International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of Events 2024-2025

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November 20th, 2025 marks the 27th anniversary of the beginning of construction of the International Space Station (ISS). The ECLS system is constantly changing to meet the needs of current missions and future exploration. The ISS has become the laboratory that was always envisioned, allowing for an ever-growing class of exploration level technologies that will propel the stage forward as humanity advances beyond Low Earth Orbit (LEO). This paper will review the past two years and look towards the future for each U.S. ECLS subsystem. The impacts, challenges, failures and successes related to the operation of incumbent and cutting-edge technologies are summarily discussed in this paper.

Acronyms and Nomenclature

ABIT	=	Active Built In Test
AC	=	Assembly Complete
ACS	=	Atmosphere Control & Supply
ACTEX	=	Activated Carbon/Ion Exchange
AR	=	Atmosphere Revitalization
BPR	=	Back Pressure Regulator
CCAA	=	Common Cabin Air Assembly
CEBAA	=	Crew Emergency Breathing Air Assembly
CHIPS	=	Charcoal HEPA Integrated Particle Scrubbers
CO2	=	Carbon Dioxide
CWC-I	=	Contingency Water Container Iodine
CDRA	=	Carbon Dioxide Removal Assembly
CLD	=	Commercial Low Earth Orbit (LEO) Destinations
DMSD	=	Dimethylsilanediol
DI	=	De-ionizing
DTO	=	Developmental Test Objective
ECLS	=	Environmental Control and Life Support
EM	=	Emergency Mask
EMU	=	Extravehicular Mobility Unit

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EVA = Extra Vehicular Activity
FCT = Flight Control Team
FDIR = Fault Detection, Isolation, and Recovery
FDS = Fire Detection and Suppression
FIT = Failure Investigation Team
FOD = Foreign Object Debris
GRC = Glenn Research Center
H2ST = Hydrogen Sensor Technology Demonstration
HEPA = High Efficiency Particulate Air
IMV = Inter-Module Ventilation
ISA = Internal Sampling Adapter
ISS = International Space Station
KSC = Kennedy Space Center
LEO = Low Earth Orbit
MCA = Major Constituent Analyzer
NASA = National Aeronautics and Space Administration
NRAL = Nanoracks Airlock
NG = Northrop Grumman
NORS = Nitrogen Oxygen Recharge System
OGA = Oxygen Generation Assembly
OGS = Oxygen Generation System
ORU = Orbital Replaceable Unit
PHA = Prebreathe Hose Assembly
PMD = Pressure Management Device
PWD = Potable Water Dispenser
QDMA = Quick Don Mask Assembly
RPC = Remote Power Controller
RPCM = Remote Power Control Module
RSA = Rotary Separator Accumulator
R&R = Remove & Replace
SBA = Sorbent Bed Assembly
SDS = Sample Delivery System
S/N = Serial Number
SSPCB = Space Station Program Control Board
SSC = Space Station Computer
SV = Solenoid Valve
TCCS = Trace Conataminant Control Assembly
THC = Temperature & Humidity Control
TMS = Trimethylsilanol
TOC = Total Organic Carbon
TT&E = Test, Teardown & Evaluation
UPA = Urine Processor Assembly
USOS = United States On-orbit Segment
WHC = Waste & Hygiene Compartment
WM = Waste Management
WPA = Water Processor Assembly
WRS = Water Recovery Subsystem
WRM = Water Recovery & Management
VAP = Vacuum Access Port
VES = Vacuum Exhaust System
VRIV = Vent and Relief Isolation Valve
VRS = Vacuum Resource System
VRV = Vent Relief Valve
xEMU = Exploration Extravehicular Mobility Unit

I. Introduction

The International Space Station (ISS) program achieved "Assembly Complete" (AC) in 2011, with the Environmental Control and Life Support (ECLS) system supporting ISS crews and visiting Shuttle and Soyuz crews since assembly began in 1998.

Through AC, a total of 18 pressurized elements have been added to the ISS. Since then, ECLS activity has focused mainly on maintaining the ISS systems currently onboard while acquiring on-orbit operational knowledge in microgravity. Additional changes to the "post-AC" ISS configuration continue to occur, including technical demonstration hardware replacing traditional, core systems.

ISS ECLS OVERVIEW

The ISS on-orbit ECLS system comprises 7 separate subsystems: Atmosphere Control and Supply (ACS), Atmosphere Revitalization (AR), Temperature and Humidity Control (THC), Fire Detection and Suppression (FDS), Water Recovery and Management (WRM), Vacuum System (VS), and Oxygen Generation (OG). The following sections briefly summarize each subsystem and its function within the ISS pressurized elements. Given the focus of this publication being on major events occurring during the past two years, not all of the subsystems below will be discussed further.

1. Atmosphere Control and Supply (ACS)

The ACS subsystem provides cabin atmosphere pressure control, overpressure relief, pressure equalization, rapid depressurization detection and response, nitrogen and oxygen distribution, and nitrogen and oxygen high pressure tank recharge from Nitrogen Oxygen Recharge System (NORS) tanks delivered on unmanned cargo vehicles.

2. Atmosphere Revitalization (AR)

The AR subsystem revitalizes the habitable atmosphere by removing carbon dioxide, potentially hazardous volatile and non-volatile trace contaminants generated by inadvertent spills, crew metabolic processes, and equipment off-gassing such that cabin contaminant levels are maintained within safe limits. Additionally, the ISS habitable environment is monitored for atmosphere major constituents O_2, N_2, and CO_2, as well as H_2, CH_4, and H_2O. In the United States On-orbit Segment (USOS), the Sample Delivery System (SDS) carries sample cabin air through lines from the various modules to the Major Constituent Analyzer mass spectrometer.

3. Temperature and Humidity Control (THC) & Fire Detection and Suppression

The THC subsystem provides airborne heat removal, air temperature control and monitoring, intra-module and inter-module ventilation, humidity removal, and airborne particulate/bacteria removal.

4. Fire Detection and Suppression (FDS)

The FDS subsystem includes smoke detection, fire isolation, fire extinguishment, and fire recovery.

5. Water Recovery and Management (WRM)

The WRM subsystem supplies potable water, hygiene water, and water for payloads and EMU Suits, as well as collecting humidity condensate and urine distillate. The WRM also provides condensate storage and potable and wastewater distribution. The WRM subsystem includes Water Recovery System (WRS) 1 and 2 racks which houses the Urine Processor Assembly (UPA) and the Water Processor Assembly (WPA). WRM includes Waste Management (WM) which, for ISS, is the Waste & Hygiene Compartment (WHC), a U.S. On-orbit Segment (USOS) bathroom that collects solid waste and collects, treats and transports liquid waste to the Urine Processor Assembly (UPA) for water recovery.

6. Vacuum System (VS)

The VS supplies the U.S. Lab module payload rack locations with access to space vacuum. The VS consists of two separate subsystems: the Vacuum Exhaust System (VES) and the Vacuum Resource System (VRS). Connected to all thirteen payload rack locations, the VES can vent payload gases overboard. The VRS provides high-quality vacuum to nine of the thirteen payload rack locations for user access.

7. Oxygen Generation (OG)

Oxygen Generation system includes the Oxygen Generation Assembly (OGA) and Advanced Oxygen Generation Assembly (AOGA).

II. Summary Discussion of Major Subsystem Events In the United States On-Orbit Segment By Function

A. Atmosphere Control and Supply

1. Air Portable Breathing Apparatus (PBA) Implementation for Fire Response

Pressurized Air Portable Breathing Apparatuses or Air PBAs were originally launched as contingency hardware to provide breathing air to crew during Crew Dragon/CST-100 safe haven, in the event the primary Crew Emergency Breathing Air Assembly (CEBAA) tanks could not be safely secured to the returning vehicles. As the on-orbit contingency operations matured and the Emergency Breathing tanks were successfully fit checked into the returning vehicle mounts, the Air PBAs had no designated purpose on board as opposed to their pure 100% counterparts (i.e. O2 PBAs), which are primary hardware that crew uses for multiple emergency scenarios.

The Air PBA posture changed quickly as the Emergency Masks (EMs), cartridge based respirators primarily used for ammonia leakage response and fire response, were deemed not good for use when a fleet wide failure was discovered in 2023. Consequently, in July 2024, the Space Station Program Control Board (SSPCB) approved the Air PBAs as the primary personal protective equipment for fire response until new hardware could replace the EMs. The Air PBA units provide crew with a portable breathable air source in the event of a cabin fire. However, it should be noted that for users with high enough demand combined with a high metabolic rate, it is possible to have negative pressure inside the mask volume during phases of the breathing cycle. This is due to the flowrate supply not being able to keep up with the demand and therefore pose a risk for the user to inhale the contaminated cabin air.

Currently in ISS, the fleet of Air PBAs is still the active and designated primary hardware for on-orbit fire response. The ISS Vehicle Control Board agreed in 2025 to continue the use of Air PBAs as long as a sufficient quantity remain viable and at that point, utilize the EM replacement hardware referred to as the new Emergency Respirators (ERs).

2. Prebreathe Hose Assembly (PHA) Blowout Investigation and Path Forward

In January 2025, the crew was in the middle of prebreathe during preparations for an Extra Vehicular Activity (EVA) when it was reported that the harness of the Prebreathe Hose Assembly (PHA) Quick Don Mask Assembly (QDMA) S/N 1103 had ruptured (see Figure 1). This harness rupture was similar to what happened to PHA QDMA S/N 1102 in July 2020 which also occurred during EVA prebreathe activities. Both S/Ns 1103 and 1102 were manufactured and launched in 2011. The investigation of PHA QDMA S/N 1102 saw that the tubing in the mask harness did not have any bonding between its internal surface (stiction). It was instead observed that there was "sweating" residue, an indication of material degradation that results in polymer embrittlement. Furthermore, the counterpart unit, PHA mask S/N 1103, is also suspected to exhibit a similar polimer embritlement degradation in its harness tubing, as these two units corresponded to the same manufactured batch.

Figure 1. PHA QDMA S/N 1103 Ruptured Harness

On-orbit, there are two types of QDMAs – PHA QDMAs and Portable Breathing Apparatus (PBA) QDMAs. The PBA QDMAs do not get used regularly, unlike the PHA QDMAs, so the status of these masks were called into question. All six on-orbit PBA QDMAs that were manufactured in 2011 were tested in April 2025. Each of the six masks had their harnesses successfully inflated with no leaks reported. PHA QDMA S/N 1105 was launched September 2025 to replace S/N 1103.

3. Vent and Relief Isolation Valve (VRIV) Cover Design and Delivery to ISS

The Vent and Relief Isolation Valve (VRIV) is part of the Vent Relief Valve (VRV) system that provides overpressure relief and atmosphere venting. In 2004 crew reported damage to the Airlock VRIV J1 power connector. Although the connector remained functional, a failure could disable Visiting Vehicle vestibule operations that use the Node 1 Vacuum Access Port (VAP) and future Exploration Extravehicular Mobility Unit (xEMU) Carbon Dioxide (CO_2) venting via the VRIV. Removing and replacing the VRV would require multiple EVAs.

To mitigate this risk, a temporary barrier was installed in 2022 behind the Airock 1D0 closeout panel to protect the VRV/VRIV while a permanent solution was developed. Engineering teams considered several iterations of VRIV cover design in 2023. In March 2024 a fit check at the Kennedy Space Center (KSC) validated the final clamshell, two-part cover with lateral foam-lined walls to stabilize the broken connector (see Figure 2).

Figure 2. VRIV Cover Fit Check August 2024

The VRIV Cover Assembly was launched on cargo flight NG-21 in August 2024 but installation was deferred pending xEMU airlock modifications. After xEMU mods were placed on hold, teams re-inspected the temporary barrier in December 2025 and found it to be in good condition. Installation of the VRIV cover remains on hold until VRV access is required for xEMU Mod Kit installation or other Airlock VRIV operations.

4. PMD Anomalies and Troubleshooting 2024-2025

The Pressure Management Device (PMD) is a large pumping and venting unit developed and maintained by KBR-Wyle Laboratories, containing two scroll pumps, four solenoid valves, and two pressure sensors, along with control circuitry and interlocks. Its purpose is to save air from vestibules and from the Nanoracks Airlock (NRAL) when volumes need to be depressurized for leak checks for docking/undocking or science payloads. It communicates with a Space Station Computer (SSC) laptop via USB cable, allowing ground controllers to send commands remotely once the crew has completed setup.

Since its inception in 2016, PMD has had occasional failures, but has generally worked well when required for use. PMD S/N 1002 was flown in September 2025 and a checkout activity on GMT 2025/269 tested its functionality in Node 3, as it was needed in Node 3 for an upcoming NRAL activity. Upon activation of the scroll pumps for the checkout, the PMD unexpectedly drew over 6 amps of current (nominal current draw is ~4 amps), causing the software fault detection and isolation response (FDIR) to engage and shut down the PMD. Since the PMD’s circuitry included a breaker that would trip at 10 amps, the flight control team (FCT) bypassed the FDIR in an attempt to complete the checkout. However, valve 2, which isolates the pumps, refused to open upon command. The

FCT power-cycled the PMD four times, each with the same result. Finally, after the fifth power cycle, the pumps drew a nominal current, valve 2 opened successfully, and the checkout was completed.

During the NRAL activity a few days later, the PMD again drew over 6 amps of current, and when the FDIR was bypassed, valve 2 would not open. Due to lack of crew time for additional attempts, the FCT decided to stand down from using the PMD and vented NRAL to space, losing ~13 pounds of air.

A Failure Investigation Team (FIT) was convened to discuss next steps. With limited data, the FIT was unable to determine a likely cause for the fault, and so a T/S activity was scheduled for GMT 2025/325 in an attempt to gather data that would help characterize the fault. Due to activities in Node 3, this T/S occurred in Node 1.

During the troubleshooting, the PMD pumps were successfully operated over 60 times in a row. Valves 1, 2, and 4 all operated successfully with and without the pumps on, and even simultaneously with each other (valve 3 is not used for depressurization and was not exercised). The fault seen previously could not be reproduced. Without any data to the contrary, the FIT concluded that PMD S/N 1002 was functional, and the issue was external to the PMD.

On GMT 2025/357, another NRAL activity called for the PMD to be used in Node 3 for air recovery. This time, the PMD's current draw was closely monitored on the supply side in real time to help characterize the issue. The PMD drew over 6 amps again when the pumps were turned on. It was evident from the real-time data that the current had hit a limit, and it was determined that the DC to AC inverter that supplied the PMD with power was limited to 750 watts at the supply voltage of 120 V. This corresponds to 6.25 amps of maximum current draw. The FCT decided to switch to a different inverter and remove all other hardware from the panel upstream of the power chain from the inverter, in the hope that power conditioning was part of the problem.

After the swap, the PMD was activated and drew a nominal current. The valves were activated successfully, and NRAL was partially depressurized before the PMD switched off, apparently due to loss of communication with the SSC, and had to be recovered by crew. The communication loss happened once more after another round of depressurization, and the PMD was recovered a second time. After a third round of depressurization, the PMD shut down again without losing communication with the SSC, which showed the error commonly associated with pump current exceeding the design limit. However, the real-time data did not show a current spike.

The on-orbit crew was called on to recover the PMD once more; however, when the pumps were turned on, they once again drew over 6 amps, and FDIR engaged. Three more attempts were made, each with the same result. With no obvious pattern to the failures, and no indication that PMD would begin working again, the FCT stood down from using the PMD and vented the remaining ~3 pounds of air to space. Work is ongoing to understand the nature of the issue, and another round of troubleshooting was expected in early 2026.

B. Atmosphere Revitalization

Figure 3. On-Orbit CDRA Bed Cleaning

1. Carbon Dioxide Removal Assembly (CDRA) Status

CDRA has had progressively less runtime in favor of NASA Technical Demonstrations CO_2 scrubbers in recent years. In 2024, the adsorbent beds in both the Lab and Node 3 CDRAs were cleaned on-orbit (see Figure 3). The beds were removed and replaced with the on-orbit spares. Then the removed beds were cleaned on a later date to be reused at a future time if needed. The Node 3 CDRA showed some slow valve transitions indicating a potential need for a valve replacement at some point in the future. It is currently not imminent but something that is being tracked.

Figure 4. Node 3 MCA Drawer

2. Major Constituent Analyzer (MCA) Status

In 2024, the Intermittent Operations of the MCAs was updated so that the MCAs would only be operated to support EVAs. The suspected partial blockage in the Sample Distribution Assembly (ORU 06) progressed to the point where the Node 3 MCA could not sample from the Forward modules. As a result, Lab MCA became the prime MCA to use. Additionally, there was an RPCM failure that affected two of the MCA SDS valves. The positions the SDS valves are stuck in prevents both MCAs from sampling any modules forward of Lab and as well as the Lab MCA cannot sample from the Lab module. At the end of 2025, the ORU 06 was replaced in the

Figure 5. Node 3 TCCS

Node 3 MCA. The R&R did not produce the expected results; the sample pump voltage did not increase off of the lower limit and stayed around 15 Volts. However, the MCA is operational. After Node 3 MCA (see Figure 4) is successfully operated during an EVA, it will be the prime MCA and Lab MCA will be retired.

3. Trace Contaminant Control System (TCCS) Status

Node 3 TCCS (See Figure 5) failed to start up following the Node 3 CDRA bed cleaning activities at the end of 2024. It was found that the TCCS power cable was severed, most likely occurring when the TCCS was slid back into the Node 3 AR Rack. The power cable was repaired and Node 3 TCCS functionality was restored.

The Node 3 TCCS Sorbent Bed Assembly (SBA) neared the end of its 6.3 year operational life and was replaced at the end of 2025. For the Lab TCCS, as a follow up to the “Lab TCCS Loss of Function on Startup” error on GMT 2023/136, the Lab TCCS went through multiple nominal startups since and the fault has not repeated in two years. Therefor this 2023 issue was declared as a transient/unexplained anomaly. Both the Lab and Node 3 TCCS continue to operate nominally.

C. <u>Temperature and Humidity Control</u>

1. Nominal Speed Intermodule Ventilation (IMV) Fan Issues Encountered Prior To Their Expected End of Life

The IMV Fans on ISS have historically performed quite well, with most installed Orbital Replacement Units (ORUs) running significantly past their expected end of life. However, starting in 2022, a string of nominal Speed IMV Fan issues was encountered on-orbit, starting with the Lab Forward Port Fan making a high pitch noise, which led to the first Remove and Replace (R&R) of an IMV Fan due to noise or failure of a fan. The next IMV Fan to be removed was the Node 3 Port Forward IMV Fan in 2024. It failed when the Remote Power Controller (RPC) associated with the fan tripped open. Several attempts were made to reclose the RPC, but, ultimately, the fan was deemed failed and crew R&R’d that IMV fan as well. Later in 2024, the Lab Aft Port IMV Fan also began making a loud noise and was R&R’d. Sparing concerns then led the ground team to request an R&R of the Node 1 Starboard Aft IMV Fan, installing the previously removed Node 3 Port Forward IMV Fan into this Node 1 location. This was done to prove that the RPC trips were not fan-related, but due to an RPC issue instead. When the fan worked, the IMV Fans were exonerated as the cause of the RPC trips. The fan that was removed from Node 1 Starboard Aft has been retained on-orbit as a functional spare. The next IMV Fan to encounter issues was the Lab Forward Port IMV fan that was previously R&R’d in 2022. Crew commented about noise in the area of the fan and acoustics data confirmed that this IMV Fan was the source of the noise. With only one available spare on-orbit at this time, the ground team requested an IMV Fan swap instead of consuming the only available spare. In this case, the Lab Forward Port IMV Fan was swapped with the Lab Forward Starboard IMV Fan. The Lab Forward Starboard IMV Fan is nominally off and only powered on when there is known low flow at Lab Forward Port or there is maintenance in Lab that requires additional airflow. Having this noisy fan in this area is deemed acceptable because it will be used for short durations and provides necessary additional airflow.

These issues have also led the ground team to assess the available ground fleet. At the time, there were three nominal Speed IMV Fans on the ground with their motors removed. The motors had been undergoing hand spins to keep the grease and oil mixed in the bearings. The ground team put the motors into Test, Teardown and Evaluation (TT&E) to test all three motors to determine which of the IMV Fans could be rebuilt without undergoing bearing replacement. Despite having similar histories, the motors all performed differently from each other: one motor performed nominally, one motor had marginally acceptable performance, and one motor had unacceptable performance. Ultimately, the ISS Program has requested that the two better units be rebuilt.

While waiting for the nominal Speed IMV fans to be rebuilt and in addition to the one on-orbit spare that is available, there are also two spare High Speed IMV Fans on ISS. These fans could be installed in place of a nominal

Speed IMV Fan, but software updates would be necessary to allow the fans to function properly and for telemetry to ensure that the data from the fans is read correctly.

2. Charcoal High Efficiency Particulate Air (HEPA) Integrated Particle Scrubber (CHIPS) Filter Life Determination

The CHIPS filters were launched and installed across the USOS in 2019. These filters are comprised of a two inch thick HEPA Filter and a two inch thick Charcoal Filter, layered with the Charcoal Filter upstream from the HEPA Filter. Each part can be replaced independently and, as such, can have an installed life that is independent of the other filter. Charcoal scrubbing was added to the filters to scrub the air of organosilicons (trimethylsilanol (TMS), dimethylsilanediol (DMSD), siloxanes), which degrade the Common Cabin Air Assembly (CCAA) Heat Exchanger (HX) coating and contribute to Total Organic Carbon (TOC) levels in the WPA, as well as create issues for other hardware downstream of the CCAA HX.

Initially, the HEPA installed life was set to the same installed life of the previous HEPA-only filters (2.0 to 5.0 years, depending on the module). The previous filters were cleaned weekly via vacuum, which left the filters vulnerable to physical damage. With the HEPA portion of the CHIPS Filters downstream of the Charcoal portion, it is only cleaned as directed by the ground and, as such, is much less vulnerable to the same types of damage. Since 2019, several inspections and cleanings have been requested, and other than a light dusting of Foreign Object Debris (FOD) seen on the surface of the HEPA media, the filters look virtually new. To better define the life of these HEPA Filters, the Node 3 HEPA Filters were R&R'd in 2023 with one returned to ground. This filter was tested at Glenn Research Center (GRC) and found to have a very minimal increase in dP of 0.04 in. H_2O compared to pre-flight testing. Additionally, the efficiency of the HEPA filter was found to be 99.98%, which exceeds the requirements for HEPA rating. With this, and how the HEPA Filters appear like-new after ~4.25 years of installation, the Program approved modifying the installed life of these filters as "Run to Failure".

Initially, the Charcoal Filter installed life was set to six years. This was based on early ground assessments. However, in early 2023, data showed an increase of TMS, DMSD, and TOC in the WPA and Potable Water Dispenser (PWD) systems, which led to a full R&R of all of the installed Charcoal Filters in mid-2023. At that time, six of the Charcoal Filters were returned for assessment. One filter was tested at GRC and five filters were tested at Boeing Central Labs in Huntsville, AL. Testing showed that, after the filters were installed for ~4.25 years in Node 3, they had reached their maximum loading capacity. The Node 2 and Lab filters showed similar loading. The filters also showed that the majority of the FOD that was collected by CHIPS was in the Charcoal Filter, despite not being HEPA-rated. Importantly, on-orbit air data indicated that the TMS levels began to rise in the air ~1.5 years after install, and returned to the higher pre-installation levels approximately three years after installation. This led the Program to reduce the installed life of the CHIPS Charcoal Filters from six years to three years.

D. Water Recovery Management

1. Water Processor Assembly (WPA) Catalytic Reactor Swap Out

In March of 2024, Catalytic Reactor Serial Number (S/N) 07 showed signs of leakage due to increasing frequency of faults in the system. This was consistent with previous Catalytic Reactors which leaked through the elastomeric seals and a plan to Remove & Replace (R&R) the Catalytic Reactor was put in work. The recommended available spare designated for installation was the "upgraded" Demonstration Test Objective (DTO) Catalytic Reactor, with exploration-minded upgrades addressing previous failure modes and enhancing functionality (ex: upgraded metal seals and the brand-new catalyst with improved performance).

At the time of the failure, there were two available spares, the "upgraded" model (S/N 1) and the baselined unit (S/N 6). Unfortunately, at the time of the hardware R&R actives, the baselined ORU was inadvertently installed and exposed to wastewater during unsterile check-outs. Due to the urgency of validating the upgraded DTO technology, it was ultimately decided to prioritize immediate installation of the upgraded catalytic reactor S/N 1, the DTO, rather than waiting until failure of the just installed Catalytic Reactor (S/N 6). Due to the nature by which the S/N 6 was exposed to non-sterile wastewater, additional steps were required to mitigate microbial concerns once removed from the rack. The mitigation steps utilized a thermal bake-out to reach thermal disinfection on S/N 6 before final removal and stowage.

After successful installation of the DTO Catalytic Reactor S/N 1, approximately thirteen days later, and after processing a total 463 lbs of water the unit saw significant water leakage signatures, similar to end-of-life signature and failure modes from the initial install back in 2021. (Jill Williamson, 2022) (Williamson, 2023) The DTO Catalytic Reactor was unable to continue processing water and was R&R'd, with reinstall of Catalytic Reactor S/N 6. Once installed, S/N 6 operated for 419 days (expected) and was subsequentially replaced with a legacy Catalytic Reactor S/N 1. As of early 2026, this unit has continued to operate since July 2025.

2. WPA Catalytic Reactor SN 01 Valve Anomaly

In September 2025, preparation for an R&R of a different WPA component, the Separator Filter ORU, required ground teams to prepare (safe) WPA by commanding to a proper maintenance state. Part of the transition to this maintenance state requires specific hardware configurations to complete leak checks, steady-state temperatures and pressures, valve isolations, etc. Upon commanding the inlet solenoid valve (SV 1126_1) to the Catalytic Reactor S/N 1, several faults occurred causing software and cross-systems alert responses. SV 1226_1 is nominally open during nominal WPA processing. The faults indicated an undercurrent fault and an overcurrent fault for the SV 1126_1 plus a non-neighboring SV located upstream at the process pump ORU. Although these two valves are physically unrelated, they do share a similar controller board. After various valve commanding, it was confirmed that the valve was unable to close, such that excessive current draw in tandem with other required valve commanding caused a hard system fault.

After discussion, ground teams acknowledged the issue with the solenoid valve of Cat Reactor S/N 1 and determined the SV 1126_1 valve was not required for nominal operations. WPA was able to return to nominal operations without further faults, but WPA has lost its ability to transition to the maintenance state with the current installed Catalytic Reactor. However, teams assessed if this particular state is needed or expected for any other upcoming WPA activities and determined that the Cat Reactor will likely be replaced before hot service is needed. Otherwise, teams will prepare the system for this expected fault response and determine an alternate work-around to desensitize the valve fault responses.

E. Vacuum System

Last year, in 2025, the Vacuum Exhaust System (VES) was approved to vent payloads simultaneously. The VES was originally designed to vent one payload at a time; however, it has become the primary vent for CO2 Scrubber Technical Demonstrations: Four Bed CO2 (FBCO2) and Thermal Ammine Scrubber (TAS). This is in part due to the fact that FBCO2 became the primary CO2 scrubber.

F. Oxygen Generation

1. Oxygen Generation Assembly (OGA):

The ISS Oxygen Generation Assembly (OGA) system has been in operation for over eighteen years and is currently installed in the US Laboratory. The Oxygen Generation System (OGS) rack was first installed in the Lab in January 2007, moved to Node 3 in March 2010, and returned to the Lab in September 2022 to support co-location and integration with Exploration demonstration air-string systems. As of February 8, 2026, the system has consumed 17,311 L of water and produced 33,894 lbm (15,374 kg) of oxygen and 4,270 lbm (1,937 kg) of hydrogen since its initial activation in 2007 (see Figure 6).

Current and ongoing OGA issues will be discussed below. These include cell stack low voltage, low recirculation loop pressure, RSA high quantity faults, ACTEX life reduction, and other issues.

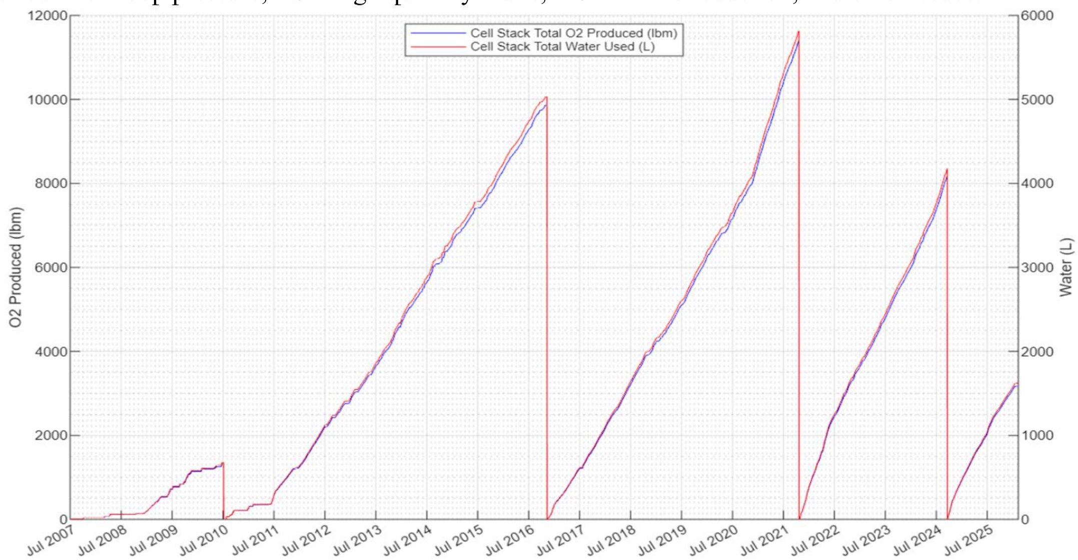

Figure 6. Oxygen Produced and Water Used Per Installed H2 ORU

a. Cell Stack

The Cell Stack was installed in 2021 and R&R'd on Sep 16, 2024 due to cell 1 degrading voltage performance. The failure signature matched those seen previously in ORU SN 2 and SN 3. Beginning in March 2024, Cell 1's voltage began to deviate from the other cells during startup and shutdown, showing a faster discharge and a longer charge period. This behavior appeared earlier than expected ~2.5 years into SN 4 operational life, compared with roughly 4 years for SN 2 and SN 3. The leading hypothesis is that SN 4 operated at a higher production rate than the

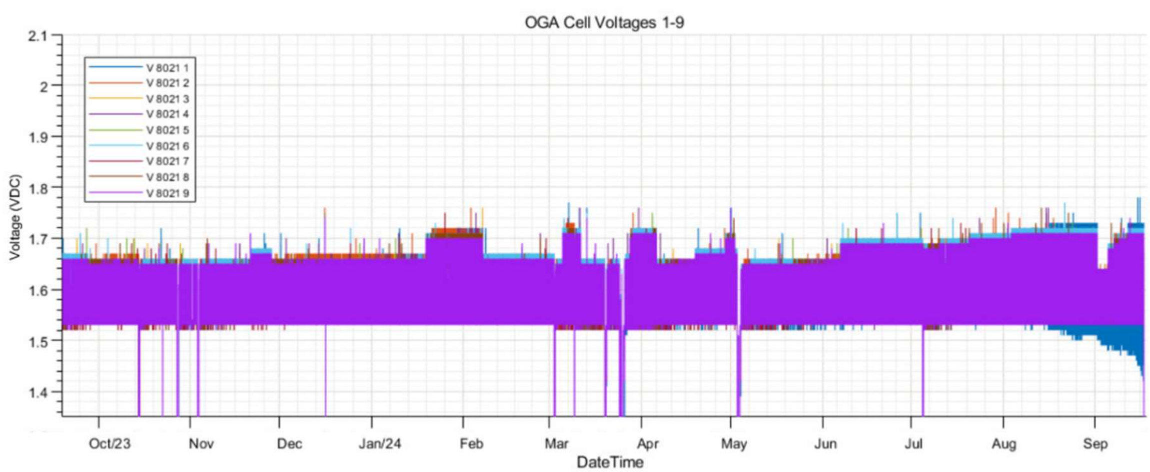

Figure 7. Hydrogen ORU (SN4) Cell 1-9 Voltages Over Time

other installed ORUs. Higher production rate can accelerate membrane thinning, which alters electrical properties and reduces cell voltage. In August 2024, Cell 1 standby voltage also started to fall outside the standard range. Prior to ORU removal, the cell voltage had dropped to 1.42 V (see Figure 7); the ORU was removed to avoid creating a localized hot spot or pinhole leak that could potentially lead to combustion.

b. Low Recirculation Loop Pressure

Nominally, the water recirculation loop pressure is maintained at 22–26 psia by the hydrogen Back Pressure Regulator (BPR) inside the Hydrogen ORU. The Hydrogen ORU SN 4 (installed in October 2021, removed in

September 2024) recirculation loop pressure was low during Standby and progressively worsened, dropping to ~20.2 psia over its service life. H2 ORU SN 3 BPR exhibited very similar BPR behavior. The root cause for SN 3 BPR performance was corrosion between the tightly-toleranced poppet stem and guide caused by improper passivation of metallics. The team has revised BPR manufacturing processes to ensure proper passivation and prevent recurrence. Hydrogen ORU SN 5 (installed in September 2024) is holding recirculation loop pressure is stable in the 22.5–25 psia range (see Figure 8).

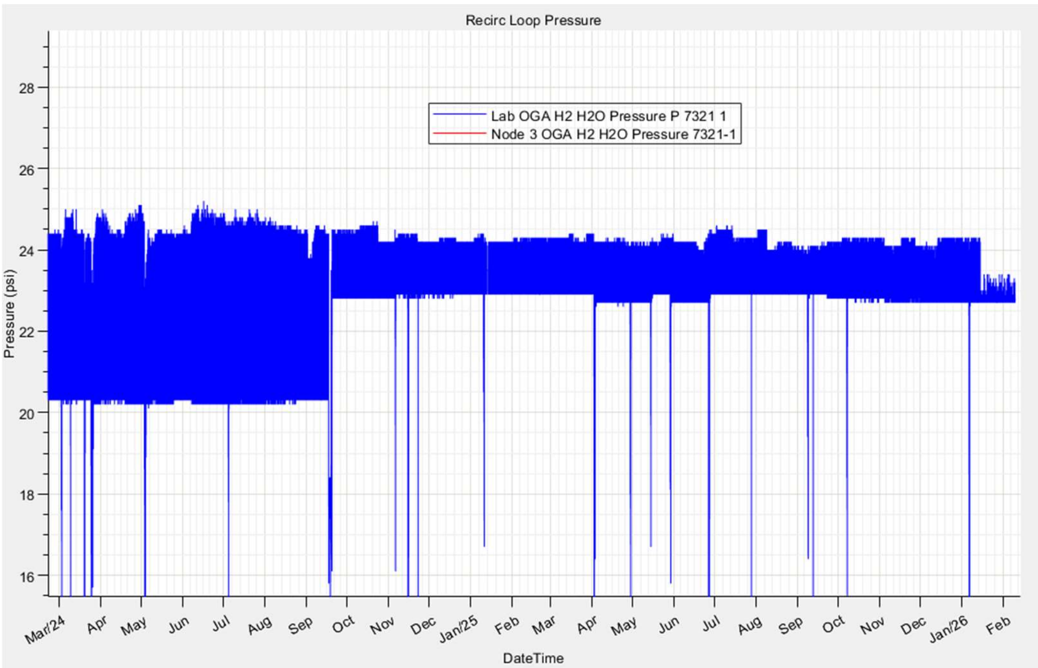

Figure 8. Hydrogen ORU (SN4 & SN5) Recirculation Loop Pressure

c. Rotary Separator Accumulator (RSA) High Quantity Faults

The RSA high-water fault trips if the RSA water volume increases by more than 10 in³ (≈164 mL) during a fill. During some reactivations of Hydrogen ORU SN 4, the Active Built In Test (ABIT) 2 test pushed more water than expected from the cell stack into the RSA, and the system pushed additional water from the feedwater line during the fill, which tripped the 10 in³ threshold. Also, on May 3, 2024, the same fault occurred after an inlet De-ionizing (DI) bed R&R (the bed was launched with an nitrogen bubble for thermal expansion). In that event, the RSA water increases were caused by gas in the inlet DI bed combined with low recirculation loop pressure due to a faulty hydrogen back-pressure regulator. That condition created a pressure differential across the check valve between the feedwater section and the recirculation loop, unintentionally pushing extra water into the RSA. In 2025, to protect against nuisance shutdown, the RSA high fault limit was increased from 10 in³ to 15 in³. Also, the extended pump run time on shutdown was increased from 1 minute to 5 minutes to reduce the amount of H2 remaining in the system and maintain a stable configuration for reactivation.

d. Activated Carbon/Ion Exchange (ACTEX) Life Reduction

The ACTEX has always had an assigned life of 675 days. The ACTEX is a mixed resin bed, with its primary purpose being to remove fluoride (a byproduct of cell stack operation) from the recirculation loop to prevent corrosion caused by a reduced pH level. In October 2024, the OGA team made a decision to reevaluate the 675 day life for the ACTEX. The installed life assumed a 10% remaining resin capacity. Chemical analysis on three returned ACTEXs determined that fluoride was near the outlet, and that there was the potential for other chemical species, such as sulfate and bicarbonate, to displace the fluoride, increasing the risk of breakthrough, which would be detrimental to the cell stack. After reviewing this data, the team decided to lower the assigned life to 527 days, with an assumed remaining capacity of 30%. This would minimize the chance of fluoride breakthrough and better protect the cell stack.

e. Other Issues

Other issues are failed pump DP sensor, nitrogen leakage, QD partial mate, and drifting venturi sensors. There is not any new progress to report on these issues, but will still be tracked until final closure..

2. Advanced Oxygen Generation Assembly (AOGA)

The AOGA design was focused on enabling component-level maintenance, modifying the existing cell stack design to improve both shelf and operating life, and enabling dormancy. The system design is similar to the OGA, with the notable differences being that the AOGA will incorporate a redesigned cell stack, two independent domes, new hydrogen sensors, redesigned ACTEX, and a manual nitrogen purge and water flush capability for the water recirculation loop (see Table 1) as denoted by the red and blue dotted lines (see Figure 9).

Upgrade	Reason	Description
Redesign Cell Stack	Implement corrective action based on the cell stack failure investigation to mitigate membrane thinning as well as implement current industry best-practices and standards	Provide better mechanical support for the cell membranes, replace the obsolete membrane with chemically stabilized Nafion
Replace the single dome with two domes	Reduce logistics resupply requirements	On-Orbit crew will be able to access and maintain the cell stack, RSA and other components
Replace the hydrogen sensors	Reduce crew maintenance time, improve reliability, eliminate need for specialized purge tools	Replace hydrogen sensors with a more reliable technology that requires less crew intervention
Redesign the recirculation loop ACTEX	Increase installed life and reduce the delta pressure	The existing design is not optimal as it was not specifically designed for the OGA application
Manual recirculation loop purge and flush	Reduces contaminants within the AOGA recirculation loop that could be sent to Sabatier and cleans the system in preparation for dormancy	Purge hydrogen from the recirculation loop with nitrogen, then flush with potable water into a CWC-I bag or the ISS wastewater bus

Table 1. AOGA Summary of Improvements

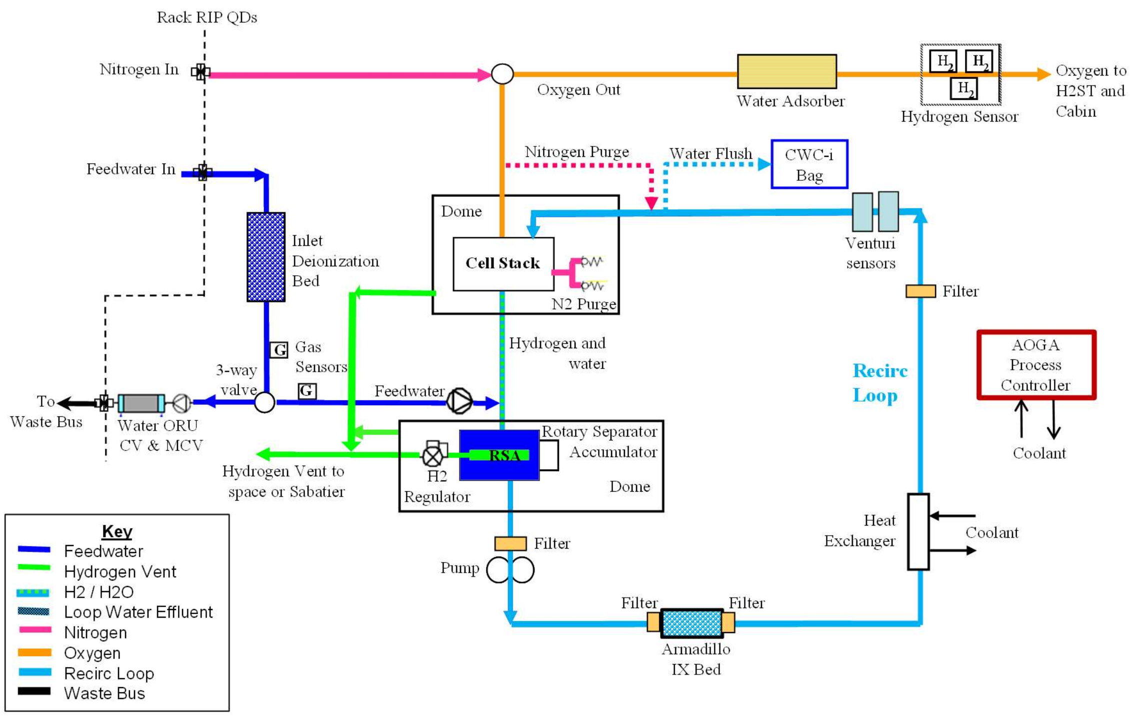

Figure 9. AOGA Simplified Schematic

3. Hydrogen Sensor Replacement

The Hydrogen Sensor Technology Demonstration (H2ST) will demonstrate the performance of four new COTS hydrogen sensors for at least three years while connected to the ISS OGA's oxygen outlet line to monitor for hydrogen.

On July 14, 2022, Sensor 3 failed, after about three months of powered-on operation, with its output dropping off scale low, from 0% to -1% H2, while the other sensors remained at the expected 0% H2. Nominal input current of all four sensors is approximately 150 mA. Sensor 3's input current has dropped from ~150 mA to ~70 mA.

On January 19, 2025, Sensor 1 failed, after about 2.9 years of powered on operation. Similar to Sensor 3, Sensor 1's output dropped off scale low to -1% H2 and its input current became erratic before settling to ~50 mA (see Figure 10).

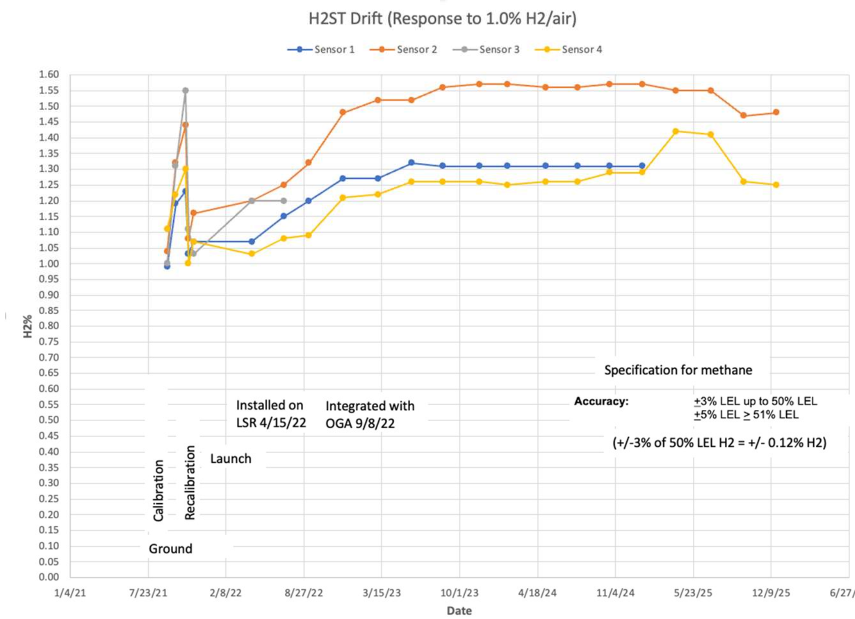

Figure 10. H2ST Sensor Readings

III. Conclusions/Forward Work

This paper documents ECLS system events encountered over a two year period, mostly between January 2024 and December 2025 with a few events dating back to previous years not documented in systems status papers. We are in the twilight years of the ISS, however it continues to operate as a valuable platform for research, technology demonstration, and international cooperation. ISS remains the premier platform for zero-G scientific experimentation, exploration hardware testing, and international operation. As of the writing of this paper, Artemis II's launch of crew to moon is on the immediate horizon, returning crew to the Moon for the first time in over 50 years. platform provided by ISS remains unmatched.

In the commercial sector, multiple commercial entities are aiming to commercialize Low Earth Orbit (LEO). Commercial Elements may attach to the ISS, while multiple providers vie to provide free-flying solutions under the Commercial LEO Destinations (CLD) Contracts. The options are varied, providing for anything from short time visits, to extended length missions. NASA Ignition initiatives point towards a possible re-focus on the use of ISS to enable those missions via a new core module, providing resources for CLD participants by first attaching to ISS. Only time will tell how our presence in LEO will change and evolve.

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