

## *Closing the Loop: Recycling Water and Air in Space*

### **9–12 National Science Standards:**

Life Science: Matter, Energy, and Organization in Living Systems

Physical Science: Chemical Reactions

Science and Technology: Environmental Quality

Science as Inquiry: Abilities Necessary to do Scientific Inquiry

### **Summary:**

This on-orbit video, along with the accompanying Educator Insights, can supplement any lesson relating to recycling water and air. NASA's current space missions include 2 week space shuttle flights and 6 month visits to the International Space Station (ISS), which has been manned continuously since 2000. Future missions to the ISS, the Moon, and Mars, will be aboard the Crew Exploration Vehicle, or CEV. Until an orbiting grocery store is opened, recycling of water and air will be crucial for crew survival. Supplementary information pages provide reference diagrams, as well as further insights.

### **Featured Imagery Component:**

A 6:14 minute on-orbit video of Astronaut Bill McArthur (Expedition 12) explains how water and air are recycled aboard the International Space Station. To watch the video visit this page: [http://www.nasa.gov/audience/foreducators/9-12/features/F\\_Recycling\\_on\\_the\\_ISS.html](http://www.nasa.gov/audience/foreducators/9-12/features/F_Recycling_on_the_ISS.html).

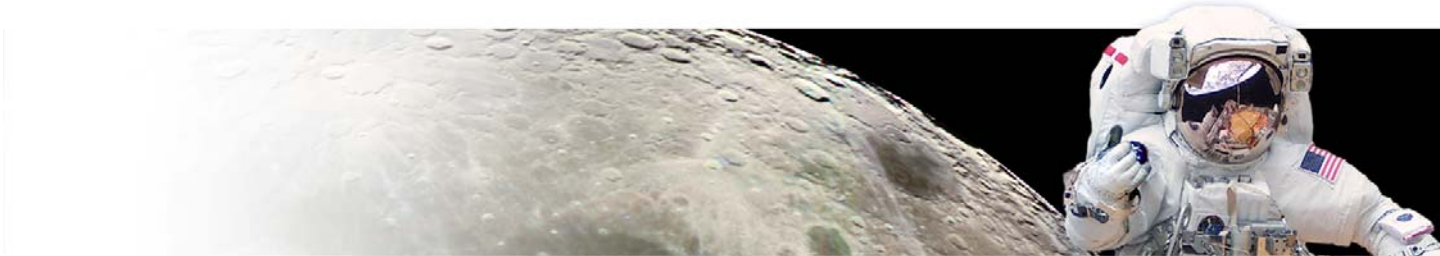
### *Post-Video Discussion:*

- 1 What are the challenges of supplying astronauts with air and water in space?
- 2 Is the process of oxygen production/carbon dioxide removal the same on Earth and in space?
- 3 How do space shuttle fuel cells contribute to water production?
- 4 How is oxygen delivered to astronauts onboard the space shuttle and the International Space Station (ISS)? What currently happens to hydrogen produced by the electrolysis of water aboard the ISS? How can that hydrogen be better utilized in the future?
- 5 How is carbon dioxide "scrubbed" from the cabin air?
- 6 What purpose does nitrogen serve aboard the ISS?
- 7 How is water currently supplied to the ISS crews? How can this be done more efficiently in the future?
- 8 How is water purified aboard the ISS?
- 9 How will NASA's future spacecraft design deal with carbon dioxide and moisture removal?
- 10 How will future astronauts contend with the excessive carbon dioxide environment on Mars?

[Click here to see an "out of this world" oxygen/carbon dioxide cycle model that does not involve plants.](#)

[This diagram can be made into an overhead transparency for classroom use.](#)

[www.nasa.gov](http://www.nasa.gov)

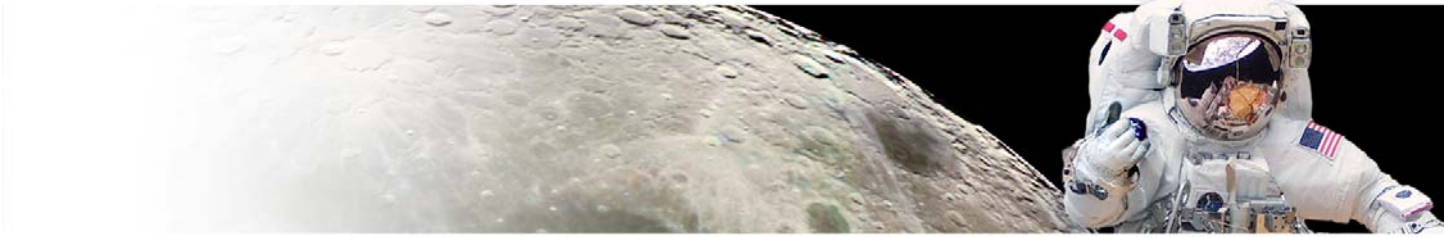


## Background:

1. It would be impractical, in terms of volume and cost, to completely stock the International Space Station (ISS) with oxygen or water for long periods of time. Without a grocery store in space, NASA scientists and engineers have developed innovative solutions to meet astronauts' basic requirements for life. The human body is two-thirds water. It has been estimated that nearly an octillion ( $10^{27}$ ) water molecules flow through our bodies daily. It is therefore necessary for humans to consume a sufficient amount of water, as well as oxygen and food, on a daily basis in order to sustain life. Without water, the average person lives approximately three days. Without air, permanent brain damage can occur within three minutes. Scientists have determined how much water, air, and food a person needs per day per person for life on Earth. Similarly, space scientists know what is needed to sustain life in space. [\(return\)](#)
2. On Earth, we often take for granted the role that plants play in the oxygen production/carbon dioxide removal process. In space, other methods are used to remove these by-products and to *reclaim* water and oxygen. Reclaiming means to produce a new supply by combining or breaking down by-products of other processes. NASA's life support system engineers refer to the recycling of water and air as "closing the loop." The by-products of human metabolism, carbon dioxide (lethal in high concentrations) and water vapor, present a challenge in terms of removing these from a spacecraft cabin atmosphere (a sealed environment). [\(return\)](#)

## Air:

3. On the space shuttle, fuel cells combine hydrogen and oxygen to produce electricity. A fuel cell uses a chemical reaction to provide an external voltage, as does a battery, but differs from a battery in that the fuel is continually supplied in the form of hydrogen and oxygen gas. A by-product of this reaction ( $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{electricity}$ ) is water, which can be used in a future *oxygen generator system* to produce oxygen for breathing. Fuel cells can produce electrical energy more safely and efficiently than just burning the hydrogen, to produce heat to drive a generator. The water supply is the limiting factor on the ISS when the space shuttle cannot routinely provide water from its fuel cells. With only two crew members, it is manageable to "truck" water tanks in the Russian *Progress* resupply ship. [\(return\)](#)
4. The space shuttle dumps  $\text{O}_2$  from the cryogenic tank for crew use. The oxygen generator system that will soon be on board the ISS will make use of electrolysis (the reverse process of fuel cell reaction) by combining water and electricity to reclaim hydrogen and oxygen ( $2\text{H}_2\text{O} + \text{electricity} \rightarrow 2\text{H}_2 + \text{O}_2$ ). It is hazardous to store hydrogen on a spacecraft because of its flammability, so the hydrogen is vented overboard. In the future, hydrogen can be combined with crew exhaled carbon dioxide to reclaim water ( $4\text{H}_2 + \text{CO}_2 \rightarrow 2\text{H}_2\text{O} + \text{CH}_4$ ). This process is called the *Sabatier (sah bah tee ay) Reaction*. Methane, a natural gas, produced by the Sabatier Reaction is vented overboard into space. The Sabatier Reaction drives what is known as the  $\text{CO}_2$  reduction assembly because carbon dioxide is reduced in the chemical process of reduction-oxidation. The Sabatier reaction will be a crucial requirement for future long-duration space flight. Future technologies may be able to use methane for propulsion fuel. The reclaimed water is passed through the *water recovery system* and can be filtered into drinking water or put into the oxygen generator system to reclaim more oxygen. [\(return\)](#)
5. The *carbon dioxide removal system (CDRA)* on the ISS works to remove  $\text{CO}_2$  from the cabin air and dump it overboard, allowing for an environmentally safe crew cabin. In the future, collected and concentrated  $\text{CO}_2$  will feed the Sabatier Reaction. Carbon dioxide removal, or  $\text{CO}_2$  scrubbing, involves the use of heterogeneous granules of a synthetic rock called *zeolite* (also known as a molecular sieve). When the cabin fans blow air through the bed of rocks,  $\text{CO}_2$  and water stick to the zeolite, while everything else passes through. The zeolite is regenerated by heating it and exposing it to the vacuum of space. A similar process can be used in hospitals to provide portable oxygen for patients. In this case, a molecular sieve (zeolite) is used as an *oxygen concentrator*. The zeolite filters nitrogen from the air, providing high concentration oxygen to the patient. This process is much safer than having a tank of high pressure oxygen next to one's bed. [\(return\)](#)



6. Nitrogen, a gas that makes up 78 percent of breathable air on Earth, is inert and can therefore be safely stored onboard spacecraft. Despite its high concentration within ambient air, nitrogen serves no particular physiological benefit to humans and only serves to keep the Space Station pressure at 1 atmosphere (14.7 psia). Prior to extra vehicular activities (EVA or space walking), astronauts purge nitrogen from their blood supply to prevent decompression sickness (“the bends”). It is neither important nor practical to reclaim this nitrogen. ([return](#))

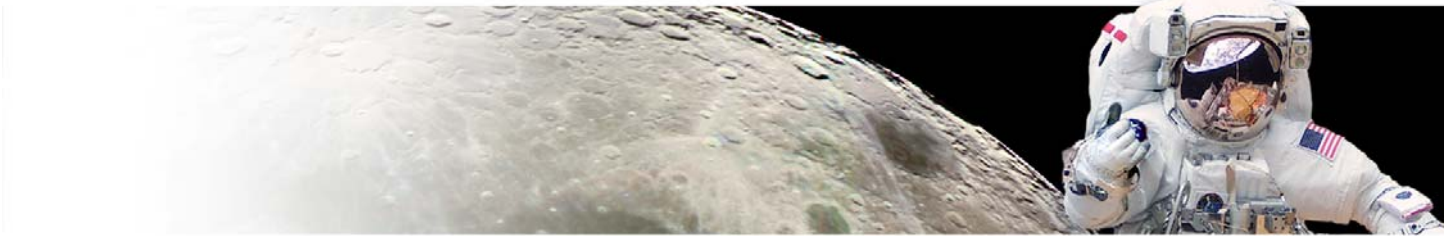
#### **Water:**

7. Reclaiming water is a more complex process than recycling air. Because water on the space shuttle is produced by fuel cells and then stored, water recycling is not an issue. On the ISS, however, there are no fuel cells. Therefore, water must be supplied by either the space shuttle or the Russian Progress vehicle. NASA’s life support engineers are working to develop a water recovery system that makes use of the Sabatier Reaction. Doing so would free up volume and weight on board the space shuttle and Progress to allow for transport of other equipment. ([return](#))
8. The ISS uses both physical and chemical processes to remove contaminants, as well as filtration and temperature sterilization to ensure the water is safe to drink. Additionally, water is checked often to ensure it meets NASA’s water quality requirements and is monitored closely for bacteria, pollutants, and proper pH (6.0-8.5). NASA’s *Exploration Life Support (ELS) Lab* at Johnson Space Center in Houston, Texas is currently developing a biological treatment system that will purify water on future space missions. The microorganisms used in this process destroy contaminants in the water. ([return](#))

#### **Moon and Mars:**

9. The first *Crew Exploration Vehicle (CEV)* missions will be about 18 days long. For this short duration, regenerative systems are not cost effective. The CEV is considering using a device called a *pressure swing bed*, which would collect the CO<sub>2</sub> and humidity condensate and dump it overboard. In a pressure swing bed, carbon dioxide and water are chemically absorbed onto a bed of beads that have an amine (an organic derivative of ammonia) chemical impregnated on them. Every 5–10 minutes the bed is exposed to the vacuum of space where the water and carbon dioxide are boiled off at the reduced pressure. Potable (drinkable) water will be stored in tanks and urine will be vented overboard. Regenerative systems will be cost effective for lunar outposts or Mars transit vehicles where missions may last 6 months to 3 years. ([return](#))
10. Excessive lunar dust brought into the Crew Exploration Vehicle (CEV) capsule during future missions to the Moon could contaminate the air and also compromise the operation of the CO<sub>2</sub> removal assembly. Since Mars has a high concentration of carbon dioxide in its atmosphere (95 percent), there will already be an abundant supply for both Sabatier water reclamation and for photosynthesis. While it is not cost effective to grow enough plants aboard the ISS to photosynthetically reclaim oxygen (the greatest costs are related to lighting and air conditioning), plants will be crucial to the survival of future Mars explorers. ([return](#))

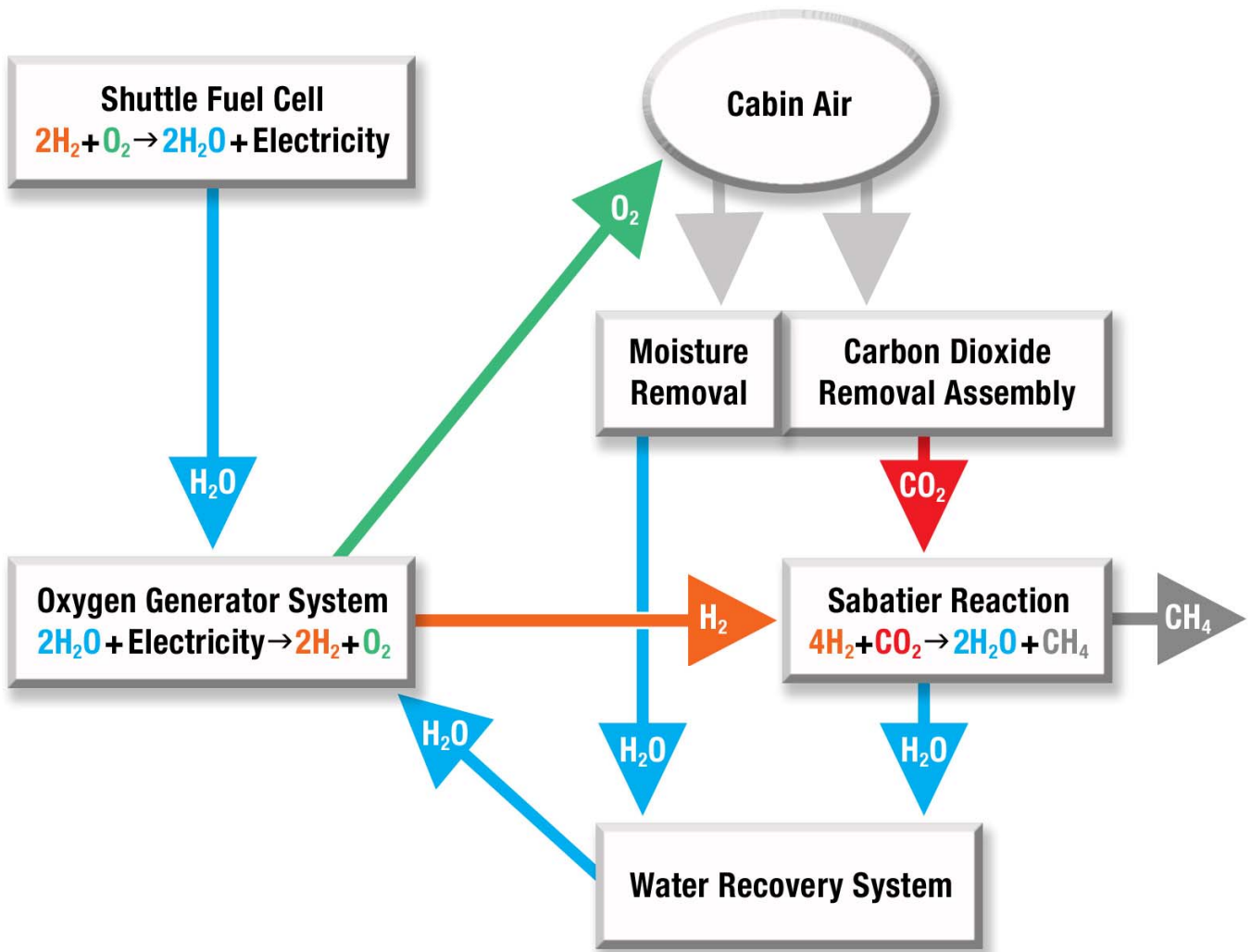
[www.nasa.gov](http://www.nasa.gov)

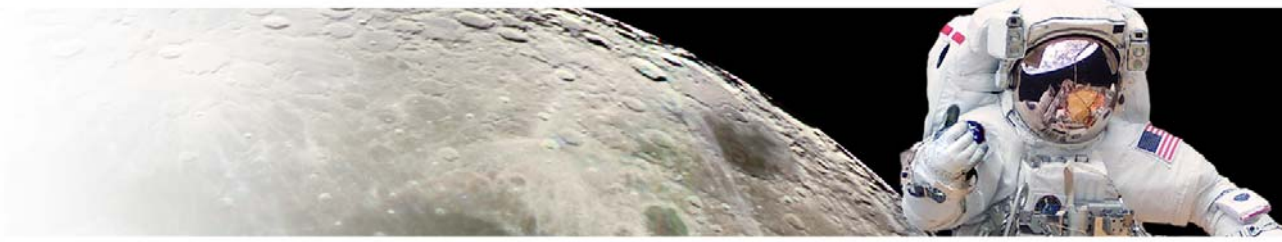


## Closing the Loop: Recycling Water and Air in Space

### The "Out of This World" Oxygen/Carbon Dioxide Cycle:

The following model illustrates how water, hydrogen, oxygen, and carbon dioxide can be utilized to supply crew members in space with vitally needed oxygen and water. Notice that, unlike traditional CO<sub>2</sub>/O<sub>2</sub> exchange diagrams, there are no plants in this model. It would not be practical to bring aboard the ISS the large number of plants that would be required to remove carbon dioxide from the air. For that reason, a carbon dioxide removal assembly is needed. [\(return\)](#)





## Closing the Loop: Recycling Water and Air in Space

### Supplementary Information:

- 1 What are the oxygen and water requirements of humans on Earth and in space?
- 2 Are there other carbon dioxide scrubbing systems?
- 3 What happens to trace contaminants aboard spacecraft?
- 4 How will astronauts deal with urine removal on long duration space flights?
- 5 Why doesn't NASA just fly plants on its spacecraft to remove CO<sub>2</sub> and produce O<sub>2</sub> ?
- 6 What other models of water recovery are NASA scientists and engineers currently testing?

[Click here for additional links to find out more on space environmental systems.](#)

#### 1. Astronaut life-support data:

[\(return\)](#)

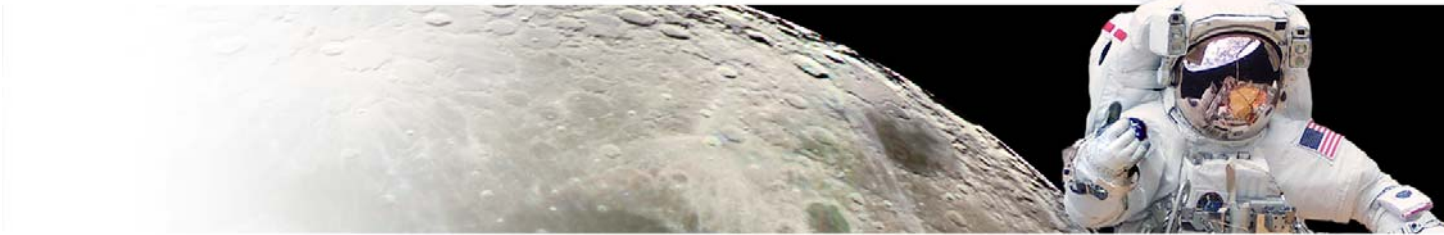
<b>Life Requirements on Earth and in Space</b>				
Item	On Earth		In Space	
	kg per person per day <sup>1</sup>	gallons per person per day	kg per person per day <sup>2</sup>	gallons per person per day
Oxygen	0.84		0.84	
Drinking Water	10	2.64	1.62	0.43
Dried Food	1.77		1.77	
Water for Food	4	1.06	0.80	0.21

[\(return\)](#)

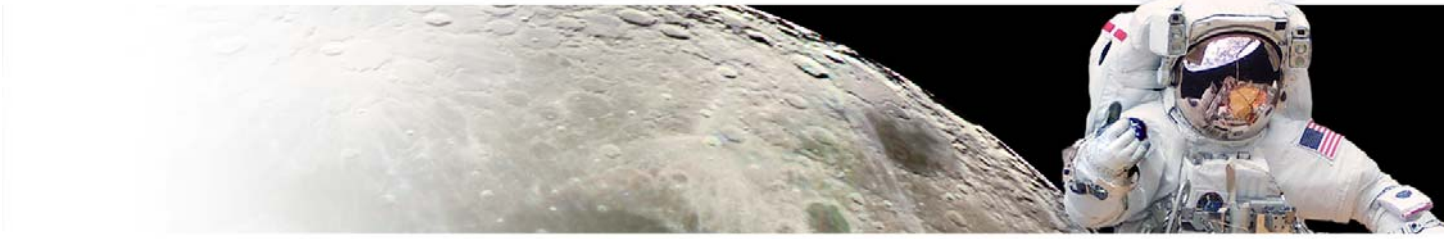
Teachers may choose to provide this data to students and ask them to calculate the water, oxygen, and food requirements for 5-7 person space shuttle crews, 2-3 person ISS crews, and 4-6 person Mars mission crews. For simplicity, figures in the chart may be rounded to the nearest whole number.

<sup>1</sup>G. Tchobanoglous and E. D. Schroeder, *Water Quality: Characteristics, Modelling, Modification* (Reading, Mass.: Addison-Wesley Publishing, 1987) 300-302.

<sup>2</sup>Environmental Control and Life Support System Architectural Control Document. Space Station Freedom Program Office, SSP 30262, Rev. D, NASA Space Station Freedom Program Office, Reston, VA, July 1991.



2. The space shuttle, like the Apollo era capsules, uses canisters of lithium hydroxide (LiOH) instead of zeolite for CO<sub>2</sub> scrubbing. After 20–30 days of use, the LiOH system becomes less cost effective than zeolite systems so the current CDRA system used aboard the ISS will serve the needs of longer duration spaceflight. [\(return\)](#)
3. There might be as many as 2000 trace contaminants (such as ammonia, ethanol, and formaldehyde) produced due to off-gassing of materials that can comprise the onboard equipment, experiments, and most importantly, human functioning. The *trace contaminant control system* cleans the cabin air by using filters and catalysts to manage the trace contaminants. Once scrubbed from the cabin, the trace contaminants are stored in a charcoal bed until the bed is saturated and must be exchanged for a new one. [\(return\)](#)
4. The ISS water recovery system consists of a *urine processor assembly (UPA)* and a *water process assembly (WPA)*. The UPA removes volatile (vaporizes at low temperatures) components in the urine using distillation, a process in which heat disinfection is used to prevent microbial growth. Urea is first stabilized chemically so that it does not turn into ammonia and volatilize with the water. Less desirable and volatile components remain as liquid brine, which is returned to Earth and disposed of. Since the UPA is still under development, water is not currently reclaimed from urine aboard the ISS. Once urine is reclaimed, the urine distillate will be sent to the WPA for further processing. The WPA includes a gas separator, a particulate filter, multifiltration beds, and a volatile removal assembly (VRA) that all work to make the water *potable* (drinkable). The multifilter removes ionic species and large organic molecules. The volatile removal assembly removes the small, volatile organic molecules such as methanol, ethanol, and isopropyl alcohol. [\(return\)](#)
5. At this point, it is determined that flying plants on board the ISS to meet oxygen production/carbon dioxide removal requirements would consume too much space, mass, water, soil, nutrients, and power for lamps, making their use impractical. At NASA's *Exploration Life Support (ELS) Lab* at Johnson Space Center in Houston, Texas, a *human metabolic simulator* called MANIAC ("man in a can") simulates up to eight people's metabolic output, consuming oxygen and producing carbon dioxide, heat, and moisture, providing one of the most complete respiratory models of a living human being ever. At the ELS lab, humans have become the subjects of tests in recent years that include living in a closed environment with plants for periods of 2 weeks to 3 months in order to determine the cost effectiveness of providing plants. [\(return\)](#)
6. The Integrated Advanced Water Recovery System Lab at NASA's Johnson Space Center in Houston, Texas tests the effectiveness of future models of water recovery, which could include the following:
  - a. Urine Treatment: Heating the urine to evaporate the water and leave the salts behind. The water vapor would then move to a condenser and be condensed as purified water. The salts remain, forming a brine solution with some of the remaining water. The brine would have to be recovered or thrown away periodically. This process would require a lot of power to heat all the water to boiling and to then cool the water vapor sufficiently to condense it.
  - b. Bioreactor: A processor that uses microbiological organisms to purify the water. The water is cleaned as a result of the microbes using the contaminants for food (similar to municipal water treatment facilities).
  - c. Multifilters: A series of chemical and physical beds that remove contaminants by chemical reaction and ion exchange and filter particles based on size to purify.
  - d. Reverse Osmosis: Using high pressure across a very fine filter or membrane to purify water. The water is separated from the salts. Brine is created from the concentrated salts that have to be recovered or periodically thrown away. This technology is often used in arid regions to convert and purify sea water into potable water.
  - e. Brine Processing: Recovering water from a brine solution by pouring the brine on a fabric (felt) wick and blowing warm air across it to evaporate the water. The salts are captured in the fabric and thrown away.
  - f. Post Processing: A series of chemical beds that remove any final remaining contaminants left behind from all other treatments. A chemical reaction and ion exchange purify the water (similar to a household tap water filter). [\(return\)](#)



**Additional Resources:**

Science@NASA: Water on the Space Station  
[http://science.nasa.gov/headlines/y2000/ast02nov\\_1.htm](http://science.nasa.gov/headlines/y2000/ast02nov_1.htm)

Science@NASA: Plumbing the Space Station  
[http://science.nasa.gov/headlines/y2001/ast03apr\\_2.htm](http://science.nasa.gov/headlines/y2001/ast03apr_2.htm)

NASA Facts: International Space Station Environmental Control and Life Support System  
[http://www.nasa.gov/centers/marshall/pdf/104840main\\_eclss.pdf](http://www.nasa.gov/centers/marshall/pdf/104840main_eclss.pdf)

NASA Video Feature "How Things Work: Environmental Control and Life Support System"  
<http://www.nasa.gov/returntoflight/multimedia/index-how-it-works.html>

[www.nasa.gov](http://www.nasa.gov)