

WATER – FAR AND NEAR

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We've had some great discussions over the last two days and everyone has learned something new, so I'm sure this will become the first of a series. Tonight, as we end today's events, I would like to talk with you about water in the interstellar context. Water lies at the very foundation of NASA's reason for being. The search for life in the universe is a search for water because life, at least as far as we know of it, cannot exist without water.

Hydrogen is the most common element in the universe. In fact, approximately 75% of the mass of the known universe is hydrogen. Helium makes up another 23%, and the last 2% are the remaining trace elements, including oxygen. (Hydrogen and helium make up the greatest proportion because they are the lightest elements.)

So, how does the hydrogen find oxygen and combine to make water? Cosmic rays in the interstellar medium collide with hydrogen to form a highly reactive form of hydrogen ions (H_2^+). This ionized hydrogen then bonds with free oxygen whenever their paths intersect and results in molecules of water – H_2O .

Water, in some form, can be found almost everywhere in the universe.

In the second half of the 20th century, around 1960-1980, scientists began using near infrared spectroscopy to detect water. They found it throughout the universe. Some examples include:

- The rings and moons of Saturn, except for Titan which is shrouded in a gas cloud that we haven't been able to see through;
- Three of Jupiter's moons – Europa, Ganymede and Callisto. As you've probably heard, NASA is very interested in Europa because the cracked surface features indicate the possibility of a liquid ocean below. That's why Europa is high on NASA's list for future visits, in order to see if it's possible to penetrate the surface and reach an ocean below.
- Comets are almost entirely water-ice, around 80%. That's why Fred Whipple first characterized them as "dirty snowballs". (That's the

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astronomer Dr. Fred Whipple, not the popular toilet paper salesman from television.)

- Water has even been observed in distant galaxies using radio-astronomy.

Finally, in 1995, the European Space Agency launched the Infrared Space Observatory and it confirmed, through direct measurements made by its suite of four scientific instruments, that water is omnipresent throughout the cosmos, from nearby planets to distant galaxies. Then in 2003, NASA launched the Space Infrared Telescope Facility (aka the Spitzer Space Telescope), which detected enough water to fill the oceans on Earth five times over inside the collapsing nest of a forming star system.

In 1999, water vapor was even observed in the sun. How could that be? A water molecule is stable up to about 3,000 degrees Kelvin, while the solar disc is about 5,600 degrees Kelvin. As it turns out, sunspots are cooler – on the order to 3,200 degrees Kelvin, and that’s where the water was observed. But, even so, water should lose stability at 3,000 degrees, so it remains a mystery how this can occur at 3,200 degrees. These are the kind of mysteries that keep solar physicists busy.

So, on the far horizon, water seems to exist everywhere, but it’s always either bound up in water-ice or liberated as water-vapor. It’s never liquid, at least not that we’ve been able to detect so far.

That’s what makes our planet so special. Earth is at just the right distance from the sun that we have abundant water in solid (ice), liquid (ocean) and gaseous (cloud) forms. And, of course, that’s why life has evolved here.

We also know there is water on Mars, in the form of an ice cap at the north pole (the south pole is actually frozen carbon dioxide). And, we also know there was once running water on the surface of Mars. Planetary geologists can tell this from the erosion patterns.

But, at some point in its history, Mars lost its atmosphere and we don’t know why. We really need to find out why Mars lost its atmosphere.

We’ve sent probes and robotic rovers to Mars and they’ve done an amazing job. In fact, if you haven’t seen the IMAX movie, *Roving Mars*, you really must. It’s an incredible record of the rovers Spirit and Discovery that searched the Martian landscape for clues to what has happened there. You’ll feel like you’re there, and hopefully one day we will send humans to Mars. But at this stage, we still don’t know what happened to the Martian atmosphere, and ***we really need to understand this.***

PAUSE

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(begin ISS fly-around movie)

One of the reasons NASA built the space station was as a stepping-stone to Mars and beyond. We don't have the technology today to take us to Mars. People understand the moon is 2-3 days away, because we've already gone there. But not all people realize that Mars is 6 months away. That is if we use chemical propulsion, and we're not even sure if that's the right way to get there. It may take a nuclear-electric energy source to shorten the trip.

We will also need to haul our own water and oxygen, so being able to recycle it as much as possible is extremely important.

The International Space Station may be the most energy efficient, environmental recycling system ever built. It has to be in order to operate in space – there's no air or water 350 kilometers up in low-Earth orbit. The ISS is a "poster child" for energy and environmental technologies.

There are many distributed systems necessary to operate a space station – electric power, thermal control, data processing & telecommunications, and about a half dozen others that we don't have time to go into today. So, we'll focus in on the Environmental Control and Life Support System – ECLSS – because that's the one that maintains the water and oxygen balance on the ISS.

We're currently on our way to closing about 80% of the oxygen and water loops on the station. It's not a totally a "closed loop" system yet, but we're getting there through programs like the ISS that serve as our test bed for research & development.

I'm not an expert in ECLS systems, but we do have an expert here with us if you really have an unquenchable need to know about things like how to operate a distillation system in zero-G, where liquids and gases behave totally different than on the ground under 1-G. (I'll give you a hint -- we use centrifuges in our stills.)

-- introduce Marybeth Edeen --

There are a lot of problems unique to zero gravity conditions. Thin films form more quickly and bind rotating mechanisms. Particulates clump together, instead of floating to the top or forming sediments on the bottom. This happens because there's no buoyancy or sedimentation, and it ends up clogging filters. Gas bubbles also get trapped everywhere, and fluid flows in slugs. We're working through all these issues. Our regenerative ECLSS components were deployed about a year ago, so we're in a "shake-down" period. We will get it all operating smoothly before the year is out – we have to. We can't afford to be hauling all that water into space.

Let me share some facts with you to help you understand the challenges of living beyond Earth's water and atmosphere:

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- 1 crewperson consumes about 2.2 liters/day. That's for drinking, hygiene and food preparation. (It doesn't include additional water needed to produce oxygen, flush the toilet, or do other daily tasks.)
- 6 crew corresponds then to about 13 liters/day, or roughly 5,000 liters/year.
- Since a liter of water weighs about 1.04 kilograms, that corresponds to about 5,000 kg of water mass that would need to be hauled to space annually.
- At an average space transportation cost of \$60,000/kilogram, that means it would run about \$300 million/yr just to keep the crew wet.

We couldn't go very far at that kind of cost, so we're highly motivated to recycle.

Now, let's look at the other end of the water cycle:

- 1 crewperson urinates about 1.2 liters/day.
- That adds up to 2,628 liters, or kilograms, /year.
- So that's valued at about \$158 million /year.

Are you getting the picture here?

Let me just summarize our ECLSS components at a high level for you:

- There's an *Oxygen Generator System* that works according to the principles of water electrolysis. (Originally we relied solely on a Russian system called Elektron that also employs electrolysis).
- There's a *Water Recovery System* that captures brine from bathing and other wastewater sources, humidity condensate, and human urine.
- The *Urine Processing Assembly* then employs centrifugal distillation in its purification cycle.
- A *Water Processing Assembly* removes air, filters particles, and oxidizes organics.
- And then, the final purity checkpoint is a *Total Organic Carbon Analyzer* that looks for residual contaminants in the range of 250 – 25,000 parts per billion (that's ppb, not ppm – we maintain some of the tightest standards in the world.)

Before this year is out, we also plan to add a *Sabatier reactor* that takes in waste carbon dioxide and hydrogen to produce about 2,000 kilograms of water per year. That could correspond to a savings of up to \$120 million/year. It could also close the ECLSS loop to about 85%.

This isn't just about space though. The technical advances needed to get to this level of performance are also applicable in ground systems. There are air & water filtration systems employed around the world that are now using various components from these spaceflight systems.

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For example, one particular *Water Purification System* that is now available commercially is a hand-pumped unit that produces about 2 liters/minute with a capacity for almost 12,000 liters. This unit has been in use at:

- Vera Cruz, Mexico for flood relief;
- Kendala, north Iraq, where it's truck-mounted to serve rural villages;
- Kampang Salak, Malaysia – where it's pedal-powered;
- Sabana San Juan, Dominican Republic; and,
- In Balakot, Pakistan for earthquake relief.

This is an important part of what this work is all about – using space exploration challenges to drive out practical new technologies that also benefit people on the ground. It's what could be called the “microprocessor model”. Just as the Apollo Program of the '60s required large-scale reductions in power and mass that drove transistor-based devices down to the integrated circuit (chip) scale, the space exploration program of the 21st century will drive out new energy, environmental and health technologies, to name just a few of the more important domains of technological advance.

With that glimpse into the future I'd like to offer a toast. You should all find a small cup of water at your place. Before we toast, there are a few suggestions though:

1. If you have a thyroid condition, please pass on this opportunity. This particular water has been treated with iodine and we don't want any “unplanned events”, as we say in the space business.
2. As you taste it, don't just throw it back like a fine tequila, aerate it and swirl it in your mouth like a cabernet. (There will be questions afterward.)
3. Finally, if you detect a slight aftertaste that's probably just from the plastic storage containers.

So then, to the innovators we have here tonight and those across our world – may we all learn to master the art of water.¹

Cheers!

¹ NASA Certification: the water provided for this toast was produced in the ECLSS laboratory at NASA Marshall Space Flight Center, Huntsville, AL during final acceptance testing of the ISS Regenerative ECLSS. The process feedwater included bathwater, humidity condensate, human perspiration and urine, and other assorted trace wastewaters.

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