Environmental Control and Life Support Systems

Sustaining Life Offworld – from the International Space Station to the Moon, Mars, and Beyond

Earth's atmosphere and planetary resources provide life-sustaining air, water, and conditions that support life, but the same natural, self-perpetuating bounty isn't available to explorers pursuing deep-space missions to distant moons or planets – and resupply shipments from Earth are neither practical nor cost-effective.

NASA's Marshall Space Flight Center in Huntsville, Alabama, with contributions by other NASA centers, is responsible for the design, construction, and testing of regenerative life support hardware for the International Space Station, including cutting-edge air and water reclamation and recycling systems which have made possible two decades of continuous crew operations on the orbiting science platform.

Now Marshall teams and their commercial partners are refining and enhancing these advanced Environmental Control and Life Support Systems (ECLSS) to serve new Artemis-era lunar missions and future exploration of Mars – the first extended human journeys of discovery into the deep solar system.

Providing Clean Water and Air to ISS Crews

The three largest ECLSS systems are the Water Recovery System, the Air Revitalization System, and the Oxygen Generation System. The first rack of air revitalization equipment was deployed in 2001 and has been active aboard the station ever since. The rest of the regenerative ECLSS racks were added in 2008, and the entire system has been kept in constant, synchronized use on station since then.

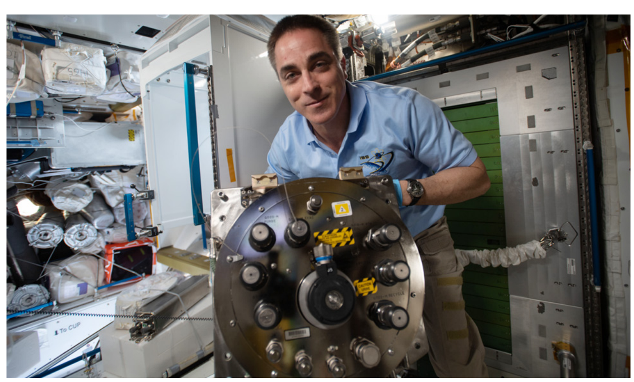
The systems were jointly designed and tested by Marshall and industry partners including Boeing, Lockheed Martin, Honeywell, Inc., and the former UTC Aerospace Systems, which became Collins Aerospace when UTC and Rockwell-Collins merged in 2018, and in 2020 merged with Raytheon to become a division of Raytheon Technologies Co. The hardware is packed into four refrigerator-sized racks in the station's U.S. Tranquility module. A second Air Revitalization System is housed in the U.S. Destiny Laboratory.

The Job of ECLSS

The space station's ECLSS system performs several functions:

- Provides oxygen for breathing
- Provides potable water for consumption, food preparation and hygiene
- Purifies recycled water from multiple sources back to potable water
- Removes carbon dioxide from the cabin air
- Recovers and recycles oxygen from carbon dioxide to resupply the crew
- Filters particulates and microorganisms from the cabin air and maintains cabin pressure, temperature, and humidity levels
- Removes volatile organic trace gases, such as ethanol, that are colorless, odorless, and can build up over time
- Distributes cabin air between each station module

The Water Recovery System provides clean water by reclaiming cabin humidity condensate – including crew perspiration and respiration moisture – and wastewater including water reclaimed from crew members' urine. Each astronaut needs about a gallon of water per day for consumption, food preparations and hygiene, including teethbrushing and shaving, but recovered water must meet stringent purity standards before it can be used to support crew, extravehicular and payload activities.



Expedition 63 Commander Chris Cassidy installs the Urine Processing Assembly's upgraded distillation assembly on the station in September 2020. (NASA)

ECLSS Stats

- The Oxygen Generator Assembly produced approximately 1,664 pounds of oxygen annually between 2008-2021. One person needs about 1.83 pounds of oxygen per day.
- The ECLSS system recovered some 6,600 gallons of water – more than 55,000 pounds – from crew urine between 2008-2021. That's enough to fill a 5-foot-by-15-foot pool.
- The Water Processing Assembly purified more than 13,414 gallons of water between 2008-2021 – or the equivalent of filling up 319 standard bathtubs to the rim.
- Since activation of the Trace Contaminant Control subassembly in 2001, it has processed the space station's complete cabin volume some 2,978 times. That cabin volume is about 31,780 feet cubed – which means the system has scrubbed the equivalent air inside 5,915 ordinary suburban homes over the past 20 years.
- The Carbon Dioxide Removal Assembly has processed 6,615 complete station cabin volumes between 2001-2021 – or the equivalent of 13,139 ordinary houses.
- Approximately 85% of the water in crew urine can be recovered and purified for reuse by the station crew. The technologies behind such leaps in water purification and wastewater recycling have been adapted on Earth to help provide water for communities in arid or remote locations or areas devastated by natural disasters.

Water reclaimed by the urine processor is combined with other wastewater and delivered to the water processor for treatment, where it goes through a series of multifiltration beds, catalytic oxidization, and ion exchange resins for purification. Water purity is stringently checked by electrical conductivity sensors in the systems; any water deemed unacceptable for use is reprocessed. Clean water is sent to a storage tank, ready for crew use. Currently, the Water Recovery System is capable of recovering and recycling more than 90% of the water on station, dramatically slashing resupply requirements from Earth.

The Air Revitalization System is dedicated to cleaning the circulating air in the space station's living quarters, laboratories, and connecting corridors. The process scrubs the air of carbon dioxide, exhaled by the crew during normal respiration, as well as trace contaminants produced by electronics, plastics and human off-gassing. Carbon dioxide is removed using molecular sieves, materials which selectively trap and separate gases based on their molecular size. Trace contaminants are removed by flowing cabin air through three separate units: an activated charcoal bed, a catalytic oxidizer and a lithium hydroxide bed. Additional carbon dioxide removal and trace contaminant control capability is provided by NASA's Russian partners on the station.

The Oxygen Generation System, which produces breathable oxygen for the crew, consists of the Oxygen Generation Assembly (OGA) and the Carbon Dioxide Reduction Assembly (CDRA). The OGA is composed of cell stacks, which electrolyze – or break apart – water provided by the Water Recovery System, capturing oxygen and hydrogen as byproducts. The

NASA astronaut Kjell Lindgren brews a cup of coffee using the station's Capillary Beverage Cup. ECLSS technology on station helps recycle the fundamental necessities for living and working in space – including water to make coffee. (NASA)

European Space Agency astronaut Samanta Cristoforetti exercises on the space station's Cycle Ergometer with Vibration Isolation and Stabilization (CEVIS). As astronauts sweat and generate carbon dioxide, the ECLSS system recycles both into usable water and breathable air. (NASA)

oxygen is delivered to the cabin atmosphere for reuse. The hydrogen is vented into space or fed to the CDRA, which combines it with carbon dioxide exhaled by the crew in a Sabatier reactor.

Based on technology developed by Nobel prize-winning French chemist Paul Sabatier, the reactor converts the carbon dioxide and hydrogen into methane – which is vented into space – and water to be repurposed for crew use once it has been recycled. NASA's Russian space station counterparts maintain a second oxygen generator as well, further reducing requirements for oxygen supplies to be ferried up from Earth.

Together, these complex, innovative systems create a nearly closed loop for the reclamation and recycling of water, oxygen, and carbon dioxide.

Taking ECLSS Beyond Earth Orbit

Marshall engineers and their partners across NASA and industry are constantly developing ways to improve ECLSS systems, making the assemblies more reliable and easier to maintain, working to refine system reliability, and ensuring future deep space missions have the right complement of spare parts to keep those systems at peak function.

In 2020, for example, a newly upgraded distillation assembly for the urine processor was delivered by Marshall and flown to the station. A significant upgrade to the assembly addresses a persistent issue with drive belt stretching and slipping, particularly when exposed to condensed steam. ECLSS engineers partnered with Marshall's Materials and Processes Laboratory to explore 3D printing options for a more durable belt drive pulley to accept a new toothed belt design. Several other component upgrades were addressed, effectively increasing hardware runtime from approximately 1,400 hours to more than 4,300 hours without parts replacement. Similar refinements are continuously being developed for assemblies across the ECLSS system.

The space station also offers a proving ground to develop next-generation life support hardware, maximizing water and oxygen recycling in an effort to develop still more robust systems capable of further reducing resupply needs – and demonstrating technologies that will help future lunar and planetary explorers harvest breathable air and potable water in situ. These advances will enable humans to travel farther into space than ever before, and live and work successfully on worlds other than our own.

Such technologies are already undergoing testing on the station. A new Brine Processor Assembly, enabling the reclamation of even more recyclable water from crew urine using a sophisticated filtering bladder, was integrated into the ECLSS system in early 2021. Developed by Paragon Space Development Corp. of Tucson, Arizona, in cooperation with Marshall and NASA's Johnson Space Center in Houston, the new technology could recover up to 98% of usable water. Marshall also delivered to the station a new air filtration technology – the 4-Bed Carbon Dioxide Scrubber – which uses state-of-the-art commercial adsorbent materials to more efficiently filter carbon dioxide out of the station's air. The new scrubber unit, to be tested on orbit for up to four years, offers better component stability and lifespan and will introduce a first-of-its-kind, magnetic bearing air blower to push air through its adsorption beds.

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