moved into UPA on-orbit
- **Advanced Recycle Filter Tank Assembly (ARFTA) Quantity Insight** – crew inspection require to ensure adequate fill/drain of ARFTA at start and end of concentration cycles
 - Sensor reduces crew time and enables automated concentration cycle
 - MSFC finishing algorithm to translate hall effect sensor readings into position for ground demonstration
- **Fluids Pump** – New design separates channels into independent pumps
 - More efficient design, independent control (advantageous for dormancy) and replaceable/repairable (reduces mass/volume of spares)
 - Working through 3rd generation of ground prototype
 - Test stand fabrication in work
 - Pump will be demonstrated via ground test: ISS flight demo not planned at this time



Water String Updates

- **Water Processing System**

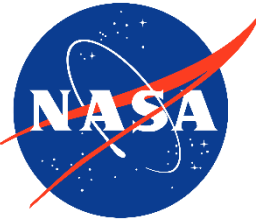
- Water Processing Assembly (WPA) on ISS will be upgraded – address key reliability issues and optimize based on lessons learned
- Multifiltration Bed (MF Bed) config reduced from two beds to one, new material added for improved performance and extended operational life
 - Improves system ability to withstand siloxanes in condensate
 - Better posture for dormancy
- Catalytic Reactor (Cat Reactor) – upgraded for improved catalyst material, robust fluid fitting metal seals to extend installed life, O₂ flow rate adjustment to improve oxidation efficiency, eliminated O₂ filter which was a consumable
 - Second attempt at installation was unsuccessful – DTO Cat Reactor failed due to seal leakage
 - TT&E pending, then team will re-evaluate options
- Microbial Check Valve – study in work to determine options for installing a solenoid valve in conjunction with resin to improve design
 - Study discussions promising, results expected late 2024



Water String Updates

- **Brine Processing System**

- Brine Processor Assembly (BPA) - proven capable of dewatering UPA-produced brine to increase overall Water Recovery rate to > 98%
- Water liberated from brine passes through semi-permeable membrane optimized to contain urine-borne Volatile Organic Compounds (VOCs)
 - Water vapor passed into cabin air; collected by CHX for processing
- Leak sensor is susceptible to corrosion which affects operation – workaround for frequent on-orbit cleaning activities has maintained operation
 - Spare detrusor (of same design) was flown and is available for installation
 - Sensor redesign, as well as making sensor replaceable on-orbit, is planned
- Inlet filter clogged after 600 days of operation, which was detected by temp sensors in the detrusor
 - Estimated life was 1-2 years
 - Able to operate on 1/3 heaters to continue dewatering while waiting for crew time
 - Filter changeout recovered nominal operations
- Upgraded exhaust adapter built and flown – awaiting installation
 - Includes air flow sensor for dewatering cycle trending
- Upgraded bladder storage bags also designed and are flying in Aug on NG-21 – intent is to reduce odor and allow for flexible storage configurations
- Ground testing in work at MSFC, in coordination with Paragon, to increase the amount of fluid that can be put into the bladders
 - Idea is to help with on-orbit storage capability given UPA issues or potentially enable a continuous mode of operation (“top-off”)
 - Consideration also being given to processing pre-treated urine instead of brine in a contingency



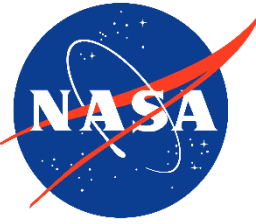
Water String Updates

- **Potable Water Dispensing System**

- Upgraded Exploration Potable Water Dispenser (xPWD) – address concerns with microbial control during dormancy through removal of stagnant portions of system
- Demonstrate flow-through ultraviolet (UV) disinfection technology at point-of-use – potential to reduce consumable filter usage
- xPWD was activated in Sept 2023 and cleared for crew use through a series of on-orbit sample activities
- Performance largely nominal with no significant periods of down-time: some nuisance issues with data collection via on-orbit systems have preventing ground trending

- **Mini Total Organic Carbon Analyzer (MiniTOCA)**

- Reduces size/mass/consumables usage rate, and expands shelf life of legacy TOCA system
- Uses different technology to assess quality of water on ISS
 - UV for oxidation (vs. boron-doped diamond coated electrodes)
 - Tunable laser spectroscopy for detection (vs. nondispersive infrared)
- MiniTOCA flight hardware testing phase begins after hardware assembly is completed October 2024
- Integration hardware (N2 and Water hoses, power and data cables, ISS interface h/w) Delivery estimated Feb 2024
- MiniTOCA Phase III Safety July 2025 and Delivery estimated fall 2025



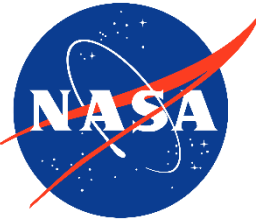
Water String Integration Approach

- **Location**

- All components of the water string are in Node 3
 - Water Recovery System (WRS) Racks and UWMS already reside there
- xPWD installed in Lab in an EXPRESS Rack - some recent discussion about moving to another rack in order to accommodate the Microgravity Acceleration Measurement System (MAMS) payload that is experiencing vibrational disturbances from nearby refrigerated payloads

- **Planned Configuration**

- WHC and UWMS are co-located in a double stall
 - Physically plumbed to deliver directly to UPA via Urine Transfer System (UTS)
- UPA upgraded in place (WRS-2 Rack)
- WPA upgraded in place (WRS-1 and WRS-2 Racks)
- BPA mounted in Node 3 Overhead Midbay
 - Interfacing hose allows direct transfer from UPA
 - Concentrated brine will be trashed
- xPWD receives potable water via USOS potable water bus



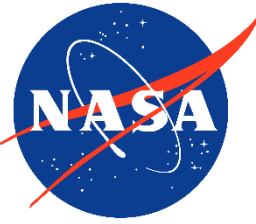
Water String Challenges

- **Concurrent USOS toilet operations**

- Urine Transfer System (UTS) developed to detect urine flow from either toilet and direct only that system's flow to UPA
 - In event of simultaneous toilet operations, second toilet flow would be sent to a backup urine storage tank
- UTS can transfer urine into UPA from the backup storage tank via an internal air compressor
- UTS has significantly reduced ISS crew time required to manage urine transfer

- **Schedule**

- All major upgrade components have been delivered – some awaiting installation
- UWMS redesign activities continue – thus far have been unable demonstrate Artemis-II mission profile on ISS for risk reduction
 - ISS can still accomplish substantive risk reduction for Orion with runtime
- Second Cat Reactor demo failure puts into question design mods – waiting for TT&E to inform future planning



General Integration

- **Operations and Certification Approach**

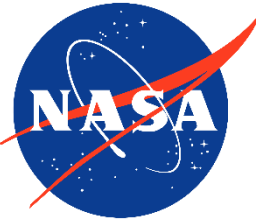
- Standalone demonstrations (CO₂ Removal, BPA, UWMS, xPWD, Mini-TOCA) developed as non-critical system tech demos
 - Reduced or eliminated reliability requirements
 - Safe operation required
- Upgrades to critical ISS system hardware (WPA, OGA, UPA) also considered demo units
 - Reduced certification requirements
 - ISS Program will maintain nominal spares fleet for legacy critical system hardware for uninterrupted operations
- ISS ECLS Team – responsible engineering org for real-time operations and hardware sustaining
- Mission Control Center – Houston (MCC-H) – responsible for installing, operating and monitoring tech demos, training crew
- MCC-H and Mission Evaluation Room (MER) – develop and execute troubleshooting strategies

- **Command and Telemetry approach**

- Arcturus system
 - Enables real-time telemetry downlink, data archiving, and commanding via MCC-H
 - Utilizes onboard Ethernet Joint Station Local Area Network (JSL)
 - Quicker turnaround for modifications/additions than ISS flight software
- Ground demonstration of autonomous operations – test case for future application in Exploration Mission system architecture

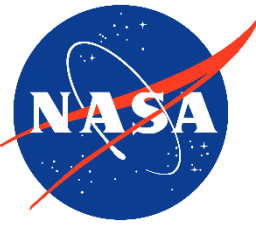
- **Integrated Ground Test Bed**

- Not covered in detail here, but development of a flight-like integrated test bed at MSFC is in work
- Significant effort involving the design and build of brand-new test beds (WPA, CCAA HX, UWMS, xPWD), the refurbishment of chambers for testing in different environments, the upgrade of existing test stands to match Exploration configuration (e.g., OGA to AOGA conversion, CO₂ Removal components updated to flight design) , and an improved data capture system
- This effort will likely be the subject of a future ICES paper
- Reviewing all avenues for accomplishing ground test objectives, such as CHAPEA for xPWD

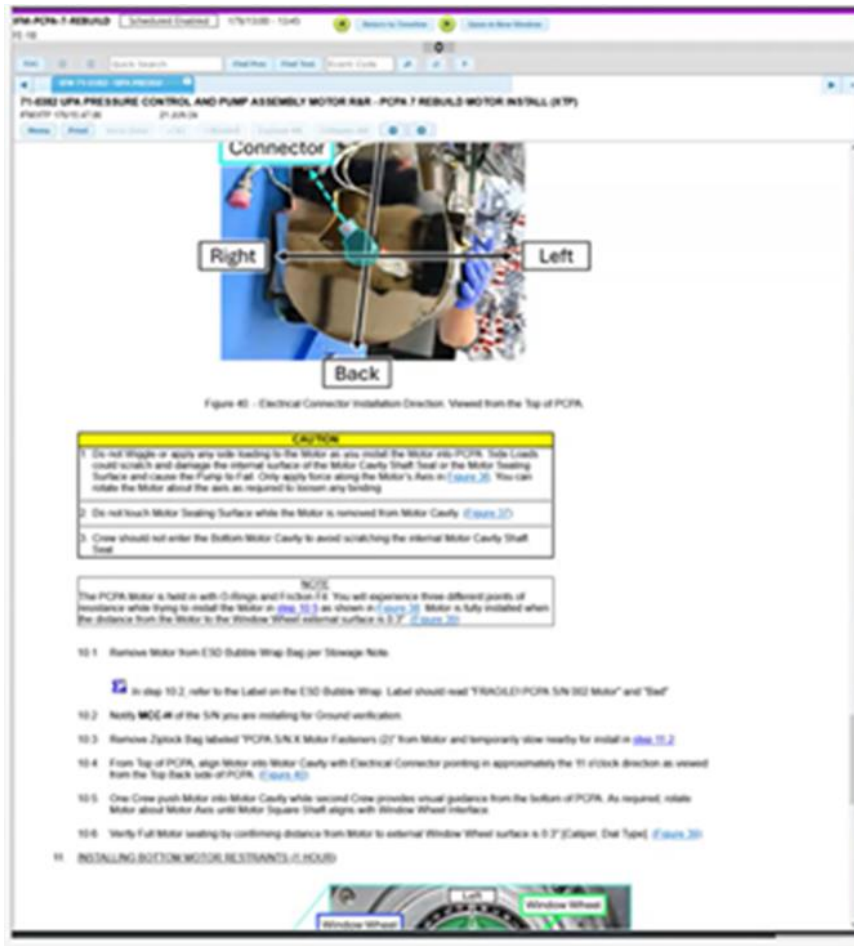


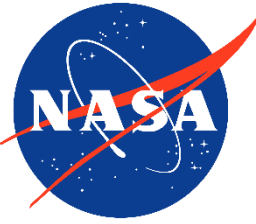
Special Topic – Designing for Maintenance

- **ISS hardware largely designed based on the ORU concept**
 - Focus on ease of maintenance activity to reduce crew time
 - Location in Low-Earth Orbit and resupply ConOps facilitated frequent return/refurbish cycles and the use of a depot-like ground capability
- **Future Exploration missions will most likely not have the benefit of a robust supply chain**
 - Everything you need on the way to Mars you must bring with you
- **Studies performed by NASA Langley Research Center showed that maintaining systems at a lower level (component vs. ORU-level) results in overall spares mass/volume reduction for equivalent mission probability of success**
 - Subject of previous ICES papers
- **ECLSS Evolution working to demonstrate component-level maintenance on ISS**
 - Primary focus of some upgrades such as AOGA and PPSA
 - Recent PCPA failure in UPA drove ground teams to develop an on-orbit procedure for crew to remove a pump from one ORU and put it in another ORU (“Frankenpump”) – activity was successful, but Frankenpump has not been installed yet to confirm operation
 - Represented extraordinary efforts from ground teams in a short period of time, as well as on-orbit support
 - Proved that special advanced crew training not required
 - Goal – do more invasive maintenance on ISS as Program heads toward completion, even if more risk acceptance is required
- **Technology developers should seriously consider low-level component maintenance at design as well as common parts/tools**



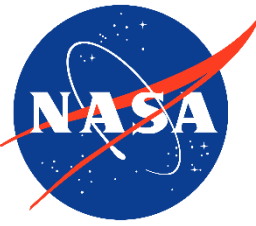
Special Topic – Designing for Maintenance



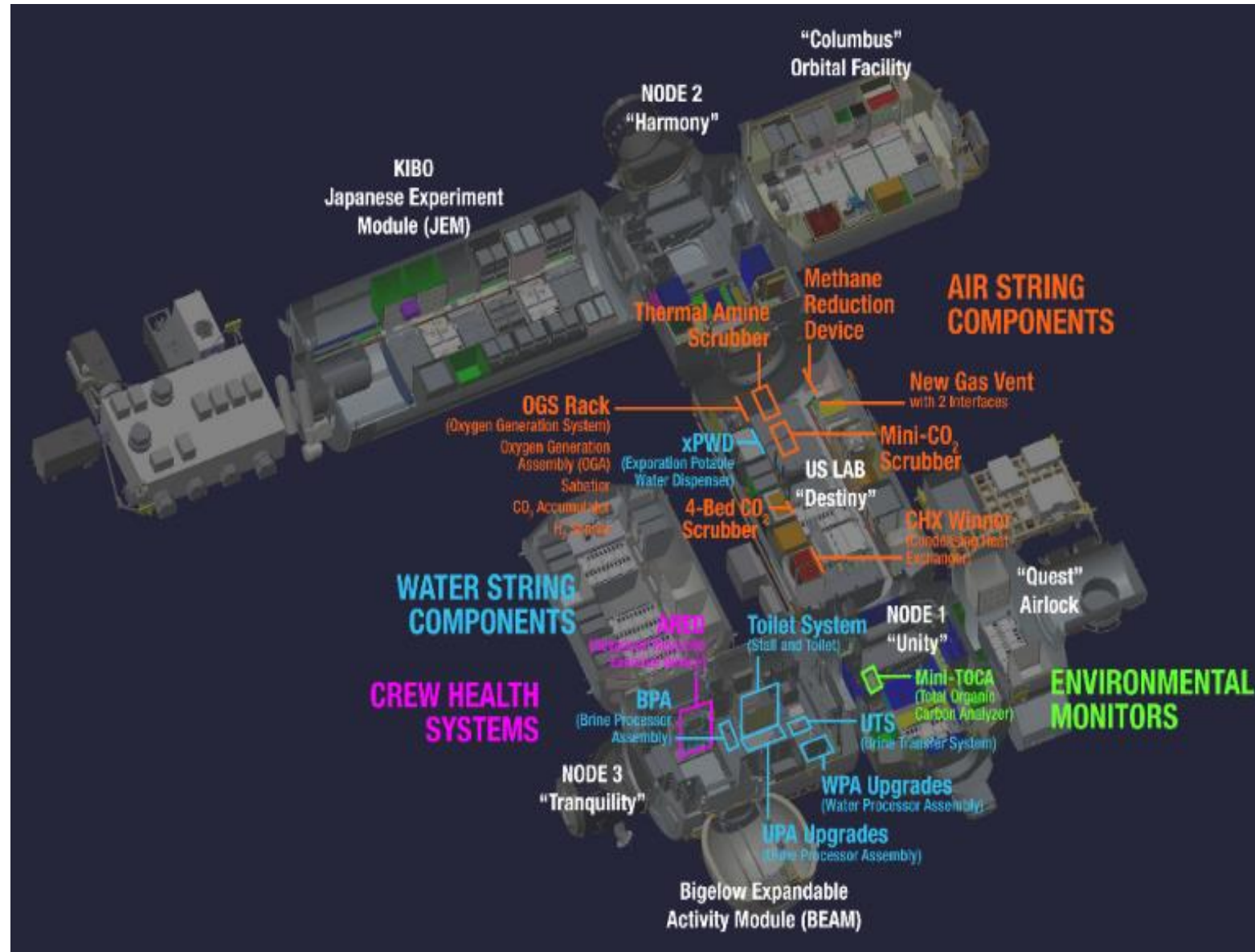


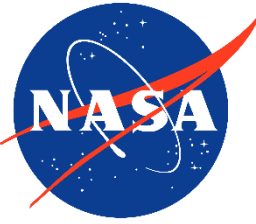
Conclusion

- **Attempting to maximize the use of ISS Vehicle as demonstration platform for Exploration ECLSS technology**
 - Identify system failure modes and correct design
 - Increase understanding of system reliability for successful/efficient spares planning
- **Many challenges related to these demonstrations have been addressed**
- **Largest areas of forward work**
 - PPSA and Cat Reactor redesign for demonstration
 - Deliver AOGA
 - Determine forward path for integrated air string demonstration
- **ECLSS Capability Advancements on ISS continue – we have a lot left to learn**

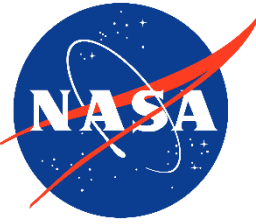


ECLSS Tech Demo Installed Locations





Backup



Acronyms

- *AOGA* = Advanced Oxygen Generation Assembly
- *AR* = Air Revitalization
- *ARC* = Ames Research Center
- *ARFTA* = Advanced Recycle Filter Tank Assembly
- *BPA* = Brine Processor Assembly
- *CCAA* = Common Cabin Air Assembly
- *CDRA* = Carbon Dioxide Removal Assembly
- *CH₄* = Methane
- *CHIPS* = Charcoal HEPA Integrated Particle Scrubbers
- *CHP* = Crew Health and Performance
- *CHX* = Condensing Heat Exchanger
- *CO₂* = Carbon Dioxide
- *COTS* = Commercial Off the Shelf
- *DA* = Distillation Assembly
- *dP* = Delta Pressure
- *DSMD* = Dimethylsilanediol
- *ECLS* = Environmental Control and Life Support
- *ECLSS* = Environmental Control and Life Support System
- *EDV* = Russian-Built Water Tank
- *EVA* = Extravehicular Activity
- *EXPRESS* = Expedite the Processing of Experiments to ISS
- *(g)* = Gas Phase
- *H₂* = Hydrogen
- *H₂O* = Water
- *HEPA* = High Efficiency Particulate Air
- *IMV* = Intermodule Ventilation
- *ISS* = International Space Station
- *JSC* = Johnson Space Center
- *MCC-H* = Mission Control Center – Houston
- *MCO* = Mars Capability Office
- *MER* = Mission Evaluation Room
- *MSFC* = Marshall Space Flight Center
- *MOSFET* = Metal-Oxide Semiconductor Field-Effect Transistor
- *NASA* = National Aeronautics and Space Administration
- *O₂* = Oxygen
- *OGA* = Oxygen Generation Assembly
- *OGS* = Oxygen Generation System
- *ORU* = Orbital Replacement Unit
- *PTU* = Pre-treated Urine
- *PWD* = Potable Water Dispenser
- *SOA* = State Of the Art
- *TBD* = To Be Determined
- *TOCA* = Total Organic Carbon Analyzer
- *TCCS* = Trace Contaminant Control System
- *TT&E* = Tear-down, Test and Evaluate
- *US Lab* = United States Laboratory Module
- *USOS* = United States On-orbit Segment
- *UWMS* = Universal Waste Management System
- *UPA* = Urine Processor Assembly
- *UTS* = Urine Transfer System
- *UV* = Ultraviolet
- *VOC* = Volatile Organic Compound
- *WHC* = Waste and Hygiene Compartment
- *WPA* = Water Processor Assembly
- *WRS* = Water Recovery System
- *WW* = Waste Water