Status of the Advanced Oxygen Generation Assembly in 2026

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Closed-loop life support systems for future missions require an Oxygen Generation Assembly (OGA) to electrolyze water for the crew's metabolic oxygen needs. The hardware will be based on the OGA that has operated aboard the International Space Station (ISS) for over 19 years and will incorporate improvements that have been made in electrolyzer technologies alongside lessons learned from operations aboard ISS. The Advanced Oxygen Generation Assembly (AOGA) combines the strengths of the OGA design with these new improvements, and it is slated to launch to ISS in late 2026. It will operate until ISS sundowning, providing the crew with oxygen and gaining valuable flight time that will inform lunar and Mars mission hardware. Upgrades from the OGA to the AOGA include a redesigned electrolyzer cell stack, separation of the hydrogen dome into two more easily maintained domes, replacement of the hydrogen sensors, an improved recirculation loop deionizing bed, and incorporation of dormancy capabilities such as the ability to nitrogen purge and water flush the recirculation loop. These changes aim to improve maintainability, reduce the spares burden, and increase the reliability of the OGA. The AOGA hardware is currently undergoing build, and this paper covers the progress, plans, and relevant analysis regarding its development since the prior publication.

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Acronyms and Nomenclature

ECLSS = Environmental Control and Life Support Systems
ISS = International Space Station
OGA = Oxygen Generation Assembly
AOGA = Advanced Oxygen Generation Assembly
ORU = Orbital Replacement Unit
DI = Deionized
H2 = Hydrogen
PSM = Power Supply Module
RSA = Rotary Separator-Accumulator
H2 ORU = Hydrogen Dome ORU
ACTEX = Activated Carbon Ion Exchange
IATCS = Internal Active Thermal Coolant System
OGS = Oxygen Generation System rack
LEL = Lower Explosive Limit
H2ST = Hydrogen Sensor Technology Demonstration
OHDA = Oxygen-Hydrogen Dome Assembly
ARMADILLO = AOGA ReMediation Advanced DeIonization and Limited Life Optimization
EDU = Engineering Development Unit
WPA = Water Processor Assembly
BPR = Backpressure Regulator
CV = Check Valve

I. Introduction

Human spaceflight necessitates an environmental control and life support system (ECLSS), and long-duration travel requires closed-loop and regenerative systems in order to make logistics burdens feasible. To support its decades-long mission, the International Space Station (ISS) has implemented its own system of closed-loop ECLSS. A major subsystem is the Oxygen Generation Assembly (OGA), which has been installed and providing crew oxygen since 2007. Water electrolysis is the core technology around which the OGA is built, enabling the conversion of water into breathable oxygen for crew metabolic needs. Nearly twenty years of operations have provided valuable lessons learned on the OGA, and those are informing future oxygen generation architecture in both near-term upgrades (e.g., cell stack improvements) and long-term planning (e.g., enhanced maintainability). The Advanced OGA (AOGA) is a planned upgrade for the ISS OGA to demonstrate oxygen generation technology intended for exploration missions beyond low Earth orbit. This paper discusses the status of the ISS OGA, the year in review for the flight system, and the progress of the AOGA demonstration build.

A. Oxygen Generation Assembly (OGA) Description

A simplified schematic of the OGA is shown in Figure 1. While the electrolysis cell stack is the core technology in OGA, there are several major orbital replacement units (ORUs) that support the cell stack operation: Water, Inlet Deionizing (DI) Bed, Hydrogen (H2), Pump, Nitrogen Purge, Oxygen Outlet, Hydrogen Sensor, Power Supply Module (PSM), and the Process Controller.

The Water ORU intakes water for electrolysis from the ISS potable water bus. It then flows into the Inlet DI Bed, which removes all iodine typically dosed in the feedwater to prevent microbial growth. The Inlet DI Bed also coalesces potential oxygen bubbles out of the water stream, which can then be detected by the gas sensors downstream. If gas is detected, the water is rejected to the wastewater bus in order to avoid adding it into the recirculation loop water, which mixes with gaseous hydrogen within the cell stack before the rotary separator-accumulator (RSA) removes the hydrogen. The wastewater stream has both a check valve and microbial check valve to protect OGA from backflow or contamination from the wastewater bus.

The Hydrogen ORU (H2 ORU) houses the cell stack, RSA, and all relevant sensors and effectors, containing all the hydrogen-wetted components within a vacuum dome. The dome is regularly vented to space to ensure a strong vacuum, and it acts as a leak barrier and combustion shield in the event of a failure. Within the cell stack, water is electrolyzed into oxygen and hydrogen in a cathode water feed process. Hydrogen is generated and mixed into the recirculating water stream, while oxygen forms on the opposite anode side of the membrane and travels through the Oxygen Outlet ORU and H2 Sensor ORU directly to the ISS cabin at just above ambient pressure. In the recirculation loop, the Rotary Separator Accumulator (RSA) separates the gaseous hydrogen generated from electrolysis of the

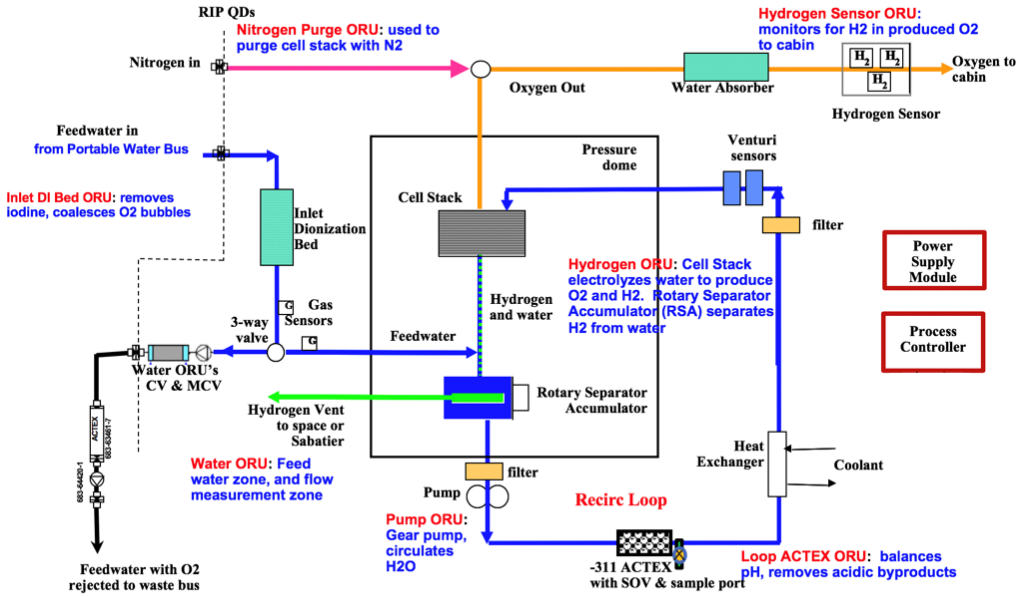


Figure 1: OGA simplified schematic. The primary functions of the ORUs are shown for the ISS OGA.

water. The hydrogen can be sent downstream to a carbon dioxide reduction process, such as the Sabatier unit, but it is currently being vented overboard, as no carbon dioxide reduction unit is installed on Station. The water from the RSA then exits the H2 ORU and is drawn into the Pump ORU, which houses an inlet filter and a positive displacement pump that provides motive force for the water recirculation loop. The recirculation water then goes through an Activated Carbon Ion Exchange (ACTEX) bed, which removes the fluoride and other contaminants generated within the cell stack during operation. It passes through another filter and a pair of venturi delta-pressure flow sensors. It then re-enters the stack for water make-up and further electrolysis. The recirculation water also serves to cool the cell stack, so it passes through a plate-and-fin type heat exchanger and removes the heat generated by the stack to the ISS water-based Internal Active Thermal Coolant System (IATCS). The IATCS coolant water heat is exchanged into the external ISS ammonia fluid and subsequently radiated out to space.

The Nitrogen Purge ORU contains a pressurized and isolated volume of nitrogen fed by the ISS nitrogen supply distribution line to the Oxygen Generation System (OGS) rack in which OGA resides. The nitrogen is used as a hazard control capability to mitigate combustion risks that can arise from mixing oxygen and hydrogen in failure events. It also is used to purge the oxygen-wetted parts of the system upon startup and shutdown. Since the oxygen stream is very humid, the Oxygen Outlet ORU contains a water absorber in the ORU that removes liquid water, and a heater in the ORU raises the stream temperature to further prevent condensate from reaching the H2 Sensor ORU, which can be damaged by liquid water. The H2 Sensor ORU contains three sensing dies that report the hydrogen concentration in the oxygen stream, acting as a rapid-detection method for quickly evolving cell stack failure scenarios and ensures the small, nominal concentration of H_2 in the oxygen output stream remains well below the Lower Explosive Limit (LEL) of 4% vol,/vol. H_2 in O_2. After flowing across the sensors, the oxygen then flows into the cabin.

The PSM supplies the power to the cell stack at a variable level from 10-46.9 amps for normal operations in Process mode, with Standby mode occurring at 1 amp. The system enters Standby mode for five minutes every 100 minutes to allow the dome to be vented to space. It then isolates the dome to enable system monitoring of external leakage into the sub-ambient dome through pressure rise. This cyclic Standby interval also provides an opportunity to monitor cell voltages at low current for out-of-family behavior that indicates membrane thinning. In Process mode at the full 46.9 amps, the OGA can produce 20.4 lb/day of oxygen, the equivalent of 10.88 crew at a base rate of 1.874 lb of O_2 per crew needed in a day; actual crew oxygen needs depends on individual variation and activity levels. The Process Controller ORU conducts all command, communication, and control actions between the ISS and the OGA. The Process Controller also can detect component and system exceedances of an array of fault limits and initiate OGA Fast Shutdowns to ensure safing of the system. Ground mission console personnel can perform controller data dumps to determine the specific faults that occurred prior to shutdowns, which enables the OGA team to troubleshoot failures and recover functionality of the system through hardware replacement or commanded software overrides.

All OGA ORUs are typically run to failure with three exceptions: the H2 Sensor ORU (201+ days, see Section E), the Inlet DI Bed (approximately 8 years based on total water throughput), and the ACTEX (527 days, see Section G).

B. Hydrogen Sensor Technology Demonstration (H2ST) Description

The Hydrogen Sensor Technology Demonstration (H2ST) aims to test alternative sensors to the legacy H2 Sensor ORU sensors [1], [2]. Given the 201-day life limit of the legacy sensors, when they must be removed and returned to ground for recalibration, they would be a significant spares burden for long-duration missions such as Mars transit. However, work is being done to extend the current 201-day life (see Section E). If the life of the legacy sensors cannot be extended, then a longer-life alternative is needed for exploration. H2ST contains four commercial-grade sensors that have been installed in-line with the OGA oxygen outlet since September 2022 and powered on aboard ISS since April 2022. They directly measure the same stream as the legacy sensors and are checked for drift every 90 days against a calibrated bottle of 1% H_2 in air. Two of the four sensors have failed (in July 2022 and January 2025), both of which are suspected due to a failure of the commercial electronics rather than a failure of the sensing element [3]. Two sensors remain active and are routinely checked for drift against the calibrated gas mix.

C. Advanced Oxygen Generation Assembly (AOGA) Description

The AOGA has been designed for exploration missions beyond low Earth orbit, and it will be implemented as a demonstration unit by upgrading the existing OGA hardware. Design and analysis work are detailed elsewhere alongside updates on critical reviews completed [4], [5], [6]. The mission scenario for AOGA is a 4-crew, 3-year mission in a small transit vehicle. A simplified schematic is shown in Figure 2, which highlights that the core features of OGA will remain unchanged. The major reconfiguration involved with AOGA is moving towards better maintainability with two separate vacuum domes for the RSA and the cell stack rather than the single H2 ORU. The two-dome scheme is named the Oxygen-Hydrogen Dome Assembly (OHDA). This change alone was determined to save an estimated 617 lb (280 kg) of spares associated with a 3-year mission by separating the RSA from the cell stack. While both components are meant to serve 5-year lifespans, the cell stack has been the primary mode of failure for the H2 ORU aboard ISS, and examinations of RSA internal components after 5 years of operation show no significant signs of degradation. This indicates the RSA dome could remain installed for longer periods and need fewer spares vs. the cell stack dome, significantly lowering overall spares mass needed. This change also includes mounting sensors externally wherever possible, enabling component-level maintenance rather than whole ORU replacements when a single component fails.

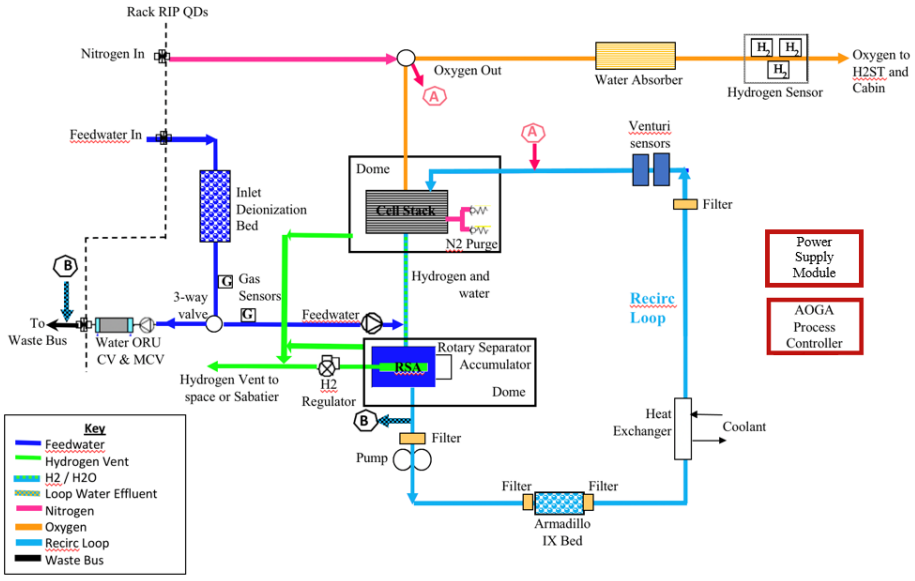


Figure 2: AOGA simplified schematic. The AOGA simplified schematic shows that core functions of the OGA have been retained, with the primary change shown here as the two separate domes; most other improvements have been made at the component level. The breakpoints marked A show where the nitrogen purge hose in the Dormancy Kit connect; the point marked B is where the flush hose connects to allow water collection as the loop is purged with nitrogen.

This change to dome configuration also significantly reduces the time it takes to replace an ORU, which will be critical in a transit vehicle such as the one for which AOGA is designed. This vehicle will not have a large-capacity cabin that acts as a buffer of oxygen such as that on the ISS, and thus the allowable downtime for AOGA is measured in hours against the days allowed for OGA downtime. Repairs to the AOGA need to be quick, easily accessible, and minimally invasive to the functioning components of the system.

In addition to reconfiguring the vacuum dome, the AOGA will improve upon OGA by upgrading the current ACTEX bed to the AOGA ReMediation Advanced DeIonization and Limited Life Optimization (ARMADILLO). The ACTEX was not designed for OGA and required multiple waivers to accommodate its retrofit into OGA. ACTEX has a high pressure drop, five times less mixed resin volume, and insufficient filter sizing and capacity; it does not meet AOGA loop maximum design pressure and uses single seals (as opposed to the required two independent seals); and the materials in ACTEX are incompatible with hydrogen. The ARMADILLO is designed specifically for the AOGA, and more details are available in Section G.

The AOGA Dormancy Kit's two hoses (Nitrogen Purge and Water Flush) and corresponding adapters enable the recirculation loop to be manually purged with nitrogen to both displace hydrogen out to space vacuum and flush loop water to an effluent collection bag for reclamation by the ISS Water Processor Assembly (WPA) [3]. The Dormancy Kit capability enables the removal of built-up contaminants in the recirculation loop and prepares the system for dormancy periods. This was a necessary upgrade to prepare for the AOGA installation, which will occur as a conversion from OGA to AOGA within the OGS rack by replacing the H2 Dome with the OHDA and other minor reconfigurations. The existing OGA dome will be stored in a dormant state as a contingency plan if AOGA experiences a critical failure and reversion to OGA is needed.

Many AOGA improvements will be made at the component level. Among the improvements is the cell stack subassembly, which was redesigned to mitigate membrane thinning and to improve operational life. The AOGA cell stack will use modern catalyst application techniques with chemically stabilized membranes and improved membrane supports. Sintered metal membrane supports with increased surface area are used in place of the expanded wire screens used in the OGA stack, which in combination with using non-stabilized membranes are suspected to contribute to the membrane thinning issue [6]. While obsolete system electronics (PSM and Process Controller) will need to be replaced in future missions, the ISS Program decided to use the existing OGA electronics for the AOGA demonstration.

II. ISS OGA Year-in-Review

The ISS OGA is operating normally in its location in the US Lab. It has been operating for 19 years and as of April 26, 2026, the OGA has produced a total of 34,342 lbm (15,610 kg) of oxygen and 4,292 lbm (1,951 kg) of hydrogen since initial activation in July 2007. The currently installed electrolysis cell stack has accumulated a total operating time of 586 days since installation on September 18, 2024 with no major anomalies as of May 4, 2026. During the period after the evacuation of Crew 11 on January 14, 2026, the OGA went into Standby to avoid creating an oxygen-enriched cabin aboard ISS during the low crew period. Upon arrival of Crew 12 on February 14, 2026, OGA returned to normal operating conditions without issue. Typical operations keep the cell stack between 30-60% of its operating range, with the current levels at 35% of maximum generation for a typical crew of 6-7 astronauts while one of the two Russian Elektron ISS units are also operating at 32 amps (3-crew equivalent O_2).

D. OGA Cell Stack Status

H2 ORU SN5 is currently installed and performing nominally. It was installed on September 18, 2024, after SN4 showed signs of membrane thinning in the cell stack [3], necessitating immediate removal to avoid combustion risks cascading to other OGA ORUs despite a heavy crew load at the time. By mid-2025, Cell 1 voltage in SN5 began to show out-of-family behavior during shutdowns, shown in Figure 3. Currently, in SN5 H2 ORU, there is no indication within cell voltage trended data of shortened cell stack lifespan, as Cell 1 behavior appears to be stable during operation. Polarization scans remain suspended for this legacy cell stack, and amperages are kept around 30-40% of the maximum levels to mitigate the potential life-limiting effects of high production rates with corresponding increased amperages, which contributes to shortened lifespans seen in more recently installed legacy cell stacks [3].

The currently installed cell stack is one of two remaining legacy stacks. H2 ORU SN1 is currently on orbit as a spare, and the next spare will be SN4, set for launch in mid-2026, which will contain the upgraded OGA cell stack. Section F details the cell stack changes for the unit installed in H2 ORU SN4.

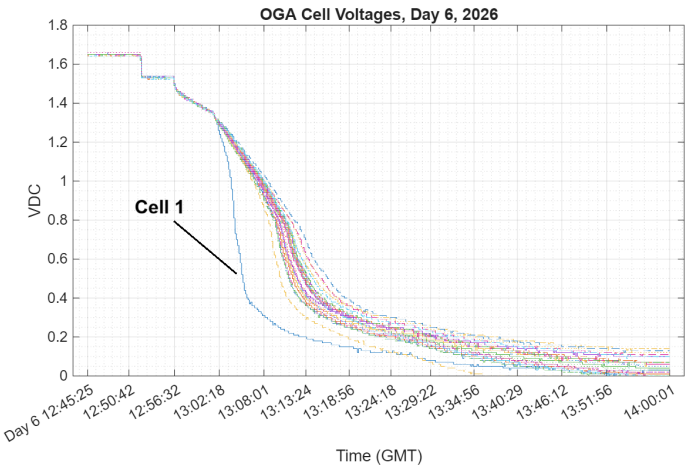


Figure 3: Cell voltage decay upon shutdown. SN5 H2 ORU Cell 1 voltage behavior is falling out of family, the first sign of potential membrane degradation.

E. H2 Sensor ORU Life Extension

The Hydrogen Sensor ORU is installed within the oxygen outlet line of the OGA, acting as a final check on oxygen quality before it flows into the cabin for the crew to breathe. It measures the trace amounts of hydrogen in the oxygen stream with three sensing dies and provides a means of detecting dangerous levels of hydrogen if a cell stack failure were to suddenly occur. It is replaced on a calibration life interval of every 201 days of cumulative operation time or upon failure of two sensing dies, whichever occurs first. Without the hydrogen sensors, a pinhole in the cell stack membrane allowing small but unacceptable amounts of hydrogen into the oxygen stream would be difficult to detect and react to in time if it occurred rapidly between OGA's Standby cycles, which happens every 100 minutes. Because the ORU is an essential hazard control, the hydrogen sensors are routinely removed and replaced with an on-orbit spare ORU. The sensing dies contain a palladium-chromium diode, with integral heaters to protect them from condensation [7]. After removal from the OGA, they are returned to the ground, recalibrated, and then refurbished for launch and future re-installation. Most ORUs have seen multiple installations in OGA over its nearly 20-year lifespan. A picture of the H2 Sensor ORU is shown in Figure 4.

It is one of the lowest mass ORUs yet highest consumables associated with the ISS OGA, with replacement initially required after 150 days, which was increased to 201 days in 2015 after examination of new ground test data. The reason for this limited life is that the hydrogen-sensing dies are known to drift over time in the humid oxygen stream of the OGA output, and there is no means of independently verifying their measurements while installed in OGA to check the magnitude of their drift, nor are there currently on-orbit means of recalibrating. Additionally, this drift causes the ORU to under-report hydrogen, which means that without a regular check against a known hydrogen gas mix, the measurements could miss a potential hydrogen release event if the drift is significant. At the time of the first extension, the mechanism behind this drift behavior was not well understood. The lifespan was limited to what the ground test data explicitly covered, which was only carried out for 201 days. These tests showed the drift rate was linear for that timespan, but the OGA team was unable to determine if the drift rate would remain linear after that time and could not rule out the possibility that it may get worse at some point after 201 days.

Work is ongoing to examine the lifetime of the sensors in order to further extend it, which saw significant progress this past year. Recently, ISS Program requested collection of as-received data on returned, specific H2 Sensor ORUs prior to recalibration in order to measure the drift of the sensors against a calibrated gas stream and to determine if any calibration life remains for each ORU by serial number. The resulting data showed that drift rates varied by ORU, with the currently installed SN 1018 showing very little drift over its 201-day operation from its prior installation. Additionally, the data shed light on the mechanism behind the drift, which is now theorized to be caused by oxidation on the Pd-Cr surface layer of the sensing die. This dulls the die's sensitivity to hydrogen over time, which correlates to the under-reporting seen in the sensor drift. The Pd-Cr oxidation mechanism can be used to characterize the physics of the sensor drift rate over time, and well-established oxidation theory supports the notion that the Pd-Cr oxidation rate will not increase in severity, and it is likely to reduce in magnitude as the sparsely-available oxidation sites react and are eliminated. This means that the sensor drift rate is most likely to decline over time and makes the linear drift rate assumption conservative.



Figure 4: Legacy H2 Sensor ORU.

Alongside the newly theorized drift mechanism, the as-received data showed that the drift for SN 1018 would not be significant enough to invalidate its calibration tolerances until 348 days under the assumption of a linear drift rate. Thus, it was approved to extend the life of SN 1018 up to 348 days while under increased monitoring, taking its planned replacement from December 2025 until May 2026. It was installed on May 29, 2025 and will see nearly a year of operation on orbit before

removal, over double the time of the original ORU lifespan. Since the data showed that drift rates vary by ORU, the current life extension is only approved for SN 1018. Future life extension plans will consider each ORU individually at this time. Once SN 1018 has been returned to the ground and analyzed to confirm the drift assumptions, life extension for the entire H2 Sensor ORU fleet will be examined.

F. H2 ORU SN4 Refurbishment

H2 ORU SN4 was uninstalled on orbit in September 2024 after detecting low voltages in the cell stack during Standby mode, indicating end-of-life membrane thinning conditions. The ISS Program desired a rapid turnaround for this ORU, and so it authorized reusing OGA parts with minimal or no reprocessing, within acceptable thresholds for safety considerations. This included keeping the RSA installed, which has a cumulative 2.9 years of run time. While a diaphragm internal to the RSA has a rating of 5 years, inspections of two returned RSA diaphragms from H2 ORU SN2 with 5.2 years and SN3 with 4.8 years runtime showed no significant signs of wear indicating end-of-life conditions. Thus, the RSA inside H2 ORU SN4 was considered to be in good condition with sufficient remaining operational life estimated to be around three years.

Many parts for the refurbishment were scavenged from H2 ORU SN2: the dome, hydrogen back-pressure regulator, pressure sensors, and some external tube assemblies. Other tube assemblies were pulled from SN3. Dual relief valves were newly installed, as was the cell stack from a new supplier. Reuse of other ORU parts was deemed acceptable because it did not impact the sparing posture of OGA due to the predicted AOGA installation in the near future, which will no longer have an H2 Dome ORU. The refurbished H2 Dome ORU SN4 is shown in Figure 5.

This ORU features the first upgraded OGA cell stack design. It is made by a new vendor, and the techniques for cell stack fabrication have been modernized over the legacy methods. This new design uses a different membrane material, new chemical stabilization materials, and a new catalyst casting technique. The membranes are made from stabilized Nafion, which should significantly reduce the fluoride emissions from the cell stack during electrolysis. Early test results confirm lower emissions in stacks using this membrane. Given their improved chemical stability, the new membranes should be more resistant to thinning, the most common failure mode for the legacy OGA stack [3]. The new cell stack is shown in Figure 6.

1. Low Oxygen Production in Upgraded OGA Cell Stacks

Low oxygen production rates were flagged as part of final testing for H2 ORU SN4, falling approximately 6% short of the required output of 20.4 lb/day oxygen at the maximum OGA current of 46.9 amps. Hydrogen was correspondingly low, and the two issues were treated as the same root cause—a loss of electrolysis capacity in some form. The test rig was thoroughly vetted and tested, and no source of error was discovered that could explain the production loss. At the cell stack vendor, an error was found in the flowrate calculations used to convert test measurements into units corresponding to the requirements; this error has since been corrected, and corrections have been retroactively applied to the test data on this cell stack. Once corrected, the vendor data also showed an underproduction in their tests, and further examination of data from other cell stacks made by this vendor revealed a 4-6% lower production rate than the legacy cell stack at the same amperage, including the AOGA cell stack.



Figure 5: Refurbished H2 ORU SN4 prepared for launch in early 2026.



Figure 6: An OGA cell stack.

Because the low production was not detected until after full integration into the H2 dome, the project would incur significant effort and schedule penalties to remove the cell stack for investigation, so initial efforts focused on the least invasive means of determining root cause(s). The investigations also prioritized potential safety and operational impacts to determine if a use-as-is scenario was infeasible from the onset.

Initial concerns pointed towards a loss of current via short or other undesired path within the dome or cell stack, as the production drop was equivalent to supplying the cell stack with 4 amps less current. This 4-amp offset was linear, as well, at various cell stack production rates, not only the maximum rate. The test rig verified that the input current and current exiting the ORU were equal, indicating no loss of current to the rig or dome. This eliminated concerns of electrical shock hazards. Individual cell voltages are monitored during electrolysis, and none were atypical or concerning during production rate testing. Measured cell voltages, cell resistance tests, and electrical models were used to determine that a short within the system was not supported by the data, as individual cells would display abnormal behavior during resistance checks and electrolysis if a short were present. Additionally, thermal modeling showed that if a short were present and draining 4 amps from across the cell stack, no meaningful thermal impacts would occur; the water in the recirculation loop was estimated to see a rise of 1 °F, easily tolerable by the cooling system. All potential hazards arising from a "loss" of 4 amps were shown to be well-controlled by existing OGA hazard controls and safety limits. The underproduction, then, was ruled a matter of operational concern only.

As stated previously, the underproduction is linear with respect to input current, and OGA typically operates at under 40% of its maximum capacity. Thus, there was little concern on the ability of the stack to provide adequate oxygen, though the power required is higher than legacy stacks. For crew handoffs, where up to 12 crew members can be on board, OGA typically operates at higher levels (around 60% of maximum production) with both Elektron units each operating at 32 amps (maximum), but it is still not typically commanded to maximum output. Analysis on production rates for the last decade of OGA operations showed that it has been commanded to full production for approximately 7 days cumulatively—0.2% of the past 10 years—and never for prolonged periods, even when crew loading was high. ISS has sufficient volume, as well, to allow for slight oxygen enrichment ahead of crew handoff periods to pre-load the necessary oxygen into the cabin and avoid needing high production rates. This ORU would likely remain in storage as a spare aboard ISS for years; SN5 is currently installed and early in its lifespan, and SN1 is the next spare to be installed for an additional 3+ years of runtime. This would allow further data collection on ground test articles before SN4 would be installed. Together, these arguments supported the use as-is case for the cell stack, and a waiver was granted to move forward without waiting for additional test results. H2 ORU preparations continued their course, and it is set to be launched in mid-2026.

The root cause of the underproduction has yet to be determined. With electrical shorting ruled out, investigations will focus on differences between the legacy cell stack and the upgraded design. A series of five single-cell testing configurations has been planned to independently test the catalyst change, the chemical stabilization materials, and the membrane material change, with a suite of 5 tests planned for 2026. The findings from these tests will apply to the AOGA cell stack, as well.

III. H2ST Status

H2ST has been installed on the OGA oxygen outlet since September 2022 and powered on aboard ISS since April 2022, achieving a continuous runtime of nearly 3.5 years to date. While it can be integrated into future oxygen generation technologies, it is its own dedicated unit and not considered a part of OGA or AOGA. A drift check is performed by crew every 90 days to monitor sensor behavior, as shown in Figure 7, and this same check is done for the Engineering Development Unit (EDU) on the ground testbed. The drift over time is plotted in Figure 8 for both the ground and flight units.

There have been no additional sensor failures in the past year; Sensor 3 failed in July 2022 after power-on but prior to installation, and Sensor 1 failed in January 2025 after almost 3 years of runtime [3]. Both sensors are suspected to have failed due to the non-aerospace grade electronics rather than a failure of the sensing elements themselves, as Sensor 3 failed before exposure to a high-oxygen stream, and Sensor 1 failure behavior mimics that of Sensor 3. Flight-grade electronics were not used in order to save cost and expedite development of H2ST, and it was not required as a technology demonstration unit. Plans are to return H2ST to the ground for teardown and examination after either a third sensor fails or ISS reaches end of life, at which point the failure mechanism can be confirmed.

Sensors 2 and 4 continue to operate on ISS, and all sensors remain operational in the EDU H2ST on the ground. The ISS sensors display stable drift behavior after an initial rise seen in the first year of operation. The latest drift check on March 13, 2026 measured 1.47% H_2 on Sensor 2 and 1.25% H_2 on Sensor 4 when exposed to 1 SLPM of a dry mixture of 1% H_2 in air. Unlike the legacy sensors, these are drifting in the conservative direction by over-reporting

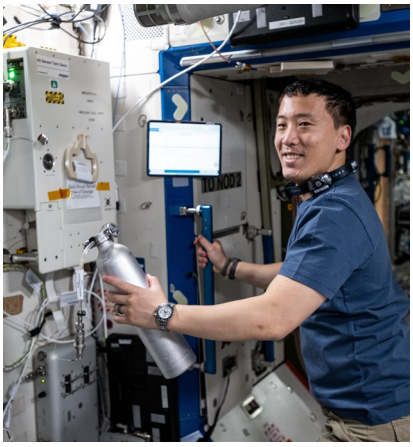


Figure 7: H2ST drift check on ISS.

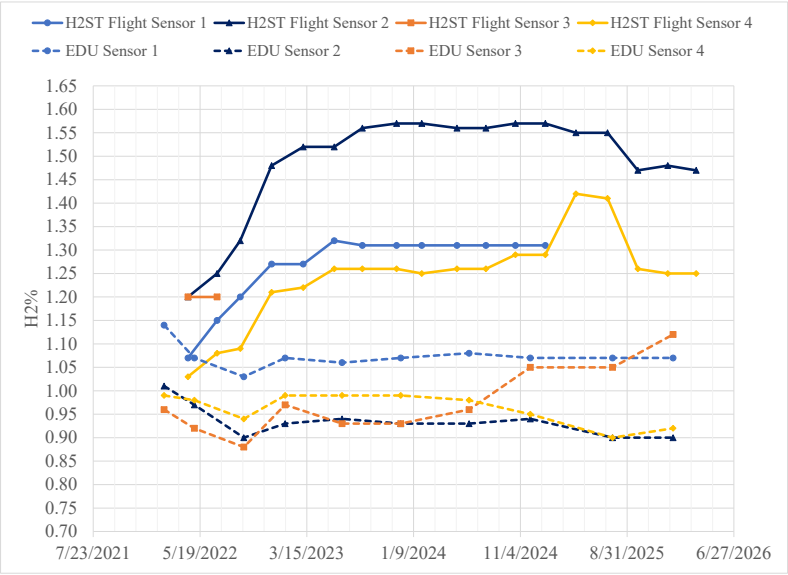


Figure 8: H2ST drift check data over time for flight and EDU sensors.

hydrogen. This is the preferred direction of drift since it will not mask potential hydrogen leaks, but significant drift in the upwards direction risks nuisance shutdowns, as well, so low magnitude drift is still highly desired.

Launched as a technology demonstration unit, H2ST is not tied to OGA automated shutdowns. However, it is considered a reliable point of reference given the consistent drift check data. Its presence was a factor in deciding to extend the legacy sensor lifespan despite 1:1 ground test data not explicitly showing safe continued operation. ISS data shows that H2ST and the H2 Sensor ORU generally agree in their measurements [3], and H2ST was considered a final check against the legacy sensors if significant drift were to occur beyond the normal 201 days of operation. Recently, H2ST's status was upgraded from technology demonstration to system, meaning it has demonstrated sufficient reliability, utility, and quailty to serve as a primary data source in the same way the H2 Sensor ORUs are used. This will enable continued use of the system as a key monitoring asset. As a system, future versions of H2ST will likely have aerospace-grade electronics in order to further extend its lifespan.

IV. AOGA Status

The build of the Advanced OGA has progressed towards flight deployment, with a delivery date in late 2026. This section reviews the major accomplishments of the past year.

G. ARMADILLO

The AOGA ReMediation Advanced DeIonization and Limited Life Optimization (ARMADILLO) will replace the ACTEX bed in the recirculation loop. The OGA was initially not launched with a contaminant removal system for the recirculation loop, but the fluoride generation from electrolysis resulted in acidifying the recirculation loop water. The resultant metallic corrosion products (cations) occupied active proton sites in the cell stack, and other byproducts of electrolysis created within the stack have been demonstrated over time to need removal to prevent buildup of corrosion products. The ACTEX is a mixed resin bed that was designed for other applications and retrofitted into OGA; as such, it has drawbacks such as high pressure drop of up to 16 psid and a non-optimized lifespan of less than 3 years [4]. Initial ACTEX installations lasted 675 days, with an assumed 10% life remaining in the beds upon removal based on modeling work. Returned ACTEX bed sampling completed in late 2024 showed that fluoride was near the ACTEX outlet alongside other signs of early breakthrough risks, and the lifespan was reduced from 675 days to 537 days to provide further buffer based on modeling [3]. This further motivates the need for a replacement designed specifically for AOGA.

The ARMADILLO has been in work since 2020 as a replacement for the ACTEX and has undergone several key analyses and reviews [4], [5]. It is optimized for a 3-year lifespan with 30% remaining buffer, with a significantly lower pressure drop at a maximum of 6.5 psid (10 psid lower than the ACTEX), hydrogen-compatible materials, and redundant seals as required for AOGA components. It consists of a cartridge, inlet hose, and outlet hose. The cartridge

contains a resin media, a new integral particulate depth filter, and quick disconnects to allow crew to remove and replace it with minimal effort.

While the ARMADILLO is larger than the ACTEX (15 inches long x 3.5 inch diameter vs. 10 inch length x 1.75 inch diameter), its appropriate bed sizing for a 3-year life and reduced pressure drop are significant improvements. The first two cartridges and first set of hoses are flight-ready in early 2026, having completed leak and proof pressure testing. Vibration testing was conducted to confirm no channeling of the resin media would occur, which would cause improper filtration. A nitrogen bubble to allow for thermal expansion was inserted, as it is for the ACTEX, in preparation for launch.

ARMADILLO is slated to launch in mid-2026 and install in late 2026 when the current ACTEX is due for replacement. The ARMADILLO is considered a piece of AOGA hardware but is also compatible with OGA, as shown in Figure 9, and so it will be the first AOGA upgrade installed into the existing OGA configuration. The first cartridge will be installed for a year and then returned to ground for analysis to confirm breakthrough estimates; all cartridges afterwards will remain installed for their full 3-year lifespan unless indicated otherwise by the analysis.

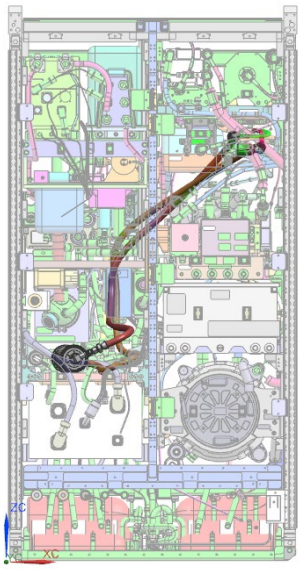


Figure 9: CAD model of ARMADILLO installed in OGA.

H. Oxygen-Hydrogen Dome Assembly

1. AOGA Cell Stack

The AOGA cell stack has been delivered for integration into its dome after undergoing a full round of acceptance testing. Design changes and completed testing for the AOGA cell stack are reviewed in detail elsewhere [3], [4], [5], [6]. In summary, the design incorporates the improvements applied to the upgraded OGA cell stack, such as modernized fabrication methods, a new catalyst, and stabilized membranes, in addition to other changes. An edge seal on the AOGA stack prevents water from migrating out of the stack and into the vacuum dome, which is considered a significant loss of water and the reason periodic depressurization commands are needed to maintain vacuum. The AOGA stack also replaces the expanded wire screen membrane supports with a sintered metal support, increasing membrane contact surface area and eliminating a potential contributor to premature membrane thinning [4], [8].

Processed by the vendor in the same timeframe as the cell stack for H2 ORU SN4, it was later discovered that the AOGA stack also produces less oxygen than expected after applying correction factors, around 4% lower than legacy cell stacks at the same current levels. Much of the same rationale and logic applies to the AOGA stack that applies to the OGA stack, and the suite of five single-cell tests moving forward to determine possible root cause(s) will also cover the AOGA. Similar to the OGA stack, this oxygen under-production is not believed to be due to an electrical short, “lost” current, or any other mechanism that will impact safe operation of the unit. The cell stack integration into its dome was recently completed, and the OHDA integration is still planned for mid-2026.

2. Rotary Separator-Accumulator

The RSA design is common between OGA and AOGA given the good performance seen in the OGA flight units. The AOGA RSA’s external fittings geometry and end capture feature to retain the RSA within the RSA Dome Assembly differ from the OGA RSA configuration. A picture of the AOGA RSA is shown in Figure 10. A new RSA was recently furnished as part of the AOGA upgrades, and it is integrated into its own independent dome as part of the ODHA. The RSA underwent leak and proof testing in 2025 and 2026 and experienced an air carryover leak into the water outlet. Disassembly showed that the check valve in the water outlet was unseated but not damaged after the test, and the issue was corrected once the valve was reseated. Further review of the RSA pressure zone definitions, test setup, and pressure test sequences led to the conclusion that an unintentional reverse overpressurization caused the check valve to unseat itself, and the test pressures the check valve experienced was up to 50% higher than the corresponding test pressures used to qualify the RSA for the OGA program. The decision was made to return to the legacy OGA test pressure for RSA leak test qualifications, which was feasible due to the similarity in conditions between OGA and

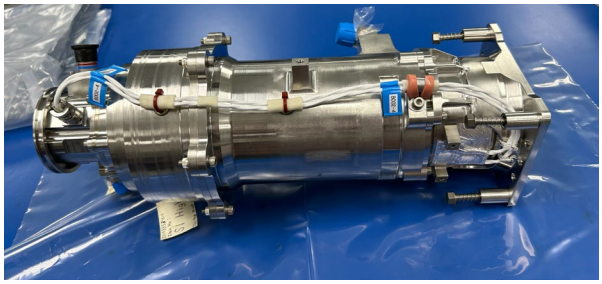


Figure 10: The AOGA RSA.

AOGA. Upon reassembly of the RSA to reseat the check valve and a after lowering test pressure for leak testing, the AOGA unit passed leak and proof testing.

Once the leak testing was completed, rust in the test setup fittings was discovered on the high pressure sensor port and the hydrogen outlet port, both of which are non-water-flowing connections on the RSA and neither of which are inlets. A DI bath of the spare fittings revealed that a single batch of a single part number of the RSA fight fittings were not properly passivated by the vendor. The DI bath test also showed that the fittings from the other ports on the RSA were correctly passivated, so the water-flowing and inlet parts of the RSA were not exposed to contamination. A flush of the RSA confirmed that it meets cleanliness requirements with no residual rust detected in the samples. Once cleanliness was confirmed, the RSA was integrated into its dome in spring 2026.

3. Other Components

AOGA originally engaged a new vendor for the pressure transducers, aiming to boost the supply chain of flight-rated components for human spaceflight. However, the pressure sensors as delivered failed acceptance testing, and the team was unable to come to a resolution that allowed continued use of the new transducers. In order to save schedule and costs, the AOGA pivoted to using legacy sensors off the shelf from OGA spares. The functional requirements were identical, though interfaces were not. This required designing and manufacturing new manifolds and adapters to accommodate the legacy sensor interfaces. Additionally, the legacy sensors were previously inside the vacuum dome and thus not considered fracture critical; in AOGA, they will be outside of the dome and thus represent a potential hydrogen leak path to the cabin if a fracture were to occur. Fracture criticality reviews confirmed that the sensors remain non-fracture critical given their sealed internal compartments that would contain any potential leak and cause a loss of signal if hydrogen were introduced, thus triggering a shutdown and alerting personnel of the leak.

Flight solenoid valves, check valves, and backpressure regulators have all passed acceptance testing and are being installed in the OHDA. Qualification unit testing is ongoing for these, as build of the flight units were prioritized first in order to accommodate schedule. The backpressure regulator (BPR) previously saw a failure at 800,000 cycles, after 700,000 successful cycles [3], which led to an inspection that showed test rig cleanliness led to particulate contamination of the qualification unit. This was believed to not be an issue for the flight unit, so it was approved for the qualification unit to continue testing after resolving the contamination. The unit was disassembled, cleaned, and reassembled in order to resume cycle testing. At 900,000 cycles in February 2025, the same qualification unit was tested for forward leakage and failed the test by a significant margin. It had passed this same test after reassembly at 800,000 cycles prior to restarting test. The primary theory is that the contamination caused damage to the seat, and reassembly exacerbated the issues to the point of regulator failure. It was confirmed that the failure mechanism was unlikely to be a design flaw, particularly in light of the fact that the contamination found was foreign material rather than anything that could be generated internally. Since the regulator could no longer be used, the qualification program was closed down for the BPR.

To compensate for the inability to cycle the qualification BPR to its full 1.2 million requirement, a waiver based on similarity to the OGA BPR is being worked to provide rationale for acceptable use. The BPR is identical between OGA and AOGA aside from certain external-only features on the AOGA version added to address assembly difficulties, and given this, the OGA BPR data is acceptable to use for qualification purposes. It was qualified to 1.0 million cycles, which was the expected cycles for a 5-year life within OGA with a lifespan factor 4 (i.e., only 250,000 cycles were expected). For AOGA, the cycle count was determined to be 1.2 million for a 5-year life with a lifespan factor of 4 (expected 300,000 cycles). The additional cycles are a consequence of the two-dome configuration of AOGA and its impact on RSA fills. The primary driver of a BPR cycle is an RSA fill, where water is replenished to replace what was consumed by electrolysis. With AOGA, the connection of the feedwater into the recirculation loop is located outside of the dome, meaning there is more tubing and thus more pressure drop between the feedwater and the RSA when a fill operation is needed. Additionally, the feedwater check valve (CV) has a higher pressure drop on AOGA than its corresponding OGA component. These increased pressure drops reduce the flowrate of water into the RSA and will lead to multiple fill cycles for a single replenishment event under certain conditions. Production rate also affects the number of fill cycles needed, and thus the number of BPR cycles, as higher production will require more refill cycles. The expected lifetime cycles assume a constant 100% production rate in order to be conservative, when in reality the AOGA will be operated in the same 30-60% capacity window as OGA, with the most likely rate to be ~38% of maximum capacity. When taking into account the differences in feedwater pressure drop that affect the BPR cycles, analysis of all conditions expected within normal operations showed that at a constant 38% production rate, the BPR has a lifespan factor of 9.1 for a 5-year life based on a qualification at 1.0 million cycles. At a 100% production rate, this factor drops to 3.2, which is below the requirement of 4 and will require a waiver to address.

The qualification unit for the check valve also experienced test issues, with higher differential pressures measured in post-vibration tests than pre-vibration tests that exceed the requirement of 4 psid. Again, the flight unit passed these

tests, and the leading candidate for root cause of the qualification unit failure is cold flow of the plastics in the sealing seat after test rig cleanliness was cleared as a potential cause. Additionally, it was discovered that in the flow-down of requirements to the vendor, an error was made stating that the qualification unit was to be vibration tested at a magnitude 6 decibels higher than the flight unit, when the true requirement is 3 decibels higher. This is considered a potential contributor. As the cold flow issue could affect the flight CV, plans are being developed to perform health checks on the flight valve, and work is ongoing to evaluate potential flight impacts. The flight CV has been assembled into a manifold, so testing and inspection is not straightforward at this point and may require some level of disassembly in order to closely examine the unit. Further evaluation of the qualification unit is also in work.

Flexible hoses for installation in the OHDA were discovered to have internal corrosion and contamination upon receiving inspection from the vendor. Investigations by the vendor and AOGA team uncovered insufficient passivation and contamination control. The vendor and AOGA team were able to agree on a remediation plan, and the vendor completed remediation; the hoses passed inspections by early 2026. The hoses are now delivered and undergoing installation. The two domes on the OHDA for the RSA and cell stack have both been fully assembled, and OHDA completion is on track to finish in summer 2026. Separately, the Dormancy Kit, as detailed in [3], has completed build and is ready to launch in 2026.

V. Conclusions

The ISS OGA has provided nearly two decades of oxygen to the crew living aboard. AOGA applies the valuable lessons learned from this extensive operating period, and sustaining work continues to ensure OGA can reliably provide crew oxygen needs. H2ST continues to demonstrate the potential of commercial sensors to reduce sparing and resupply needs with nearly 4 years of continuous runtime. Improvements to OGA consumables such as the H2 Sensor ORU life extension and ARMADILLO upgrade have made significant progress in the past year. AOGA is nearing completion, with a delivery date expected in late 2026. The goal is to install AOGA in 2027 and run for at least 3 years or until ISS sundowns.

VI. Acknowledgments

The OGA team would like to thank the ISS program for funding the sustaining OGA work and AOGA upgrades. We would also like to acknowledge the flight controllers, safety personnel, technicians, test engineers, ISS crew, and everyone else who supported OGA throughout the years and who continue to support OGA’s operation.

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