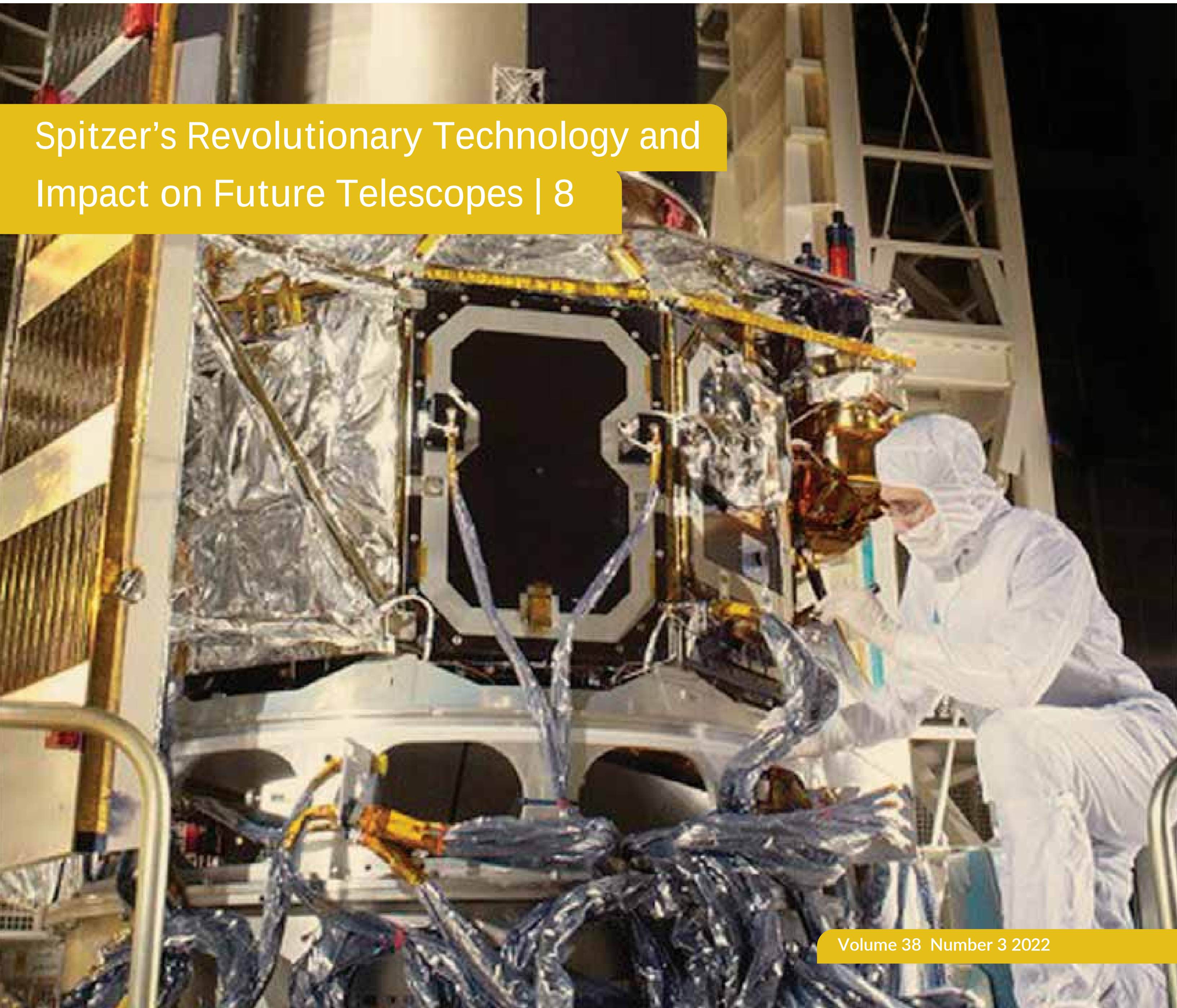
Cold Facts INTERNATIONAL

The Magazine of the Cryogenic Society of America, Inc.



Spitzer's Revolutionary Technology and Impact on Future Telescopes | 8

Volume 38 Number 3 2022

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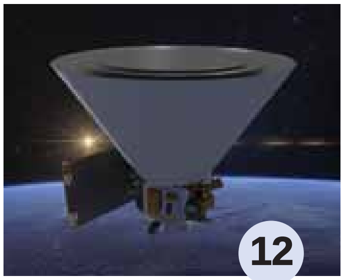

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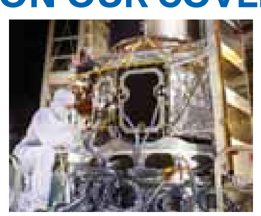

The Spitzer Telescope paved the way for future telescopes. Here, it is being prepared for thermal testing prior to launch in 2003, at Lockheed Martin in Sunnyvale, Ca. *Credit: NASA/JPL-Caltech*

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Cold Facts

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From the Executive Director

I hope all our readers (in the Northern Hemisphere) are enjoying the warm days of summer! Here at CSA headquarters in the Chicagoland area, the sunshine and warm weather is greatly welcomed and long overdue after such a cold winter. It's brought an extra boost of energy as we enter the second half of 2022.

By the time you are reading this, the CSA Foundations of Cryocoolers Short Course will likely be behind us. The short course is taking place on June 27, 2022, in conjunction with the International Cryocooler Conference. We are encouraged to see that registration numbers for the event have been on pace (or even surpassed) pre-Covid numbers. After a couple of difficult years, it's great to see that people are feeling more comfortable getting out to events again! I want to give a big thank you to our instructors of the Short Course: Dr. Ray Radebaugh, consultant emeritus of NIST Boulder, and Dr. Ralph Longsworth from Sumitomo Cryogenics of America, Inc. We recognize the time and effort that goes into planning a short course, and we are incredibly grateful you've volunteered your time to share your knowledge with other industry professionals.

Following the short course, I, along with *Cold Facts* Editor Anne DiPaola, will be attending the International Cryocooler Conference in Bethlehem, Pa. We are looking forward to seeing many of our members and partners in person at the event! We hope those in attendance will take a moment to stop by the CSA tabletop to say hello and learn more about what CSA offers to the cryogenics industry.

October 23-28, CSA will also be attending the Applied Superconductivity Conference in Honolulu, Hawaii! If you plan to attend ASC'22, don't forget to register by September 7, to take advantage of the early registration discounts! For the most up-to-date information about ASC'22, please visit **www.appliedsuperconductivity.org/asc2022**.

During ASC'22, CSA will be presenting the Roger W. Boom Award. The Roger W. Boom Award is named in honor of the late emeritus professor from the University of Wisconsin. Dr. Boom's career spanned more than 30 years, during which he motivated a great number of young scientists and engineers to pursue careers in cryogenic engineering and applied superconductivity. This award was created by CSA to be given to a young professional (under 40 years of age) who "shows promise for making significant contributions to the fields of cryogenic engineering and applied superconductivity." The spirit of the Boom Award is to recognize young people for their pursuit of excellence, demonstration of high standards and clear communications. We are now accepting nominations for the Boom Award. To view the nomination criteria and procedure, please visit **http://2csa.us/boomaward**. The deadline to submit a nomination is August 26, 2022.

As always, I hope you enjoy this issue of *Cold Facts*!

The Cold Facts of the Spitzer Space Telescope

by Michael Werner, Project Scientist, Spitzer Space Telescope—Jet Propulsion Laboratory, California Institute of Technology

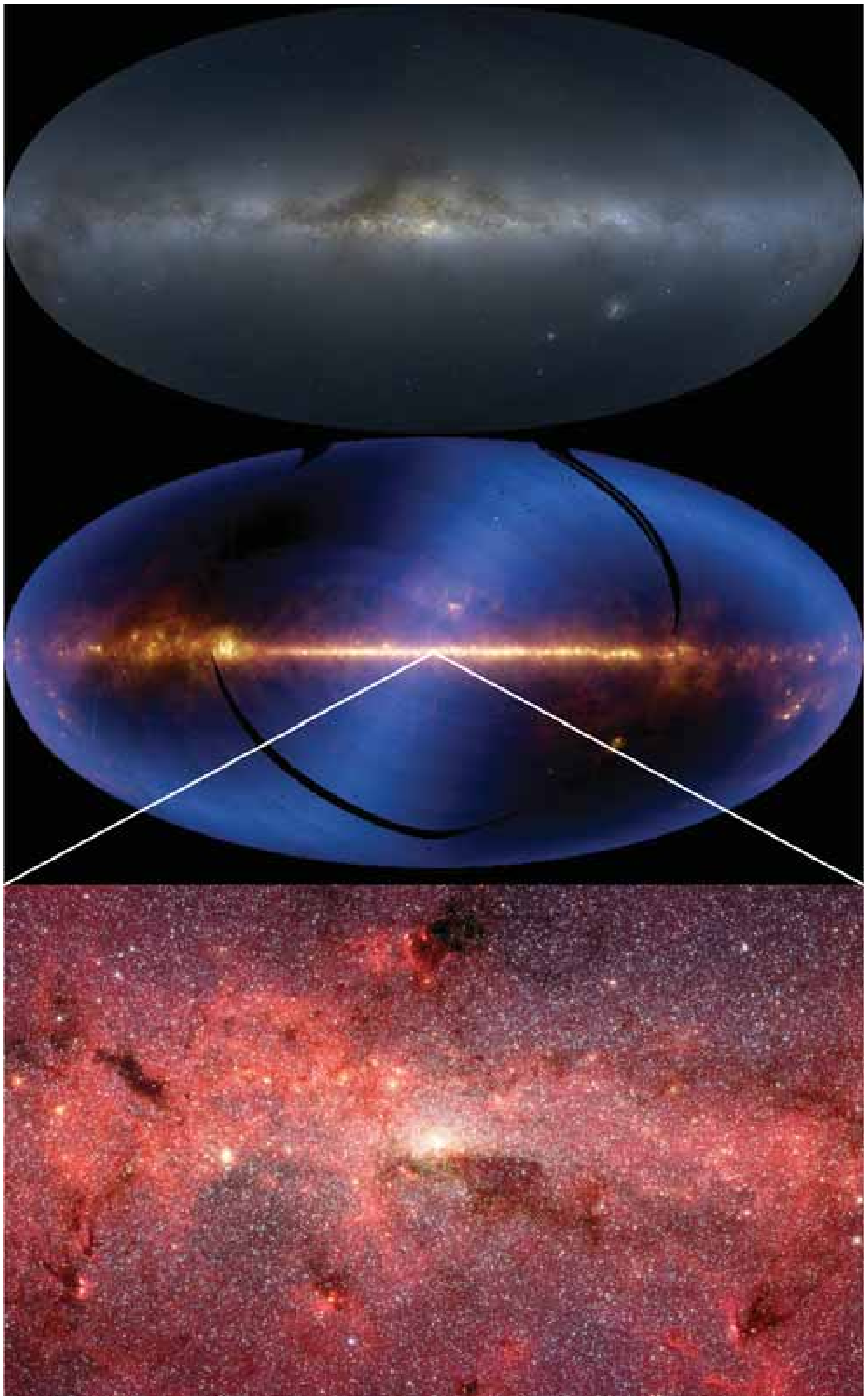

Figure 1. Visible (top) and infrared (center) views highlight the different appearance of the entire sky at different wavelengths. These images are presented so that the Milky Way, which is our view of the plane of our galaxies, runs horizontally through the center of each image. The infrared image is a signature product of the IRAS mission, discussed in this article. The bottom panel zooms in on Spitzer's view of the central 2900 x 1100 light-years of the galaxy, including the Galactic Center, home to the recently imaged black hole, Sgr A*. The red glow represents radiation from the hydrocarbon molecules which abound in the galaxy. *Credit: A. Mellinger - top; NASA/JPL-Caltech – middle; R. Arendt/AAS – bottom*

NASA's Spitzer Space Telescope, launched in August 2003 and decommissioned in January 2020 after more than 16 glorious years of exploration of the universe at infrared wavelengths, was a technical and scientific marvel. Infrared astronomical studies at wavelengths longward of 1 micron, somewhat beyond the limit of human vision at around 0.7 microns, began in earnest around 1960. These early studies, carried out on ambient temperature telescopes within the atmosphere, advanced astronomical understanding of targets from planets within the solar system to distant and highly luminous galaxies. However, they could not disguise the fact that the earth is a hostile environment for infrared astronomy.

The reasons for this reside in Planck's Laws of Blackbody Radiation, which tell us that both the earth's atmosphere, at a temperature around 270 K, and a telescope within it at a similar temperature, will radiate copiously at infrared wavelengths longward of several microns. This bright foreground radiation swamps the faint infrared radiation from all but the brightest astronomical sources. Beginning with early rocket flights and culminating with the highly successful Infrared Astronomical Satellite (IRAS), which flew in 1983, scientists and engineers demonstrated and exploited the fact that a cold telescope in space operates in an environment where the sky brightness is a million times less than that encountered within the atmosphere. (Cold refers to truly cryogenic, with temperatures as low as 5 K or below.) This is about the factor by which the sky at midnight on a moonless night is darker than that at high noon. So, to work "at night" in the infrared, we use a cold telescope in space and can see the infrared sky in all its glory. As shown in Figure 1, the sky can look very different in the infrared than in visible light.

Several other cryogenic missions, most notably the European Space Agency's Infrared Space Observatory (ISO), succeeded IRAS and advanced the science and technology of infrared space astronomy significantly. These programs led to the Spitzer Space Telescope, which was NASA's (first) Great Observatory for infrared exploration of the universe. The gains of a cryogenic telescope in space are so great that, at wavelengths longward of 3 microns, the 85-cm-diameter Spitzer was at least 50 times more sensitive than the 8-m-diameter telescopes of the ground-based Gemini observatory. The use of monolithic detector arrays (similar in principle, if not in cost, to the megapixel cameras now found in every cell phone) in Spitzer's three instruments assured that the sensitivity gain was achieved at many spatial or spectral resolution elements simultaneously. In addition, of course, operation in space provides access to all infrared wavelengths, many of which are obscured by Earth's atmosphere. As a result of all these considerations, Spitzer had tremendous scientific power.

Spitzer's scientific achievements are summarized in the book *More Things in the Heavens: How Infrared Astronomy is Expanding our View of the Universe* (Princeton University Press, 2019) by the author of this article and his NASA Jet Propulsion Laboratory colleague Peter Eisenhardt. Highlights of Spitzer science range from the discovery of a giant ring around Saturn (Figure 2); to the identification of seven Earth-sized planets orbiting a faint red star only 40 light-years from Earth (Figure 3); to comprehensive studies of nearby galaxies that reveal the full range of phenomena available for study in the infrared (Figure 4); and finally, to studying distant galaxies as they appeared when the universe was less than 3% of its current age and 7% of its current size.

Even though Spitzer is no longer taking data, its scientific legacy is assured by a readily accessible data archive, which interested readers can access at **www.irsa.ipac.caltech.edu/Missions/spitzer.html**. More than half of the over 10,000 papers which have been published using Spitzer data included archival data, even as new observations were ongoing and new data were entering the archive. Thus, Spitzer is a gift that keeps on giving.

The cryogenic and thermal performance of Spitzer may be of particular interest to readers of *Cold Facts*. Spitzer orbited the sun rather than the earth, and thus was far from the substantial heat load attributable to Earth's own infrared radiation. In this solar orbit, it was possible to keep Spitzer oriented so that the sunlight was always incident on the fixed solar panel, and this facilitated the simple, robust thermal architecture illustrated and discussed in Figure 5. Spitzer was launched with a tank, located within the outer shell identified in Figure 5, which, at the start of scientific observations, contained 42.4 liters of superfluid liquid helium that cooled the telescope and the detectors (also located within the outer shell). The outer shell was always shaded from direct

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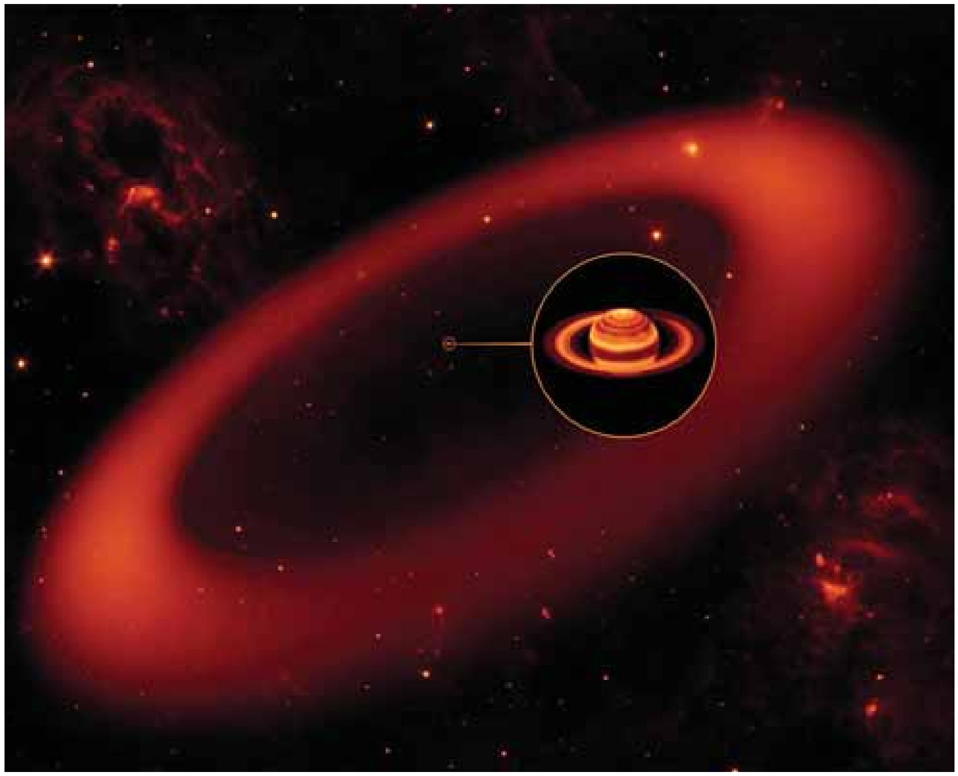

Figure 2. The giant ring of Saturn found by Spitzer is shown on a scale that shrinks the planet and its previously known rings (shown enlarged in the circular inset) to a point. Note that the tilt of the giant ring differs from that of the previously known rings. The giant ring is attributed to material from Saturn's outer satellite, Phoebe, which orbits within it. *Credit: A. Verbiscer*

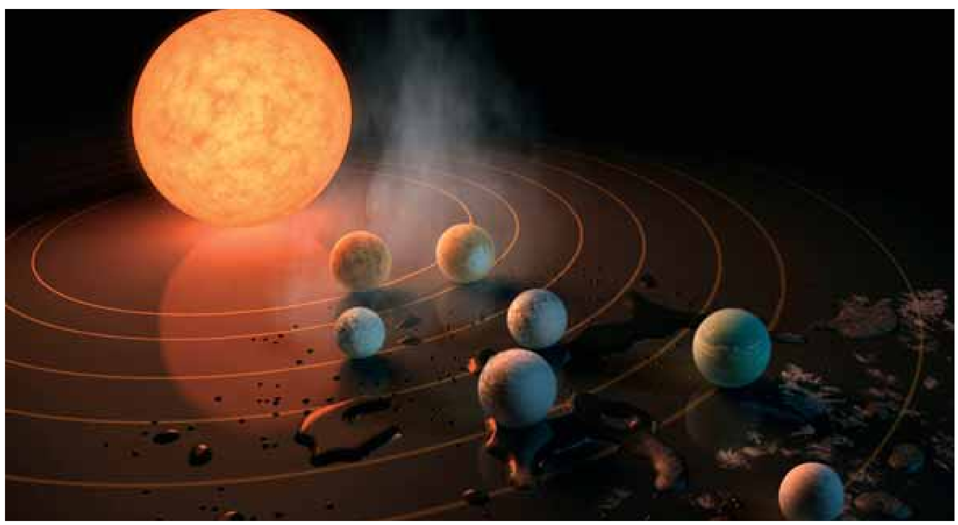

Figure 3. Seven Earth-sized planets identified by Spitzer orbiting the small star, TRAPPIST-1, 40 light-years from Earth. This artist's conception shows the expected state of water on the planets' surfaces. Those closest to the star show steam; the farthest show ice. Those in the middle, where water would be liquid, are in the habitable zone and could be hospitable to life as we know it. *Credit: NASA/JPL-Caltech/R. Hurt (IPAC).*

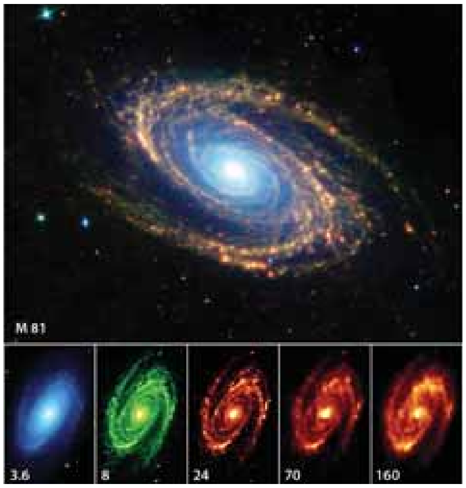

Figure 4. Spitzer images of the nearby spiral galaxy, M81, at wavelengths from 3.6 to 160 microns. The large image at the top is a composite of the 3.6, 8, and 24 micron images. In this composite, old stars in the center of the galaxy dominate at the shortest wavelength (blue), while emission from hydrocarbon molecules (green) and interstellar dust (red) become dominant at longer wavelengths. At 224 microns, regions where stars are forming are strung out along the spiral arms like ornaments on a Christmas tree.
Credit: S. Willner & K. Gordon/AAS.

Figure 5. Spitzer being prepared for thermal testing in 2003 at Lockheed Martin in Sunnyvale, Ca. The tall structure on the right is the solar panel, which is always kept oriented towards the sun. To the left of the solar panel, the outer shell, which contains the telescope, the instruments, and the cryogen tank, is seen atop the spacecraft. These are shielded by the solar panel from direct sunlight. The black anti-sun hemi-cylinder of the outer shell is always oriented towards deep space and radiates away heat which leaks inward from the solar panel or the spacecraft. The structures to the left of the outer shell/spacecraft stack are part of the test configuration. Lockheed Martin provided the solar panel and the spacecraft, while Ball Aerospace provided the outer shell, the telescope, the cryogenic system and two of the three instruments; the third was built by NASA's Goddard Space Flight Center.
Credit: NASA/JPL-Caltech

sunlight by the solar panel while it cooled by radiation into the vast refrigerator of deep space, facilitated by the black coating on its antisolar side. Careful thermal design, tests and fabrications of this system, and thoughtful choices of the thermal properties and coatings of the elements shown in Figure 5 allowed the outer shell to cool to below 36 K entirely by radiative cooling; the telescope and instruments were cooled well below 36 K by the liquid helium cryogen. At 36 K, the power carried to the interior of the outer shell, either by conduction or by radiation, was virtually negligible. This meant that the main heat source, which boiled away the liquid helium, had the small amount of electrical power required to operate the detector arrays.

To summarize, before the cryogen boiled away almost six years after launch, the average heat load into the cryogen was only 5.1 mw, and the original 42.4 kg of liquid helium lasted over 2,000 days. By contrast, IRAS started scientific observations with 73 kg of liquid helium, which lasted for 10 months, or 300 days. This comparison shows that the Spitzer cryogenic system was an order of magnitude more efficient than IRAS; the difference is largely due to the fact that IRAS operated in low Earth orbit. The earth's infrared radiation warmed the exterior of the spacecraft (equivalent to Spitzer's outer shell) to several hundred kelvins, so that much more "parasitic" heat was conducted into the helium tank than was the case for Spitzer.

Following the exhaustion of the liquid helium supply in 2009, the outer shell warmed up by only about a degree, so the heat conducted into the helium tank from the outer shell remained small. Consequently, the temperature of the telescope and the instruments equilibrated at a value of about 26 K, with the cooling due entirely to radiation out of the open aperture of the outer shell. This was cold enough for efficient operation of Spitzer's two shortest wavelength detector arrays at 3.6 and 4.5 µm. Spitzer continued to observe with these two arrays for almost 11 years. During this Warm Spitzer mission, extremely important scientific results, including the detection of the Trappist-1 planets shown in Figure 2, were gathered, reduced, published and added to Spitzer's archives.

As is always the case for NASA missions, success builds upon success, and Spitzer's successor, the James Webb Space Telescope (JWST), has been launched and deployed successfully and is within a few months of extending Spitzer's results with higher sensitivity and spatial and spectral resolution. JWST's primary mirror has 50 times the collecting area of Spitzer's, and its detector arrays have hundreds of times as many pixels; so the gains which it will bring over Spitzer will be marvelous, but we should not lose sight of the fact that Spitzer's scientific and technical results (the latter particularly in the cryothermal area) have motivated the design and scientific use of JWST in many ways.

Further details on Spitzer's thermal/cryogenic system and other characteristics of the mission can be found in papers by R. Gehrz et. al. (*Review of Scientific Instruments*, Vol. 78, 2007, p.1) and M. Werner et. al. (*Journal of Astronomical Telescopes, Instruments, and Systems*, Vol. 8, id. 014002, 2002).

This paper is based on work carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. ©2022. California Institute of Technology. Government sponsorship acknowledged.

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Job openings from CSA Sustaining Members and others in the cryogenic community are included online, with recent submissions listed above. Visit **http://2csa.us/jobs** to browse all current openings or learn how to submit your company's cryogenic job to our list of open positions. Listings are free for Corporate Sustaining Members.

Illustration of NASA's SPHEREx spacecraft. *Credit: NASA/JPL-Caltech*

NASA Readies to Build Cosmic Mapmaker

SPHEREx is scheduled to map millions of galaxies starting as soon as 2024

by Samantha Hill, Staff Writer, astronomy.com

Over the past three decades, the Hubble Space Telescope has helped astronomers unlock many mysteries about planets, stars, nebulae, and even distant galaxies. The James Webb Space Telescope (JWST), launched last December, aims to soon extend Hubble's gaze even farther out into the cosmos. However, both Hubble and JWST tend to set their sights on individual targets for scrupulous observations. That's not the case for NASA's *next* great space observatory, SPHEREx, which will have its eye set on the bigger picture.

In March 2022, NASA approved the design of SPHEREx, short for Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer. With the approval, the mission is now ready to move into the building phase. SPHEREx is expected to launch sometime between June 2024 and April 2025, with its primary mission expected to last about two years. With such a lofty name, the telescope is destined to pursue its goal of capturing data on more than 300 million distant galaxies, as well as about 100 million stars within our own Milky Way.

During its mission, the telescope will scan nearly 99% of the entire sky every six months. To do so, according to SPHEREx Project Scientist Olivier Dore, it will target each section of space a total of four times for 112 seconds each time. By taking this approach, SPHEREx will use its relatively modest scope to get a broader picture of the universe than either Hubble or JWST can.

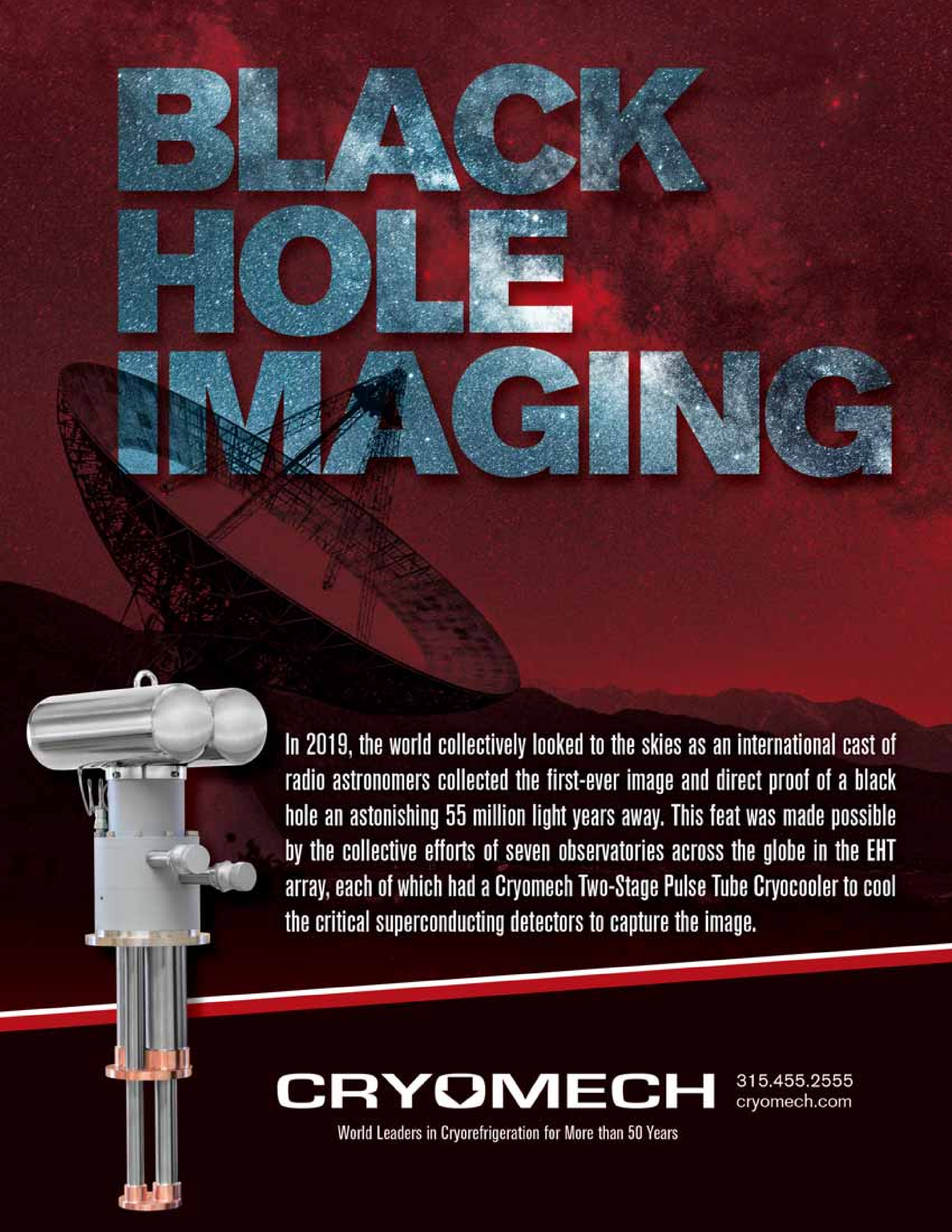
"It's the difference between getting to know a few individual people and doing a census, and learning about the population as a whole," said Deputy Project Manager for SPHEREx Beth Fabinsky. "Both types of studies are important, and they complement each other; however, there are some questions that can only be answered through that census."

One of SPHEREx's mission objectives is to hunt for galactic objects containing water and organic materials, helping astronomers identify areas with the greatest likelihood of harboring life. According to SPHEREx Principal Investigator Jamie Brock, each of the scope's pixels will take in 6.2 arcseconds worth of sky, meaning SPHEREx will not be able to resolve individual objects. However, that resolution is perfect for pinpointing promising areas worthy of further investigation by more high-powered tools.

To capture information about specks of dust or water droplets located some ten billion light-years from Earth, SPHEREx will study the sky in 96 bands of optical and near-infrared light using a technique called spectroscopy, which is a method for breaking light into its component colors (wavelengths). Researchers will then analyze the various wavelengths observed, enabling them to glean information about the elements contained within their targets.

Unlike other recent space telescopes, SPHEREx will be relatively small, sporting a 7.8-inch (20 centimeter) mirror and a 10.5-foot (3.2 m) sunshield. For comparison, JWST, the largest space telescope yet, has mirrors about twice as large as SPHEREx's sunshield.

With SPHEREx's expected launch as little as two years away, the mission's recent approval paves the way for the all-important build phase. The California Institute of Technology and NASA's Jet Propulsion Laboratory will develop the SPHEREx payload, while Ball Aerospace will build the spacecraft and provide mission integration. The Korea Astronomy and Space Science Institute will provide test equipment for the craft, such as an earthbound cryogenic test chamber, as well as help analyze the data SPHEREx returns once it reaches its 430-mile-high (700 km) orbit and starts observing.


BLACK HOLE IMAGING
In 2019, the world collectively looked to the skies as an international cast of radio astronomers collected the first-ever image and direct proof of a black hole an astonishing 55 million light years away. This feat was made possible by the collective efforts of seven observatories across the globe in the EHT array, each of which had a Cryomech Two-Stage Pulse Tube Cryocooler to cool the critical superconducting detectors to capture the image.
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The Journey of the Maglev Train—A History and a Forward View

by Rijkert Knoppers, Freelance Journalist and author

Background

In early January 2022, a prototype maglev train was rolled out in southwest China's city of Chengdu, one of the latest developments in magnetic levitation trains. The domestically developed locomotive uses high temperature superconducting and will travel with a designed speed of 620 km/h, according to Southwest Jiaotong University, one of the train's designers. Maglev trains, levitated from the tracks and propelled by powerful magnets to avoid wheel-rail friction, are designed to break the speed bottlenecks facing high-speed trains.

The floating maglev train has a long history, and developing the revolutionary technology does not go as frictionless as the trains float over the tracks. What are some of the most notable maglev projects in history, and what is the status of maglev trains today?

A maglev train prototype using the high temperature superconducting (HTS) maglev technology is unveiled in Chengdu, southwest China's Sichuan Province, January 13, 2021. /CFP. *Credit: CFP*

The L0 series maglev at Yamanashi test track in Japan. *Credit: Saruno Hirobano*

The repelling force of magnets

To make a vehicle float, the repelling force of magnets is an intuitive way. To create the required magnetic field, electromagnets, or permanent magnets, are attached to the underside of the vehicle. This is a dynamic system because when the magnets installed in the train move along coils of wire arranged on the guideway, electric currents are generated within the coils. These induction currents, in turn, produce magnetic fields that repel the magnets in the train. This magnetic flux allows the train to float. A disadvantage of this technology is that the magnetic field is only generated when the vehicle is moving fast enough to produce the required induction current.

Another option is to attach a curved construction to the underside of the train that embraces the guideway. At both ends of the C-shaped arm, there are electromagnets, which exert an attraction on the magnetic material at the bottom of the guideway. An advantage of this electromagnetic suspension approach is that with this technology, hovering always works, even when the train is stationary.

The first commercial maglev project

The world's first commercial magnetic levitation transport system was launched in the UK in Birmingham on August 16, 1984. Three fully automatically controlled low-speed trains were in operation, floating at a height of 15 millimeters and a maximum speed of 42 kilometers per hour above the track between Birmingham airport and the nearby intercity station. The six-meter vehicles in question each had six seats and 34 standing places. The weight of the three-meter-high vehicles, including passengers, was eight tons in total.

However, the transport system suffered several setbacks. For example, one of the companies involved had decided at one point that the bottom of the maglev vehicle was too weak. This led to the vehicle being reinforced with an extra layer of fiberglass. However, this increased the weight of the already relatively heavy vehicle to such an extent that the electromagnets could no longer keep the train afloat. Another issue was that the conventional speedometers did not work because there was no contact with the concrete guideway. By 1995, there was no choice but to discontinue the maglev.

The Berlin M-Bahn

Between 1989 and 1991, the inhabitants of Berlin could use the M-Bahn, also known as Magnetbahn. The line was 1.6 kilometers long, and there were three stations: Kemperplatz, Bernburger Platz and Gleisdreieck. The floating train operated at a cruising speed of 80 kilometers per hour. Originally, the M-Bahn was to start operating in May 1987, but a terrorist attack on April 18, 1987, disrupted the planning. A second attack at Kemperplatz station was foiled by the security service at the last moment.

In the meantime, however, an important event took place, which the initiators of the M-Bahn could hardly have foreseen—the fall of the Berlin Wall on November 9, 1989. The event completely changed the local transport concept; it now made more sense to restore the U-Bahn, which used to run between Gleisdreieck and Potzdamer Platz before the construction of the Wall, for the route of the M-Bahn to become part of the U2 line. The demolition of the M-Bahn began two months after its official opening in July 1991 and was completed in February 1992.

In the Netherlands, there were also plans for a maglev route between Schiphol airport and Groningen, but the project team decided in 2006 that the construction would be too expensive.

Six maglev projects in operation

At this moment, six commercial maglev projects are in operation worldwide: two in South Korea, one in Japan and three in China. What is striking is that in five cases, they are low-speed floating trains; only in Shanghai does the maglev reach a high average speed of more than 400 kilometers per hour, an interesting fact because one of the selling points of maglev is the exceptional high speeds it can achieve.

There are also several maglev projects worldwide in preparation. Brazil, for instance, floats an experimental maglev train between two university buildings. In the US, there are plans for a maglev connecting Baltimore and New York City called the Northeast Maglev, among others. In Fenguhuang, China, a low-speed maglev line is under construction, and in Japan, a 286-kilometer-long route between Tokyo and Nagoya is expected to be finished around the year 2027. Thus, in the next decade, maglev trains could gain a more prominent role in the world of transportation.

Rijkert Knoppers studied mechanical engineering at Delft University of Technology and is author of the book Maglev Trains, the Attraction of Levitation.

How Maglev Works

What if you could travel from New York to Los Angeles in just under seven hours without boarding a plane? It could be possible on a maglev train.

Maglev – short for magnetic levitation – trains can trace their roots to technology pioneered at Brookhaven National Laboratory. James Powell and Gordon Danby of Brookhaven received the first patent for a magnetically levitated train design in the late 1960s. The idea came to Powell as he sat in a traffic jam, thinking that there must be a better way to travel on land than cars or traditional trains. He dreamt up the idea of using superconducting magnets to levitate a train car.

Superconducting magnets are electromagnets that are cooled to extreme temperatures during use, which dramatically increase the power of the magnetic field. The first commercially operated high-speed superconducting maglev train opened in Shanghai in 2004, while others are in operation in Japan and South Korea. In the United States, a number of routes are being explored to connect cities like New York and the greater D.C. area.

In maglev, superconducting magnets suspend a train car above a U-shaped concrete guideway. Like ordinary magnets, these magnets repel one another when matching poles face each other.

"A maglev train car is just a box with magnets on the four corners," says Jesse Powell, who now works with his father, the maglev inventor.

It's a bit more complex than what Powell describes, but the concept is simple: the magnets employed are superconducting, which means that when they are cooled to less -450 °F, they can generate magnetic fields up to 10 times stronger than ordinary electromagnets – enough to suspend and propel a train. These magnetic fields interact with simple metallic loops set into the concrete walls of the maglev guideway. The loops are made of conductive materials, like aluminum, and when a magnetic field moves past, it creates an electric current that generates another magnetic field.

Three types of loops are set into the guideway at specific intervals to do three important tasks: one creates a field that makes the train hover about five inches above the guideway; a second keeps the train stable horizontally. Both loops use magnetic repulsion to keep the train car in the optimal spot;

▶ *continues on page 16*

Illustration of a futuristic maglev train. *Credit: US DOE*

Inox Air Announces 750C Greenfield Project

Inox Air Products, a manufacturer of industrial and medical gases in India, has announced its largest greenfield project at Steel Authority of India Ltd.'s (SAIL) Bokaro plant with an investment of Rs 750 crore. This is the company's second cryogenic air separation unit at the Bokaro plant in Jharkhand, and it is also its largest investment in a new oxygen plant.

"The new unit will generate 2,150 tonnes per day (TPD) of industrial gases, including 2,000 TPD of gaseous oxygen, 150 TPD of liquid oxygen, 1,200 TPD of gaseous nitrogen and 100 TPD of argon," a spokesperson for Inox Air said.

Inox Air Director Siddharth Pavan Jain boasted, "With the commissioning of this project, the company's combined production capacity at the Bokaro plant will be over 6,300 TPD for all gases. This is our largest ever greenfield investment to date."

The new unit will also greatly augment the availability of vital liquid medical oxygen, not only in the eastern parts of India, but also across the country.

Inox's long-term onsite gas supply partnership with SAIL began in 2008 with the setting up of its first cryogenic air separation unit of 1,250 TPD on a build, own and operate basis at the Bokaro plant, followed by another unit at SAIL's Salem plant with a capacity of 108 TPD in 2011.

Inox has been servicing the needs of the manufacturing and healthcare sector for over six decades now. Through its 45 air separation units located across India, Inox manufactures over 3,300 TPD of liquid gases.

The enhanced availability of medical and industrial gases from the new Bokaro unit will aid industrial growth in Jharkhand and eastern states while ensuring supplies for the electronic manufacturing and pharmaceutical sector, and helping iron, steel and automobile industries to ramp up production, the company claimed.

During the pandemic, Inox catered to over two-thirds of the medical oxygen demand in the country, supplying to more than 800 hospitals through a fleet of 550 cryogenic transport tanks and 600 drivers from across its 45 plants with an installed capacity of over 20,000 TPD.

An air separation unit at a SAIL plant, where oxygen is generated. *Credit: Inox Air*

How Maglev Works...

Continued from page 15

the further it gets from the center of the guideway or the closer to the bottom, the more magnetic resistance pushes it back on track.

The third set of loops is a propulsion system run by alternating current power. Here, both magnetic attraction and repulsion are used to move the train car along the guideway. Imagine the box with four magnets, one on each corner. The front corners have magnets with north poles facing out, and the back corners have magnets with south poles facing outward. Electrifying the propulsion loops generates magnetic fields that both pull the train forward from the front and push it forward from behind. This floating magnet design creates a smooth trip. Even though the train can travel up to 375 mph, a rider experiences less turbulence than on traditional steel wheel trains because the only source of friction is air.

Another big benefit is safety. Maglev trains are "driven" by the powered guideway. Any two trains traveling the same route cannot catch up and crash into one another because they're all being powered to move at the same speed. Similarly, traditional train derailments that occur because of cornering too quickly can't happen with maglev. The further a maglev train gets from its normal position between the guideway walls, the stronger the magnetic force pushing it back into place becomes.

This core feature is what's most exciting to Jesse Powell. "With maglev, there is no driver. The vehicles have to move where the network sends them. That's basic physics. So now that we have computer algorithms for routing things very efficiently, we could change the scheduling of the entire network on the fly. It will lead to a much more flexible transportation system in the future," he said.

While this exciting technology isn't deployed in the US today, if Powell and his team get their way, you could someday be floating your way to your next destination.

Cryogenics for Green Business

by Jean Philippe Vernet, EOSgen-Technologies, jean.philippe.vernet@eosgen-technologies.com

Imagine a new world without any addiction to fossil energies. At EOSgen-Technologies, we have adopted Maupertuis's principle, described in the 17th century: "Nature, in its different processes, always uses the least energy possible." This is the building concept of our machines.

Today, if you live in a remote village, a long distance from an industrial center, it is difficult to be supplied with oxygen for a medical center, argon for soldering or repairing car bodies, nitrogen for inerting fresh foods in a blister package, or CO_2 for soda or beer. Some solutions exist (membranes, molecular sieve, etc.) but with big energy expenses. At the core of our system is a Stirling cryogenerator and a cryopump.

After having cleaned the air, The Stirling liquefies it and a high pressure cryopump puts it in pression. Then liquid air comes into a first stage that separates pure oxygen (Oxusgen process®) from the rest of the gases contained in the air. A second stage is composed of a distillation column (Gengas®) that separates nitrogen and rare gases from argon. Pure nitrogen and argon flow out at a liquid state, while rare gases remain gaseous but can be recovered. N_2, O_2 and Ar are stored in cryo tanks, one for each liquid gas.

Finally, the Auregen process® is a Nitrogen Rankine cycle which is operated at the hot source by flue gases, sun, hot water (sewage, hot spring water), flare gases, etc., and at the cold source by our core (Stirling cryogenerator plus high pressure pump) that both condenses nitrogen and pressurizes it. Nitrogen is reheated through the industrial gas process that must be cooled. However, ambient air is sufficient to reheat nitrogen. Afterward, nitrogen is heated above ambient temperature by the renewable heat (from 20 °C to 500 °C). A Ljungstrom turbine makes the mechanical job (500 °C < T < 0 °C as hot intake to -200 °C cold exhaust), and a high-speed cryogenic alternator finishes the action with electricity production. The Ljungstrom allows us to have an expansion from 25 bars to 0, 2 mbars (80 K) with a 90% polytropic efficiency. Remember that liquefying a gas is equivalent to a very high compression, dwindling volume 700 times. Through our system, the cooling of gas is recovered by its heating after the liquefaction. Thanks to the Stirling cycle, we use only liquefaction and pressurizing energies. We are able to produce hydrogen with energy recovery and to separate nitrogen from air (Oxusgen process). Through our practices, we can also produce green ammonia (Uma NH_3 process®), and because we know how to recover and purify CO_2, we can produce 2G methane (Uma CO_2 process®) or make methane from CO_2.

Current projects for customers

Flue gas-off of a boiler: For this customer, the project consumes 450 kW of natural gas for heating a building while rejecting 45 kw of flue gas at 180 °C. Auragen makes it possible to produce 100 kW of electricity + 5,000 m³/h of air conditioning by trapping CO_2 and condensing water contained in smoke.

Green H_2 production: (Uma H_2) Auragen and 11,000 square yards (ground surface) allow us to produce 683 kg/day of H_2 with heat storage and sun capture. Capital expenditures: 10,600 k€. The overhaul maintenance of this project occurs every 15 years and amounts to 850 €/month.

Industrial gas production in Caribbean: This project is for an island and a surrounding archipelago. The producer can sell 8,000 m³/y nitrogen, 20,000 m³/y oxygen, and 4,000 m³/y argon. However, with Auragen, the plant doesn't require any outside energy supply. Capital expenditures: 1,000 k€. (The maintenance cost is 20 k€/y; the production cost of nitrogen is 0,006 €/m³; the cost of oxygen is 0,016 €/m³; and the argon is 0,355 €/m³.)

Aluminum production: For this project, the furnace flue gas flow is 1,960 m³/h with a temperature of 543 K. Auragen condenses and cleans the water (180 kg/h), condenses and cleans CO_2 (223 kg/h), and captures process dioxyne. N_2 + O_2 and rare air gases, released in air at 120 K, were issued from the initial combustion air. The electrical energy produced is 392 kW. Capital expenditures: 1,100 k€ with a maintenance cost of 0 k€/y.

Flare gas recovery: Worldwide, 145 x 106 m³ is flared, producing 350 million tons of CO_2. Flare gas is HHV of 13,06 MWh/Nm³, 0,0863 kg produced CO_2 / FG m³ + 0,071 kgH_2O/ FG m³. The solutions are: separate components through our Gengas; burn all and recover water and CO_2 through Auragen; and recover H_2, CH4, CO_2 and water, and burn all other components through the use of Gengas and Auragen.

Look who's NEW in the Cold Facts Buyer's Guide

Cold Facts Buyer's Guide is the place to find suppliers in every area of cryogenics and superconductivity. These are the new suppliers added to the Buyer's Guide since the last issue of *Cold Facts*. Find it online at **csabg.org**.

Brymill Cryogenic Systems

Manufacturer of hand-held LN_2 cryosurgery devices used to treat common skin lesions and offering a comprehensive selection of cryosurgical spray tips, probes and other accessories enabling greater control and accuracy.

Canadian Nuclear Laboratories*

Canadian Nuclear Laboratories has significant expertise in tritium handling, including the design of tritium removal systems from air and water and the use of cryogenic systems to concentrate tritium and store it as a metal hydride.

Danaher Cryogenics*

Offering a wide range of cryogenic solutions, from high-efficiency pulse tubes to full cryostat systems. Custom, one-off designs and standard models. Also integrating Chase Research Cryogenics coolers and representing Leiden Cryogenics in North America.

Hylium Industries, Inc.

Hylium's LH_2 technologies, created by industry specialists with R&D experience of over 20 years, offer ASME, ISO, KGS certified storage, transportation, bulk and fuel tanks that can be utilized across multiple sectors within the hydrogen industry.

Ishani Engineers

Manufacturer specializing in manifold and gas fittings in both standard and custom design based on customer specifications.

Paragraf Limited*

Paragraf develops contamination-free, high purity 2D graphene, manufactured at scale. Its cryogenic Hall sensor is the only Hall sensor capable of measuring magnetic field strengths of 7 T and above, at mK temperature extremes.

***CSA CSM**

Breaking the Ice with Imtek Cryogenics

Family Dedicates Lifetime to Developing Next-Generation Cryocoolers Through Product Mobility, Stand-Alone Architecture and Scalability

View of the new Imtek Cryogenics building. *Credit: Imtek*

Since its establishment, Imtek Cryogenics has been developing cryogenic liquefiers, test and measurement systems and nanotechnological equipment to meet the demand for high performance and energy efficient cryogenic products used in universities, R&D centers, clean rooms, industrial establishments, IVF Centers, dermatological and cryotherapy clinics and livestock centers. Recently, the family-owned company has expanded the scope of its R&D activities and has increased its thermodynamic efficiency and reduced unit costs in its new generation cryoplants.

With a wide range of products, such as the liquid nitrogen (CNP) and laboratory liquid nitrogen generator (CNLab), the liquid oxygen generator (COP) and the argon liquefier (CAP), Imtek Cryogenics continues to provide solutions for all LN_2 delivery and storage needs. The technology used in new generation liquid nitrogen generators purifies nitrogen from air around the plant and converts this to Liquid N_2, ready for utilization. The dispensing thermos, wherein Liquid N_2 is transferred, is filled via a flexible hose to an external dewar by simply the push of a button. This is what sets Imtek Cryogenics products apart: easy use of interface.

Usable, accessible and scalable

The most important thing for Imtek Cryogenics, when it comes to design, is meeting the user's requirements. Imtek works with clients strategically to develop a progressive design language (PDL) that meets all three criteria. The idea behind our PDL is simple: bringing intelligent, easy and on-demand operation to the consumer. Experience, knowledge and ideas come together to create a one-of-a-kind product with a consistent design development for user-friendly liquid N_2 consumption.

Imtek Cryogenics has also released the world's first portable stand-alone nitrogen liquefier. Easy installation and unlimited mobility are the most desirable benefits of a wheeled platform concept, which is the key differentiating factor for usability and accessibility. CNP10/40 arrives as a plug-and-produce system with a fully integrated design, which makes the cryogenics as simple as a one-button operation. This simplicity allows the usage of cryoplants in research laboratories and many more environments. Advanced alarm management systems are designed to decrease user burden while increasing user accessibility: simply plug in the device and start producing your own cryogen.

The CNP60 is the first member of Imtek's large capacity cryoplants providing high performance LN_2 production, while requiring low maintenance operation. The modularly designed CNP120 is also a member of the CNP family, with a capacity of 120 liters-per-day (expandable up to 480 liters-per-day). Each of these standardized modules can be built and tested independently and stand on its own until the main module is ready to accept it. Modular design has many benefits for cryoplant customers, both from an economic standpoint and an efficiency standpoint, as it allows for incremental upgrades as opposed to replacing an entire unit. Modular design is the present and future of design.

There is a range of developmental areas, such as minimizing the losses that occur due to the execution of all cryogenic applications at temperatures much lower than room temperature, material deformation, and the effect of thermal aging on the efficiency of this field. Imtek Cryogenics' R&D team is where mechanical, material, chemical and physics engineers work together to find solutions to these problems. Moreover, there is experimental research conducted on new materials daily, as well as new techniques and forms found for furthering the development of cryogenic technologies.

Where modeling and simulation studies are carried out, Imtek's hardware and software infrastructure ensures that critical design parameters can be optimized in terms of high energy efficiency. The support of the ultraprecision machining infrastructure with high quality measurement systems makes it easier to overcome all the difficulties in prototype production, with close to design precision and to reach the expected theoretical efficiencies. With its experienced manpower and ability to produce fast solutions, Imtek Cryogenics has succeeded in developing 21 model products in four different groups and bringing them to THS-9 level in a short time.

▶ *continues on page 20*

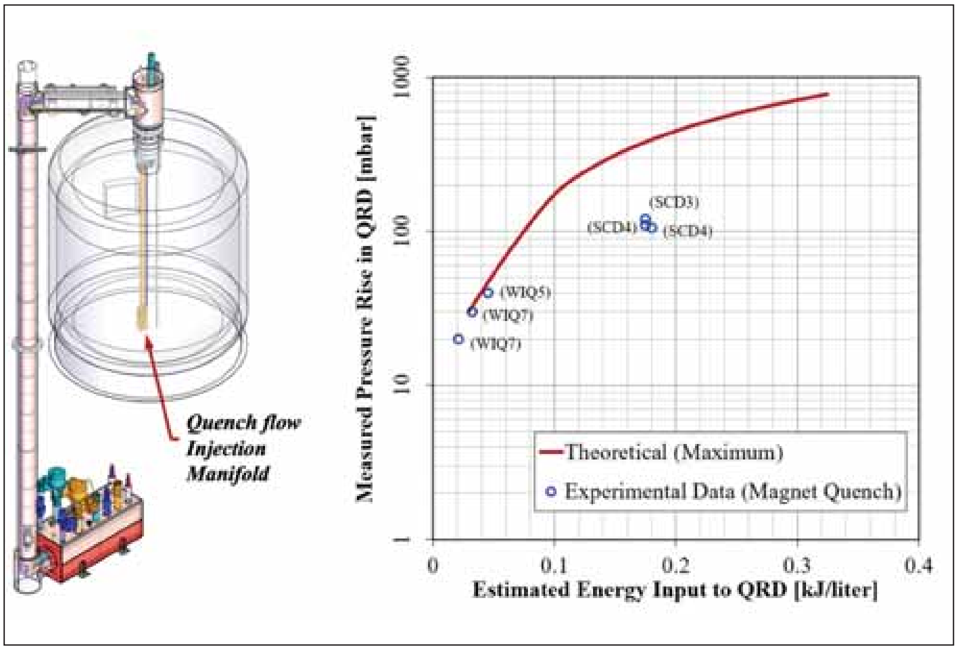
Designing the Cryogenic Distribution and Quench Management System for FRIB's Target and Fragment Pre-Separator

by Nusair Hasan, Facility for Rare Isotope Beams, Michigan State University

The Facility for Rare Isotope Beams (FRIB) at Michigan State University uses projectile fragmentation and induced in-flight fission of heavy-ion primary beams at energies of 200 MeV/u and higher and at a beam power of 400 kW to generate rare isotope beams.[1] The heavy-ion beams are accelerated in a superconducting radio frequency, three-segment-folded (in the shape of a paper clip) linear accelerator (linac), consisting of 46 cryomodules and four superconducting dipole magnets.[2]

The experimental system of the accelerator consists of 14 new superconducting magnets, which are dipoles and quadrupole triplets, in the target and fragment (pre-) separator section. The design and operating requirements for these large magnets are significantly different from the rest of the smaller beamline cryostats at FRIB. These superconducting magnets have a cumulative liquid helium inventory of approximately 8,000 liters and a total heat load of about 700 W at 4.5 K, and approximately 2 kW of shield load at 50 to 65 K. The stored magnetic energy can be as high as approximately 2.0 MJ per magnet. A single refrigeration system supports the three linac segments and the experimental system magnets through a cryogenic distribution system that is separated into four segments following their geometrical arrangement along the beamline. This simplified the installation, commissioning and troubleshooting efforts to meet a very aggressive project schedule.

Design of the cryogenic distribution and transfer line for large-scale cryogenic systems in particle accelerators is a complex task, involving design consideration for unique devices (i.e., cryomodules, superconducting magnets) and their varying operating modes (i.e., steady-state, cooldown, warm-up, quench-handling and recovery). Since all cryostats are supported by the same refrigeration system, the superconducting magnet quench aspect poses a particular potential risk on the stability of the sub-atmospheric (2.0 K) operation of the cryomodules provided by the multistage cryogenic compressor system. Traditionally, a quenched superconducting magnet is isolated from the rest of the cryogenic system (to prevent operational instability), and the cryogen (helium) is expelled from the magnet cryostat via a pressure relief valve to prevent over-pressurization. Under such conditions, this results in a loss of both the cryogenic coolant (released to the atmosphere) and the stored refrigeration. The cost is then both to replenish the helium expelled and the additional input power to recover the lost refrigeration (i.e., the exergy contained in the helium that adsorbed the magnet quench energy). In the US, more than one-third of the total annual helium consumption is from the cryogenic refrigeration sector. Since the known helium reserves are depleting, a significant amount of cost can be expected from price escalation to replenish the expelled helium.



At left, Quench Recovery Dewar (QRD) for FRIB's target and fragment pre-separator magnets and (right) observed pressurization of the QRD due to different magnet quenches at FRIB experimental system. *Credit: FRIB*

Efficient design of a cryogenic distribution system to manage the operational stability, while maintaining the cryogenic system availability, requires adequate knowledge of the overall cryogenic system, different operating modes and stability criteria for the loads. Based on these considerations, the cryogenic distribution system for FRIB's target and fragment (pre-) separator section was designed and fabricated completely in-house by the FRIB cryogenic department staff.[3] Of course, the design and fabrication experience gathered from past projects (i.e., design of FRIB's linac cryogenic distribution) greatly helped in the successful execution and commissioning of this project. However, detailed planning, concept development and design efforts were still required due to the novel features (i.e., cooldown, quench management) of the target and fragment (pre-) separator cryogenic transfer line and the distribution system interfacing with the associated superconducting magnets. Several components of the distribution system (i.e.,

▶ *continues on page 20*

Breaking the Ice with Imtek Cryogenics... *Continued from page 18*

The machining facilities at Imtek Cryogenics house a range of ultraprecision turning and milling machines from leading suppliers. High precision parts are being used more and more frequently in the manufacture of optics, air bearing systems, laser system components, in medical technology and in tool making. Ultraprecision machining technologies are crucial to the successful production of high precision mechanical components in a wide range of different materials with the highest level of form accuracy and surface quality. The company's precision machining assembly capabilities include a clean room, integration services, and a turnkey product management process to manage every aspect of the production cycle, including finishing, testing and handling.

Imtek Cryogenics' younger generation managers are looking forward to a bright future of developing a wide range of new high performance and energy efficient cryogenic products, as well as researching new industrial applications. Imtek Cryogenics employees are provided with a dynamic work environment where they can be personally inspired to achieve their best. To encourage individual ideas and creativity and to achieve common success through cooperation and competition, Imtek Cryogenics enables its employees to easily reach the creativity they need to advance rapidly in their careers while providing them with outstanding training and research opportunities. **www.imtekcryogenics.com**

FRIB's Target and Fragment Pre-Separator... *Continued from page 19*

transfer line anchors, vacuum breaks) were originated and developed with careful mechanical and thermal analysis and testing. The experimental system cryogenic distribution system consists of three different cryogenic circuits: 4.5 K helium, thermal shield and cooldown/quench return. These are enclosed with a single 175-meter-long vacuum jacketed transfer line with associated magnet distribution boxes, cooldown heat exchanger, utility piping (such as magnet lead flow return, purge gas, etc.) and a 10,000-liter cryogenic storage vessel. The thermal energy and boiloff flow released during quench in FRIB's target and fragment (pre-) separator superconducting magnets are handled using this cryogenic storage (buffer) vessel, also known as the Quench Recovery Dewar (QRD).

The unique quench management system implemented at FRIB is based on a concept that was originally developed and successfully demonstrated at the Superconducting Super-Collider Lab (SSCL) for the magnet string test in 1993. The QRD incorporates some specific design features like a quench flow sparger and a segregated quench flow circuit. The QRD volume is sized to store the FRIB experimental system superconducting magnet inventory in the case of maintenance and also to absorb the pressure pulse and energy released from these magnets as a result of a quench, while completely containing the helium without venting to atmosphere. Following a quench, the stored refrigeration is recovered by the FRIB cryogenic refrigerator by depressurizing the QRD. Due to the implementation of the Ganni Floating Pressure process,[4] this does not pose a risk to the refrigerator stability or operation of the rest of the loads. Different quench scenarios were studied by the FRIB cryogenic department staff, and the cryogenic system response in the event of a magnet quench was automated. It has provided a robust and stable operation for the superconducting magnets during training and normal operations, while preserving the helium inventory and allowing a quick turnaround time for operation and availability. Based on the operational experience to date,[5] the recovery time from a quench event until the QRD and quenched magnet have been depressurized and the quenched magnet has been refilled, is approximately 30 to 45 minutes.

To meet the FRIB project schedule and magnet testing requirements, the target and fragment (pre-) separator distribution system was planned to be installed and commissioned in two phases. The first phase involved installation and commissioning of approximately 100 meters of the cryogenic transfer line, associated cryogenic interfaces, a magnet test station and a cooldown heat exchanger. This phase was installed and commissioned by the end of 2020. The second phase involved the rest of the cryogenic transfer line, magnet distribution boxes, and the QRD. This phase was installed and commissioned by spring 2021. To date, all the superconducting magnets have been cooled, energized and field-mapped, using this cryogenic distribution and quench management system. There have been 18 recorded events of a quench, with the QRD absorbing each of these without affecting the cryogenic refrigerator or the other operating magnets and cryomodules operating at 2 K, and without venting helium.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB), which is a DOE Office of Science User Facility, under Award Number DE-SC0000661. Michigan State University operates the Facility for Rare Isotope Beams as a user facility for the U.S. Department of Energy Office of Science (DOE-SC), supporting the mission of the DOE-SC Office of Nuclear Physics. **https://frib.msu.edu**

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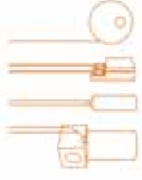
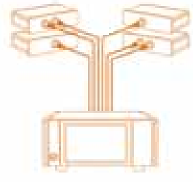
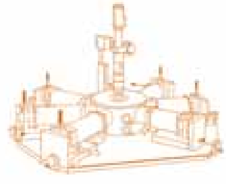






Eta Space Develops Cryogenic Propellant Depots for Earth and Space

Digital rendering of Lunar Propellant Production Plant. *Credit: Eta Space*

Eta Space, a new space company dedicated to developing advanced cryogenic systems for the modern space and energy age, is celebrating its three-year anniversary in June with milestones scheduled for several key projects.

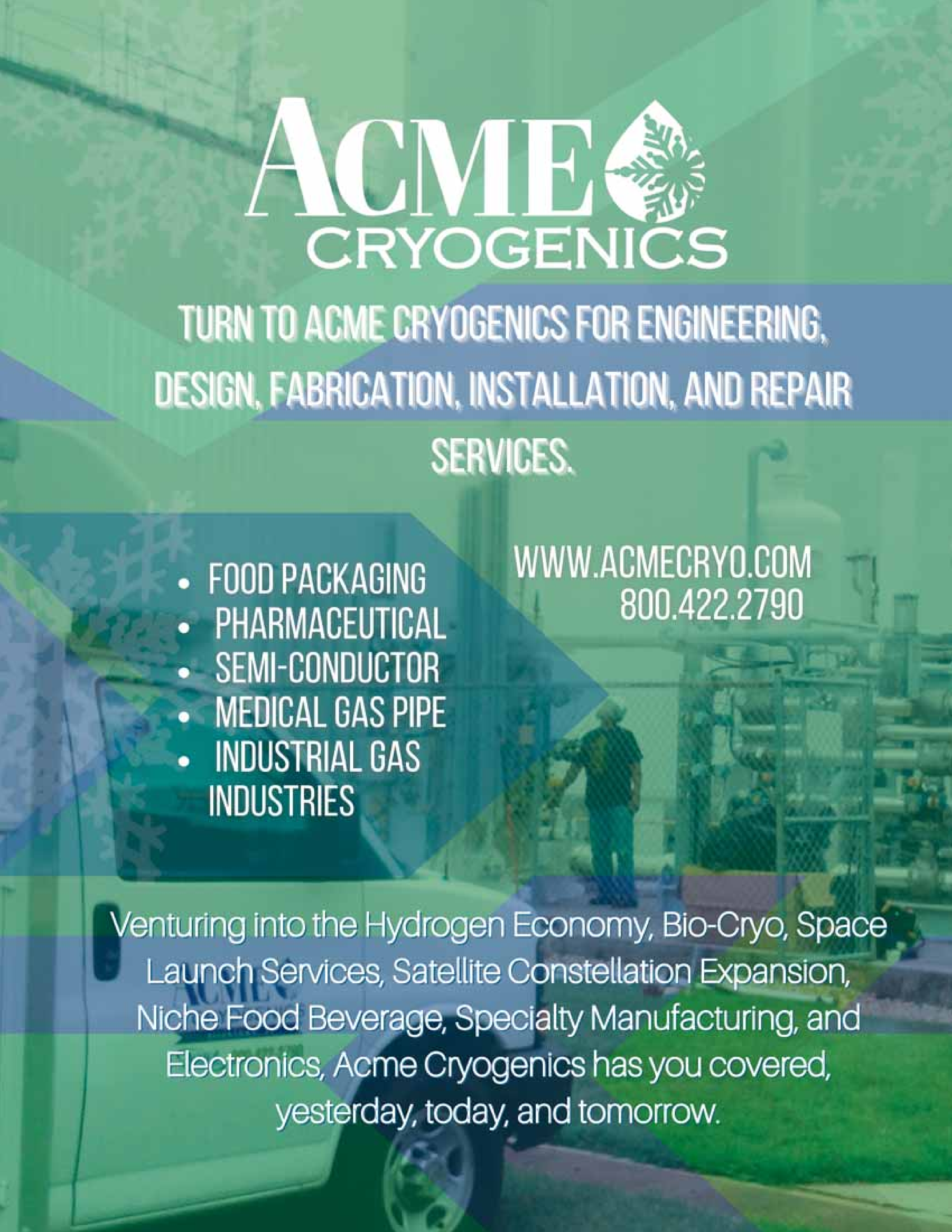
Eta Space is developing LOXSAT, a 135 kg demonstration satellite designed to test critical cryogenic fluid management (CFM) technologies in Earth's orbit. Funded as a Tipping Point public-private partnership with NASA Space Technology Mission Directorate (STMD), LOXSAT will include 12 individual test objectives to be operated in a microgravity environment for the first time, bringing the Technology Readiness Levels of these systems to TRL7. The demonstrations include zero boiloff storage, propellant densification, pressurization and pressure control, and no vent chilldown and transfer of LOX. The payload will include fluid visualization integrated into the storage tank, enabling validation of zero-g computational fluid models. LOXSAT is scheduled to complete the critical design review in June, a milestone that demonstrates design maturity is sufficient for fabrication and assembly of the payload. LOXSAT is planned to fly on a Rocket Lab Electron rocket in March 2024 on a nine-month mission.

In parallel with the LOXSAT design work, Eta Space is proud to announce the development of Cryo-Dock™, the world's first commercial cryogenic propellant depot in Earth orbit. Cryo-Dock is designed to service spacecraft stages and orbital transfer vehicles with high-energy liquid oxygen/liquid methane, using a standardized, automated umbilical. Leveraging the successful demonstration of the CFM technologies during the LOXSAT mission, Cryo-Dock will feature full control of the cryogenic propellants in microgravity, including long-term zero boiloff storage and zero-loss chilldown, as well as transfer of the cryogenic propellants. This capability will enable a new era of sustainable space transportation, where spacecraft refueling and reuse will dramatically lower the cost of in-space transportation.

NASA has awarded another Tipping Point contract to Eta Space for development of a liquid oxygen/liquid hydrogen (LOX/LH_2) propellant depot for lunar exploration. The entire system is designed for operation in the extreme environment of the lunar poles, where permanently shadowed regions in craters have been subjected to cryogenic temperatures for millions of years. These cold-trap areas are thought to contain large reserves of volatile elements including water ice, which can be collected, purified and split into its hydrogen and oxygen elements. Eta Space and Skyre are building and testing a ground-based version of a 1/50th-scale Lunar Propellant Production Plant (LP3). Skyre is providing the warm electrochemical systems, while Eta Space is providing the cryogenic components for liquefaction and storage. The long-term goal is production of ten metric tons of LOX/LH_2 per month.

While enabling technology for this sustainable lunar base architecture, the LP3 cycle also has direct applications for "green hydrogen" on Earth. LP3 uses the same process of producing hydrogen from water and solar energy that is the "holy grail" of terrestrial hydrogen energy. However, LH_2 production and storage is historically an energy-intensive process, and the ability to liquefy and store large quantities of hydrogen efficiently is a prime goal of Eta Space. While at NASA KSC, founder Bill Notardonato pioneered the concept of Integrated Refrigeration and Storage (IRAS) that allows for direct control over the state of the cryogenic fluid. First working with Dr. Jong Baik at the Florida Solar Energy Center, the IRAS concept was successfully demonstrated on small scales starting in 2004. Later tests culminated in a full-scale demonstration of zero-loss liquid hydrogen storage and transfer and hydrogen densification using an IRAS system for the Ground Operations Demonstration Unit for Liquid Hydrogen at Kennedy Space Center in 2014. This technology is being incorporated into the world's largest LH_2 tank at LC-39B at KSC. Eta Space also operates a small-scale hydrogen liquefier (150 liters) and thermal vacuum chambers to enable testing of materials and components intended for use with LH_2.

Eta Space is leveraging its engineering skills, honed from decades of experience at NASA, to develop a series of in-space cryogenic propellant depots critical to creating a sustainable space program. This experience of using ultrahigh efficiency in cryogenic storage and transfer systems is necessary to help transition the earth towards a clean hydrogen energy foundation. **https://etaspace.com**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Cryo Bios

by Dr. John Weisend II, European Spallation Source ERIC, CSA Chairman, john.weisend@esss.se

Fritz Wolfgang London

Fritz London and his younger brother, Heinz, both together and separately made fundamental contributions to the fields of cryogenics and superconductivity. The accomplishments and the story of each of these brothers is sufficient for their own column, so this time Fritz will be the subject and Heinz will be discussed in the following issue of *Cold Facts*.

Fritz Wolfgang London was born in Breslau, Germany (now Wroclaw, Poland). His father was a mathematician who early in Fritz's childhood became a professor in Bonn, Germany. Fritz completed his secondary education in Bonn and studied at universities in Bonn, Frankfurt, and Munich. His first interest was philosophy, and the thesis that he wrote for his doctorate from the University of Munich in 1921 was on that subject. London briefly taught in secondary schools, but he found the new field of quantum mechanics fascinating; and in 1925 he began to study theoretical physics. He studied at a number of universities with leaders in the field, including A. Sommerfeld (Munich) and E. Schrödinger (Zurich).

In 1927, while in Zurich, he wrote a paper with physicist Walter Heitier, using quantum mechanics to describe the bonds in a hydrogen molecule. This was a landmark paper that started the field of quantum chemistry, the application of quantum mechanics to chemical processes and interactions. London continued to contribute to this field for the rest of his career. In 1930, he described what is now known as the London Dispersion Force. This is a very weak intermolecular force, which, among other effects, explains why noble gases such as helium can become liquids at sufficiently low temperatures. In 1933, after Hitler came to power in Germany, London, who was Jewish, was forced to leave his position at the University of Berlin. He moved to Oxford, England, where he was joined by his brother, Heinz, who had similarly fled from Breslau.

Superconductivity had been discovered in 1911. In the 1930s, there was still no theoretical explanation of superconductivity, and new phenomena continued to be discovered. In 1933, W. Meissner and R. Ochsenfeld discovered that superconductors would expel magnetic fields from inside them upon becoming superconducting and would not permit the penetration of applied magnetic fields into them once in the superconducting state. This was known as the Meissner effect. Working together shortly after this discovery, Fritz and Heinz London developed the London equations, which modeled the electromagnetic behavior of superconductors. These equations, essentially a limited example of the Maxwell equations, correctly described the Meissner effect and predicted the London penetration depth, the thickness at the surface of a superconductor in which the magnetic field decays exponentially. The London penetration depth varies with materials but is generally very small, on the order of tens of nanometers. The London equations were not a fundamental theoretical model of superconductivity. However, they remain valid today and provided an important early insight into the physics of superconductivity, stressing the importance of superconductors as perfect diamagnets rather than perfect conductors. Crucially, Fritz and Heinz London recognized that superconductivity represented a macroscopic example of quantum mechanics.

Due to a lack of funding in Oxford, Fritz London moved to the Institut Poincaré of the University of Paris in 1936. During his three years there, he made another important contribution to cryogenics. In 1935, superfluidity in He II had been simultaneously observed by J. Allen (*Cold Facts*, 2020, No. 4) in Cambridge and P. Kapitza (*Cold Facts*, 2018, No. 5) in Moscow. London proposed, somewhat controversially, that the onset of superfluidity could be explained if a fraction of the He II had undergone Bose-Einstein condensation to the quantum ground state. Also at the Institut Poincaré at that time was Laszlo Tisza (*Cold Facts*, 2021, #4). Using London's insight and working together with him, Tisza developed the two-fluid model of He II.

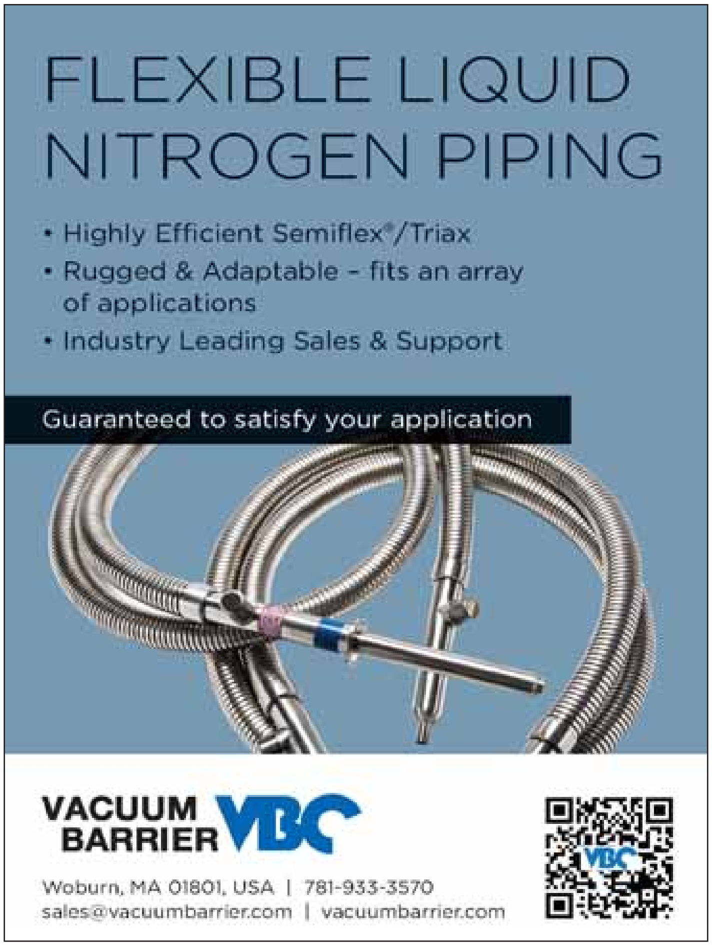
Fritz Wolfgang London

Born March 7, 1900

Died March 30, 1954
Durham, North Carolina

With World War II looming in 1939, Fritz London emigrated one last time. He moved to the US, where he took a position as a professor of chemistry at Duke University in Durham, N.C. He remained at Duke for the rest of his life. There, he lectured on topics such as quantum chemistry, quantum mechanics and statistics. He continued to publish articles on cryogenics, superconductivity and quantum chemistry. He summed up a great deal of his work in a two-volume set, *Superfluids*, published by Wiley in 1950 and 1954.

Fritz London was awarded the Lorentz Medal by The Royal Netherlands Academy of Arts and Sciences for his contributions to theoretical physics. He is further honored by the Fritz London Memorial Prize, which is administered by Duke University and awarded every three years for outstanding contributions to low temperature physics. Further details of London's life and scientific output can be found in *Fritz London: A Scientific Biography* by K. Gavroglu (Cambridge, 2005).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Cool Fuel

by Dr. Jacob Leachman, Associate Professor, Washington State University, jacob.leachman@wsu.edu

A Tale of Two Kilograms

It was the best of fuels... It was the worst of fuels...

Hydrogen has always been the fuel of the future. Hydrogen's high activity and zero carbon wins the award for best fuel from an energy standpoint. The problem has always been getting it there, literally. The logistics of storing and distributing hydrogen are often the most challenging of any fuel and the deciding factor in projects. Convenient hydrogen production from water electrolysis is rapidly changing this logistics challenge. In this tale, we'll consider the respective paths of two hydrogen kilograms from point-of-production to end use. Let's assume both kilograms were produced via green electrolysis and output at 3.4 MPa (500 psia). One kilogram is transferred through a standard natural gas pipeline.[1] A second kilogram is transferred through a standard 4,300 kg liquid hydrogen tanker truck.[2] Both kilograms are going to the same end location. Which kilogram arrives with the least work? Let's find out!

The US has operated over 2,500 km (1,600 miles) of hydrogen pipelines for several decades.[3] We'll assume a typical 10 cm (3.7-inch I.D.) pipeline with hydrogen compressed to 10 MPa (1450 psia) and 300 K, delivering 0.5 kg/s (1.1 lb/s) of hydrogen. To compress our hydrogen flow up to the pipeline pressure, a dual-stage reciprocating compressor is specified, requiring 920.9 kW of work.[4] This one-time fee to "pack" the hydrogen for transport is known as a packing cost. As the hydrogen flows in this pipeline, friction losses (even though hydrogen has one of the lowest viscosities of any fluid) cause viscous dissipation of fluid power into entropy generation. (We'll call this accumulating fee the transport cost.) One analysis found hydrogen will lose half the initial fluid power over 80 km (50 miles). As the hydrogen flows, the density reduces, causing an increase in velocity and resulting in shockwave formation and choking the flow above 100 km (62.1 miles). A 464.5 kW reciprocating booster compressor is specified (neglecting intercooling) to recompress this flow every 80 km but can be averaged on a per-km basis for simplicity.

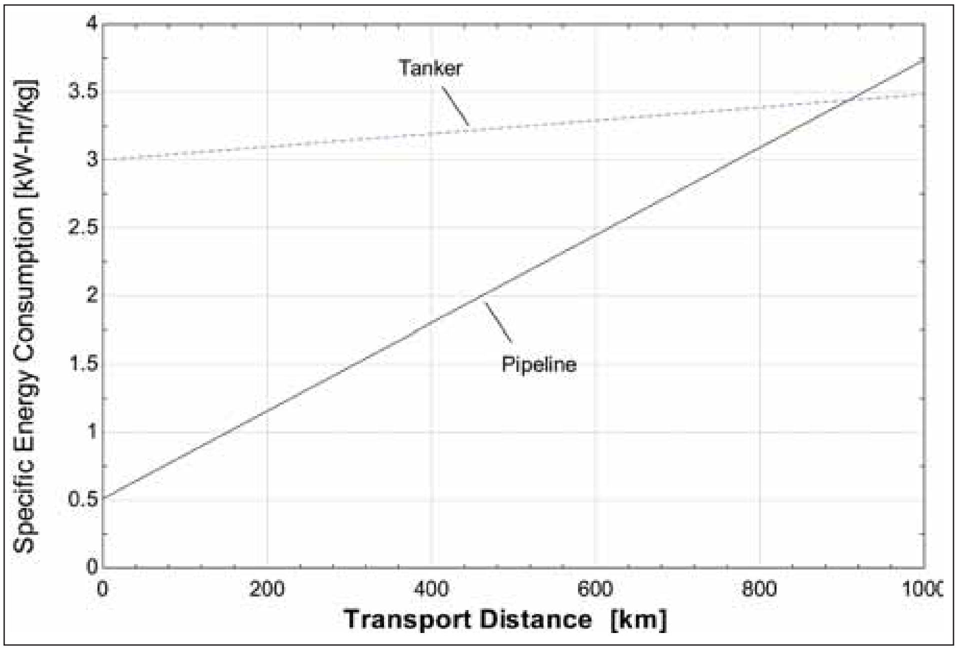

Figure 1: Comparison of packing and transport costs delivered by pipeline vs. liquid tanker truck. *Credit: Jacob Leachman*

The second kilogram of hydrogen is liquefied, a substantial packing cost, for tanker transport. The theoretical minimum specific energy consumption (SEC) for a liquefaction cycle operating with these conditions is nearly 3 kW-hr/kg. (For anyone wondering, that's about 7% of the usable energy content of the fuel, and the realistic SEC is ~12 kW-hr/kg.) Once loaded into a 4,300 kg tanker, we need to estimate the energy penalty for moving the tanker. We'll assume the tanker is pulled by a Kenworth T680 with a PEM fuel cell stack achieving 8 km/kg (5 miles/kg), operating with the boiloff gases (1.5% or ~65 kg of contents per day, enough for roughly 520 km range per day).[5] One hidden perk of liquid hydrogen is the relative ease of compression at the end use. Liquid hydrogen grabs free heat from the surroundings to warm up, and it autogenously pressurizes from the normal boiling point up to 192 MPa (27,900 psi).

Figure 1 compares the packing and transport costs for the kilogram delivered via pipeline versus delivered by liquid tanker truck. The packing costs are shown by the y-intercept and the transport costs by the slope. Although liquid hydrogen has a much higher packing cost (even in the ideal case), the transport costs are considerably less. Notice the pipeline kilogram takes less work to deliver at all distances up to 909 km (564 miles). This value is comparable to a similar study out of the European Union last year that found the breakeven point to be ~3000 km, which corresponds to more realistic liquefier SECs.[6] Remember the assumptions we made: this pipeline is delivering hydrogen to a single location and is transporting roughly 10 tanker loads equivalent per day. This is a likely scenario for refinery use, which is the application for current hydrogen pipelines. However, this is not the highest value scenario, which is vehicular refueling. What happens when our pipeline delivers a tanker load equivalent through a network to ten or more different vehicular refueling locations?

The resulting pipeline network can become complicated and subject to many variables quickly. To generalize this, Figure 2 shows the allowable pipeline length before choking, versus mass flow rate at various diameters. If we ideally assume the flow bifurcates just before choking (i.e., splits into two with the internal diameter reducing two cm in each of the subsequent branches), we can get about 100 km after every branch, with recompression, of course. Our hydrogen pipeline network could then arrive at ten different refueling locations positioned approximately 500 km away from the source. This hydrogen would only be at two atmospheres and would need recompression all the way up to the vehicular storage pressure (typically 35 or 70 MPa). If you add in this repacking cost at the point of use (assuming ~1 kW-hr/kg packing cost), our two kilograms have a nearly equivalent distribution cost.

From this, we see that liquid hydrogen transport can be competitive with pipelines for the high-value end uses of hydrogen in zero-emissions vehicle markets. Notice that I said '**can**.' I assumed an ideal liquefier and no liquid compression or pumping costs. We need basic research programs to greatly improve these capabilities. While hydrogen pipelines are the talk of the town, liquid isn't going away any time soon.

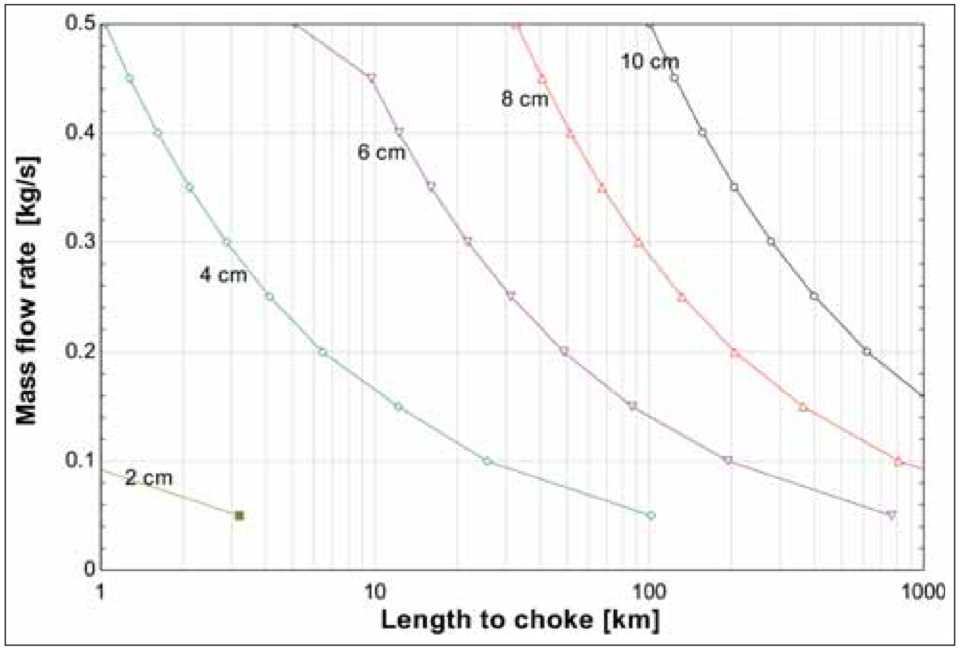

Figure 2. Allowable pipeline length before choking vs. mass flow rate. *Credit: Jacob Leachman*

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by Ian McKinley, Dean Johnson, and Jose Rodriguez, Jet Propulsion Laboratory, California Institute of Technology

The ECOSTRESS Instrument After Four Years in Space

The ECOSystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) instrument is a multispectral thermal infrared imaging radiometer, and its primary mission is to investigate and understand how climate change affects water and carbon usage on Earth.[1] The instrument measures the surface temperature of Earth with a resolution that is able to capture individual farm fields.[2] The data collected by ECOSTRESS is processed into a product called the Evaporative Stress Index, which indicates whether plants are stressed and if a drought is likely to occur.[2]

ECOSTRESS attaching to the ISS. *Credit: NASA*

In early July 2022, ECOSTRESS will have operated for four years in space. Launched on June 29, 2018, and originally scheduled for a one-year science mission, its mission has been extended multiple times, with the current planned end of operations scheduled for September 2023. The instrument was transported to the International Space Station (ISS) as unpressurized cargo aboard a SpaceX Falcon 9 rocket that launched from Cape Canaveral Air Force Station Space Launch Complex 40. On July 2, 2018, the spacecraft successfully arrived and docked at the ISS, and on July 5, ECOSTRESS was extracted from the cargo trunk and installed on the Japanese Experiment Module-External Facility (JEM-EF) by robotic arm. The following day, the instrument was successfully powered on and officially began its science mission.

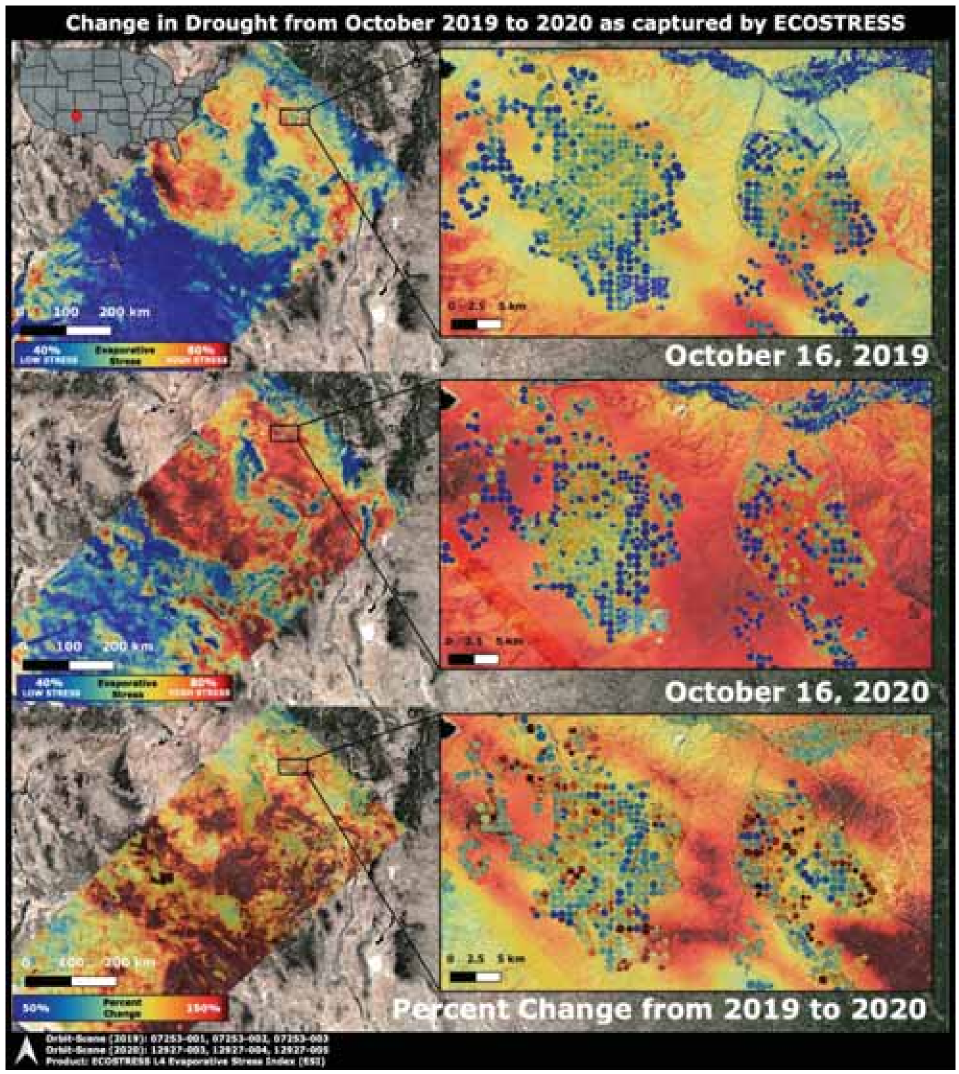
The ECOSTRESS instrument is housed in a six-sided box roughly two meters by one meter by one meter. The nadir panel of the box has a baffle opening that is roughly one meter by 0.25 meters. A scan mirror continuously rotating at approximately 0.423 Hz inside the enclosure allows for the focal plane array (FPA) to cyclically see the temperature of two different blackbody targets within the enclosure as well as the earth. The instrument electronics boxes populate one of the two meters by one-meter side panels of the enclosure, and one of the enclosure ends is comprised of the payload interface unit. This interface unit is Government Furnished Equipment that is like an umbilical cord for the instrument and used to make the electrical, thermal and mechanical connections to the JEM-EF module.

The thermal control system of ECOSTRESS consists of a combination of active and passive components to maintain the instrument temperatures within the allowable limits. The FPA detector is maintained at 65 K by two Thales Cryogenics LPT9310-HP cryocoolers[3] and is surrounded by a cold shield that operates at 130 K and is cooled by a single LPT9310-HP cooler. The waste heat generated by the three cryocoolers, electronics and one of the blackbody targets is removed by non-planar cold plates and tube-on plate heat exchangers.[4] The heat is then transported by a single-phase circulating fluid loop in the JEM-EF module to radiators external to the space station. In fact, requirements were in place to limit the radiative heat exchange between the instrument and its surroundings. This limitation on radiative heat transfer out of the instrument made compliance with the JEM-EF pumped fluid loop requirements for pressure drop and outlet fluid temperature with a given minimum specified mass flow rate one of the key thermal design drivers of ECOSTRESS.[1] The fluid loop requirements, together with the limited available electrical power for the cryocoolers, led to the development of high-efficiency cryocoolers[3] as well as high-efficiency non-planar heat exchangers.[4] The Thales Cryogenics commercial off-the-shelf (COTS) LPT9310 flight-qualified cryocooler is optimized for operation at 80 K, and its power consumption to provide cooling to the ECOSTRESS FPA at 65 K was prohibitively large; so Thales developed a high-performance version of their LPT9310 that was optimized for 60 K and preserved the form, fit and flight qualified elements of the COTS LPT9310.[3] In addition, the surfaces of the LPT9310 coolers from which heat needs to be rejected are curved, making effective and efficient heat removal challenging. Meeting the JEM-EF fluid loop requirements for pressure drop required highly optimized, custom designed non-planar heat exchangers to effectively remove the heat of the cryocoolers.[4]

The instrument is approaching four years of operation in space, with its overall thermal performance as predicted and no changes to cryocooler performance. To date, all three cryocoolers have accumulated over 32,000 operating hours. On the 210th day after the initial power-on, a fault condition was detected, and the instrument put itself into standby mode with the coolers off.[1] On the 258th day, the instrument went through a planned power cycle for firmware updates that left the coolers off for 45 days.[1] The coolers have since undergone eleven additional short duration power cycles to date. The heat rejection system, including the custom cryocooler heat exchangers, has performed as expected by maintaining all components within their allowable flight temperatures while meeting the fluid loop requirements for pressure drop and outlet fluid temperature.

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004).

ECOSTRESS cryocoolers. *Credit: Jet Propulsion Laboratory, California Institute of Technology/ Ian McKinley*



Change in drought from 2019 to 2020. *Credit: Jet Propulsion Laboratory, California Institute of Technology, NASA*

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by Cody Bateman and James E. Fesmire, Founders of GenH2

The GigaSphere: Game Changer for Next Generation of Clean Energy

Large spheres have been used to store liquid hydrogen for decades. In fact, two 3,218 cubic meter (850,000 gallon) liquid hydrogen storage spheres have supported space flight programs at the Kennedy Space Center since the mid-1960s. Currently, NASA plans to use the latest and largest liquid hydrogen tank ever put into production for the Artemis exploration missions to the moon and Mars.

Liquid hydrogen storage sphere at KSC. *Credit: GenH2*

With the rapid growth of the hydrogen economy worldwide, there remain several key technologies that must be developed at scale to support the hydrogen infrastructure. One such technology is the GigaSphere. President Biden's $8 billion infrastructure plan includes as many as six hydrogen hubs. GigaSpheres will become the anchors for each hub as the country begins deploying them over the next decade. With GigaSpheres in place, these hubs will have the capability to advance the essential role of hydrogen to support all facets of our energy needs by 2030 and beyond.

There are smaller spheres in use today and a few larger spheres in development, but the GigaSphere is a game changer. Building GigaSpheres is not just a concept on the drawing board or outer space technology. GenH2, an industry leader in hydrogen infrastructure solutions, is dedicating a team to design and engineer the next generation of large liquid storage solutions. GenH2 is already taking orders for 1.25 million-gallon-capacity GigaSpheres and expects much larger vessels will be required in the very near future, which the company will be able to provide.

While much of the industry has been focused on developing hydrogen hubs, most conversations have been centered around hydrogen production, pipelines and transportation depots. Comparatively little attention has been paid to advancing liquefaction and storage technologies. Interestingly, however, much of the proposed technology is not significantly different from that used in the early days of the Apollo program. This is why the GigaSphere is such an exciting development, and the capability to manufacture them at scale is pivotal. The larger the liquid storage vessel, the easier it is to achieve high thermal efficiency and "make hydrogen happy." The boiloff loss rate of the first GigaSphere is less than 0.05% per day, and adding a refrigeration system to make it a fully zero loss system is now practical to do.

With experience gained over the decades from NASA's operational units, the team at GenH2 has the know-how to deliver advanced, yet cost-effective, liquid hydrogen storage solutions for large-scale industrial applications. All the R&D years have now culminated in a currently existing, practical and solid solution that is necessary to meet the rapidly growing needs of the hydrogen industry.

If we can use the GigaSphere to go to Mars, why can't we use it on our roads, seas, and air travel? Well, the answer is, we most certainly can, and we are moving quickly to a future where we will do exactly that.

Where do you put a GigaSphere?

The hydrogen infrastructure must evolve as fast as possible, as it is the catalyst that will feed the growth of the entire development and utilization of hydrogen as an energy source for any type of use. The GigaSphere plays a critical role at each hub for distribution on any scale. Wherever the GigaSphere is placed, it will be the primary dispensing source, or it can feed a network of satellite dispensing units, as well as key infrastructure around it.

As an example, let's consider building a GigaSphere at Port Canaveral. Cruise and cargo ships will need large quantities of hydrogen. More so, the entire infrastructure of ports can also run on liquid hydrogen, and the GigaSphere can provide the necessary quantity on demand. There are also additional uses for the hydrogen: forklifts, delivery trucks, cranes, taxis, golf carts and others.

With Port Canaveral's Florida coast location, hurricanes are a constant threat and the command-and-control center for the port must remain open regardless of weather. A hydrogen GigaSphere is the ultimate solution. 1.25 million gallons of liquid hydrogen could power buildings and all the equipment in the port for several days, as well as provide power needed for the port's cranes, forklifts and trucks to quickly offload and transport critical supplies. Another example is the Port of Houston, which is larger than Port Canaveral and could be more than adequately supplied with two GigaSpheres.

GigaSpheres strategically placed through a geographic area, such as states or regions around the United States, will enable feeder distribution to smaller locations for dispensing and will be accomplished faster than developing isolated units.

GenH2 GigaSpheres at KCS. *Credit: GenH2*

Collaboration to build the hydrogen economy

With the knowledge of how to produce a GigaSphere, the team at GenH2 has formed the right relationships and strategic partnerships that are making the GigaSphere a reality. Based upon the core belief that "together we can make this happen," the hydrogen economy is moving so fast that companies that can only make one-offs will fall behind. To achieve the 2050 clean energy goals, we must start to concentrate on solutions that can be duplicated at scale.

Cody Bateman, founder and CEO of GenH2, is widely recognized as a leader in the field of hydrogen infrastructure and is an outspoken advocate for the hydrogen economy. James Fesmire, GenH2's executive vice president and chief architect, was a leader in the technology development for NASA's liquid hydrogen storage. Learn more at **www.codybateman.com**.

New Accelerator's Particle Beam Makes Waves

The HElmholtz LInear ACcelerator (HELIAC) is a continuous wave linear accelerator being planned at GSI/FAIR (Facility for Antiproton and Ion Research) that will allow new research opportunities with its continuous particle beam. The first cryogenic accelerator module for the HELIAC, the so-called advanced demonstrator, has now been cooled down to four kelvins with liquid helium and has been tested.

The cryostat of the HELIAC demonstrator has a length of five meters in total. In the future, it will contain three accelerator cavities of Crossbar H-mode (CH) type, as well as a beam-focusing cavity (buncher). These components are still being tested or manufactured, and temporary, externally identical dummy cavities have been installed, cavities which do not contain the internal structures. They are used to ascertain the mechanical behavior of the module under cryogenic conditions. Two finalized solenoid lenses and two steering elements — both superconducting — are already installed.

The HELIAC cryostat was conceived by Cryoworld in collaboration with GSI at Darmstadt and Helmholtz Institute Mainz (HIM). The HIM, a branch of GSI, is responsible for all R&D activities to realize the HELIAC project. The design is really the first of its kind. The most important mechanical requirement for the cryostat is that all cavities and solenoids must be aligned accurately; the center line needs to remain during evacuation and cooldown within a cylinder of 0,2 mm.

An additional technical challenge was to fulfil the requirement on access to components inside the cryostat to assemble the RF-power couplers at all cavities and the current leads to the solenoids. Access to the measuring marks at each component is required to check and, if necessary, to correct alignment according to the external beam axis. Normally, magnet cryostats do not have active components like valves and safeties. The helium supply is usually done by a dedicated jumper or valve box. In this case, an accelerator tunnel does not have enough to allow for a separate valve box. This meant that the active parts needed to be integrated

The new linear accelerator HELIAC opens up new research opportunities with its continuous particle beam. The first cryogenic accelerator module loaded with dummy cavities has been recently tested. *Credit: G. Otto, GSI/FAIR*

in the cryostat as well, leading to a more complex design and uncertainty of the accuracy that can be reached on the beam alignment.

Cryostats are always loaded by the vacuum force caused by the insulation vacuum; this force induces deformation to the cryostat, which may lead to an undesirable displacement of the entire string. The solution is the so-called "neuclotron suspension," a symmetric suspension of each component on eight roads fixed on a 300 K anchored rigid frame. The frame itself rests on a reinforced cryostat floor at dedicated points, where deformations are negligible. Cryoworld designed the cryostat from scratch. The huge door openings are a proven concept, coming from an earlier Cryoworld project, but the integration of the cavities really had to be carried out from the ground up. A cryostat with such large openings and a less symmetrical design must be constructed differently than classical magnetic cryostats in terms of overall alignment accuracy. Through FEA, the cryostat design was checked for displacements. For the applied smart design, the displacements of each component were kept to a minimum.

The cryostat undergoes the rigorous testing within SAT at GSI/HIM under 4 K conditions. Using special targets installed on the axis of components, and a camera with high-end optics, the actual displacement of the components during evacuation and cooldown was observed within the required cylinder of 0,2 mm. For the first time, the cryomodule has been successfully tested with heavy ion beam from the GSI High Charge State Injector. The superconducting solenoid lenses have been used to focus heavy ion beams through the cryomodule, keeping them on axis-applying correction coils.

"All relevant, transverse-beam optical investigations could already be successfully performed with the setup. This means an important milestone in the commissioning of the module has been achieved," explains Professor Winfried Barth of Johannes-Gutenberg University Mainz, head of Section 1 for Accelerators and Integrated Detectors at the Helmholtz Institute Mainz, and head of the GSI "Linac" department.

"Soon, the Advanced Demonstrator will be transported to the Superconducting Radio Frequency Laboratory of the HIM, which provides unique testing infrastructure with an ISO class-4 cleanroom, a necessary high-purity condition for the final assembly of the accelerating string and integration into cryogenic module," adds Barth's deputy and HELIAC project manager Dr. Maksym Miski-Oglu. "The next step is the integration of the three functional CH cavities and the buncher into the cryomodule. Final commissioning with heavy-ion beam is planned for mid-2022 at GSI/FAIR." **www.cryoworld.com**

Penflex Controls Pressure at the Intersection of Vacuum and Cryogenic Sciences

by Ronit Patil, Sales Engineer, Penflex

Reliability Spurs Innovation: Dependable Flex Hoses

Vacuum technologies have advanced the field of cryogenics, allowing researchers to push the frontiers of what we know and businesses to apply that knowledge and drive innovation across a wide range of industries. The intersection of vacuum and cryogenic sciences is a demanding one. Pressure and temperature requirements create a playing field where only certain materials of construction and precise techniques and processes can play. Whether a component within a closed cryogenic system or a transfer link to be reused and repurposed, metal hoses are well suited for these exacting environments.

Design considerations for pulling vacuum

Pressure requirements are among the main reasons users opt for metal hoses, whether to accommodate high pressures or the lack thereof. And while many materials would buckle when pulling a vacuum, metal will not. Tensile strengths of the commonly used 300 series, austenitic stainless steels, along with hose geometry, ensure these components maintain their shape under great hoop stress.

It's important to remember that both ends of the hose need to be properly anchored. Otherwise, it will shrink once in operation. There are additional considerations when working with vacuum jacketed hoses where the pressure differential may be greater than what we are used to. The pressure of the inner hose should always be greater than the pressure of the outer hose, as negative pressure on the inner hose could cause buckling.

We would also need to ensure that, under pressure, the inner and outer hoses elongate to bring both braids into tension, thereby allowing the hose to reach its full

Tensile strengths of the commonly used 300 series, austenitic stainless steels, along with hose geometry, ensure these components maintain their shape under great hoop stress. *Credit: Penflex*

pressure-carrying capacity. This will not happen if there is net external pressure on the inner hose.

Low-temperature properties

Many metals have good "room temperature" characteristics, but they do not necessarily maintain those characteristics as temperatures decrease. Witness the way materials become brittle and break at low temperatures.

The 300 series stainless steels are suitable for low-temperature service and are thus classified as 'cryogenic steels.' Yield and tensile strengths actually improve for these materials as the temperature drops. While 304 and 316 have minimum design temperatures of -452 °F, 321 has a minimum design temperature of -325 °F and is limited to liquid nitrogen applications.

Components you can count on

With such a wide array of constructions, hoses remain a reliable means of fluid and gas conveyance that enable further creativity and ingenuity among original equipment manufacturers in this exciting space. Penflex has consistently refined its design, manufacturing and leak testing processes to best serve the cryogenic market. Our annular, thin wall, compressed pitch cryogenic hoses prioritize flexibility and movement. Annular hoses, where individual corrugations are "stacked" parallel to one another, consistently achieve longer dynamic cycling than helical hoses, where the corrugations are one continuous helix, given that bending happens between the corrugations rather than through them.

Made from thinner strip material, a thin wall hose requires less force to bend. This is a key indicator of flexibility, and an aim that is achieved further through placing the corrugations closer together and raising the height of them. A hose must be designed properly for the space it is to operate in, but with less risk of overbending and frictional damage due to sharp bends; a more flexible hose will generally be easier to install.

The utmost care is taken to prevent matter from settling within hoses during manufacturing and to produce hoses to the highest level of cleanliness. Our welders are certified to American Society of Mechanical Engineers Section IX, the industry's highest standard. Welds are purged using argon gas, a proven process that enhances weld quality by decreasing—or even preventing—oxidation. This, in turn, maintains the corrosion resistance of parent materials and delivers contaminant free welds.

Once hoses pass visual inspection, a borescope is used to identify and remove any contaminants that may have entered the hose as a final step before leak testing. A mass spectrometer with helium tracer gas, one of the most accurate methods of leak detection, is then used to test the hoses. With the ability to detect leaks as small as 10-12 cubic centimeters per second, mass spectrometer testing reduces the risk of cryogen loss. The clean, controlled environments vacuums create to enable cryogenic processes depend upon reliable components such as these, which are similarly clean and leak tight. **www.penflex.com**

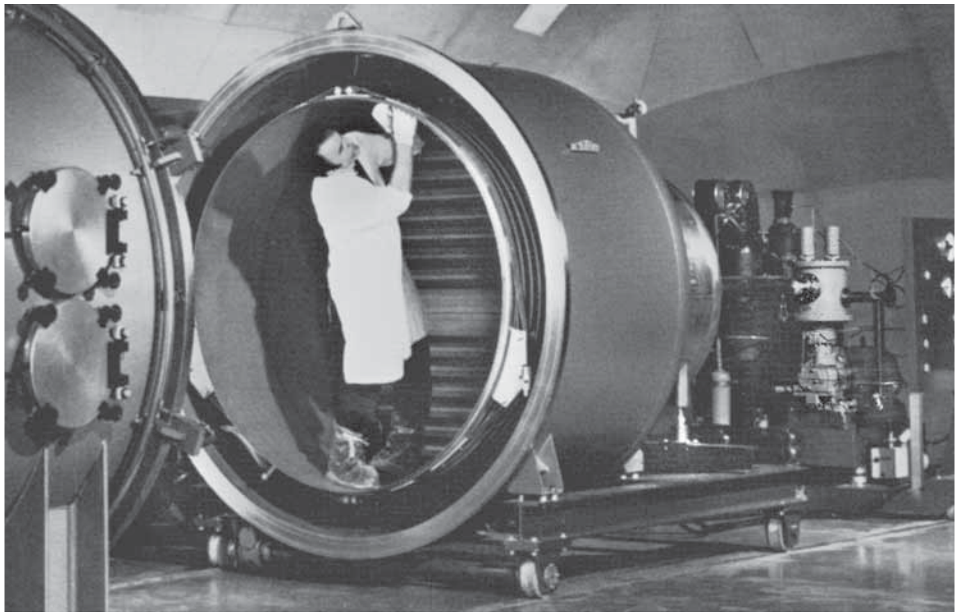
Cryogenerators Cool Superconducting Magnets

In the mid-1960s, the two-stage Stirling cryogenerator was developed in Eindhoven, The Netherlands, to fill the need to reach even lower temperatures than what was necessary for the liquefaction of nitrogen. This was done using the one-stage Stirling cryogenerator, on which the two-stage is based, changing only four of the machine components. This had the production and service advantage of having the major number of parts remaining the same.

However, the initial reason to develop cryogenerators for 20 K was not for superconducting magnets because, at the time, there were none; so in the early days of cryogenerators, they were made for applications like space chambers to cool shields acting as big vacuum pumps, and for the liquefaction of hydrogen. While hydrogen liquefaction can be done directly on the Stirling cold head, a second development project was required for the space chamber application. To transport and distribute the Stirling's cooling power to and over the shields, a flow of cold helium was envisaged, making a thermal connection between the cold head and the application.

This led to the development and production of Stirling Cryogenics' CryoFan, providing such cold and pressurized He flow. With the CryoFan, only the impeller and pumphouse are at low temperature, while the electric motor remains at ambient through the use of a long shaft. This impedes an as-low-as-possible flow of energy to the cold loop in order to have maximum cooling capacity available to the application. In the early days, only two sizes of cryofans were developed for the one-cylinder and four-cylinder machines. Today, however, a whole range of sizes is available to the market and for use with other sizes of cryocoolers or other cold sources.

With the two-stage Stirling cryocoolers with cryofans in existence, Stirling was prepared when the first superconductive magnets appeared in the early 1980s. Since then, the two-stage Stirling cryogenerator has been used widely for magnet cooling. Some of these magnets are one-off development magnets like the hybrid one at the High Field Magnet Laboratory in Nijmegen in The Netherlands, where it is used for initial cooldown and to keep the cold of the shielding. However, most magnets are for commercial MRI systems.



On the right, an SPC-1T two-stage Stirling cryogenerator with 2x CryoFans on top, cooling vacuum chamber shields for cryopumping at 20 and 80 K. Circa 1969. *Credit: Stirling*

In the first 10 years of MRI systems, many Stirling cryogenerators were used to cool the magnet shields at 80 and 20 K. This avoided consumption of LN_2 and reduced LHe consumption as much as possible. With the construction and insulation of superconductive magnets getting more advanced, the cooling of serial produced MRI magnets was taken over by much smaller cryocoolers. Yet these magnets still needed to be cooled from ambient to final temperature, requiring LN_2 and LHe. With LHe getting more and more expensive and due to the development of LHe-free magnets, this initial cooldown of magnets by a Stirling cryogenerator proves to be economical.

The internal design of the magnet must allow a cold pressurized helium flow, which is usually the case, or the magnet design is specifically adapted. Several concepts can be thought of for this, such as a one-cylinder Stirling cryogenerator used to cool one magnet individually or a four-cylinder cryogenerator cooling two to four magnets. The choice depends on magnet design and the logistic requirements. With fewer magnets per cryogenerator, cooldown is faster to the extent that the magnet will not allow a faster decrease in temperature each time. More magnets mean a longer, steadier cooldown time, as well as operators needed to spend less time on decoupling and re-coupling magnets to the cooling system.

Stirling Cryogenics can assist in the development of such a cooldown setup, including the piping, valving and the system control to safely connect, cool down and disconnect the magnets from the system. **www.stirlingcryogenics.eu**

CONFERENCE CONNECT

International Cryogenics Community Meets Virtually for ICEC28-ICMC 2022

by Limin Qiu, Ph.D., Zhejiang University

Plenary talks at the Theatre Hall. *Credit: ICEC28-ICMC 2022*

The 28th International Cryogenic Engineering Conference and International Cryogenic Materials Conference 2022 (ICEC28-ICMC 2022) was successfully held from April 25 to 29, 2022, on Yaotai® (a virtual conference software) as an immersive, virtual event like "metaverse." The ICEC-ICMC series conference is one of the largest and most influential international conferences in the cryogenics field, held every two years alternately between Europe and Asia. The conference was originally scheduled to be held in person by Zhejiang University in Hangzhou, China, in the early autumn of 2020, but was cancelled due to the outbreak of the COVID-19 pandemic and finally postponed to this year as a virtual conference. After four years of waiting, the international cryogenics community finally had an opportunity to spend a valuable week together to share information, news and ideas on cryogenic engineering and materials.

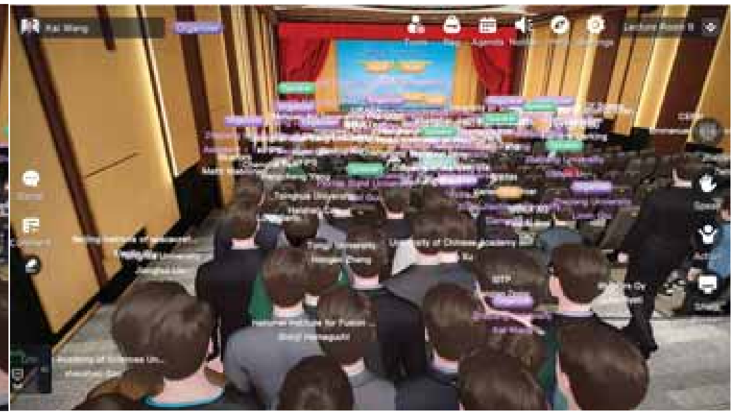
The conference attracted more than 300 attendees from nearly 20 countries, and the scale was comparable to previous offline conferences. A total of one short course, five plenary talks, 20 oral sessions and 22 poster sessions were arranged during the conference. A total of 229 papers were presented, including 114 oral and 115 poster presentations. Despite the virtual format, the conference attracted wide interest and great enthusiasm from the industry, with 17 cryogenics-related companies from across the globe participating as sponsors and exhibitors.

The conference was kicked off with the four-hour short course "Helium Refrigeration for Large Powers," which was given by Guy Gistau Baguer. In order to benefit as many people as possible, in particular the young generation, the short course was made available for free, which turned out more than 500 in attendance worldwide. The first day also included a virtual welcome session that enabled attendees to get familiar with the meeting platform.

The second day started with the opening ceremony, with welcome addresses from Conference Chair Limin Qiu of Zhejiang University (ZJU), ICEC Chair Marcel ter Brake of University of Twente, and ICMC Chair Mike Sumption of The Ohio State University. The 2020 Mendelssohn Award was awarded to Guy Gistau Baguer in recognition of his lifetime achievement in helium refrigeration. The 2020 and 2022 Gustav and Ingrid Klipping Awards were given to Andrew May of STFC Daresbury Laboratory and Shiran Bao of ZJU, respectively. The 2021 Cryogenics Best Paper Award of the journal *Cryogenics* went to the paper "A ruthenium oxide thermometer for dilution refrigerator operating down to 5 mK." Two plenary talks were presented in the morning session, one given by Guy Gistau Baguer, "Helium Refrigeration," and used for his Mendelssohn Award talk, and the other given by Matti Manninen of Bluefors, "Cryogenics for Quantum Technology."

In the morning session of the third day, the 2022 Mendelssohn Award was given to Ray Radebaugh of the National Institute of Standards and Technology for a lifetime's achievement in regenerative cryocoolers, in particular pulse tube cryocoolers. Following the award ceremony, Ray gave the Mendelssohn Award talk "Thermodynamics and Heat Transfer in Cryogenics."

The mornings of both the fourth and fifth day began with a plenary session. Day four's plenary was presented by Bo Gao of Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, and titled "New Kelvin at Low Temperatures." Day five's plenary, given by Mike Sumption, was called "A Look at Cryogenic and Superconducting Solutions for Electric Aircraft Propulsion." During the closing ceremony, on behalf of the ICEC, Marcel ter Brake announced that he stepped down as the ICEC chair and that John Weisend of European Spallation Source will take over as the new chair. Laurent Jean Tavian of CERN, the chair of the next ICEC29-ICMC 2024, gave a brief introduction to the next event,

Oral presentations at the Lecture Rooms. *Credit: ICEC28-ICMC 2022*


Posters and sponsor exhibitions at the Exhibition Halls. *Credit: ICEC28-ICMC 2022*

which will be held in Geneva (Switzerland) from July 22-26, 2024.

Every day of the conference was filled with oral sessions and poster sessions – 42 in total. The topics covered a wide range of focuses in cryogenic engineering and materials, such as large-scale refrigeration and liquefaction, cryogenic components/systems/facilities/tests, cryogenic heat transfer and thermal insulation, cryocoolers, space cryogenics, cryogenics for superconducting materials/devices/systems, superconducting materials, and devices, etc.

Group photo of the local organizers of the ICEC28-ICMC 2022. *Credit: ICEC28-ICMC 2022*

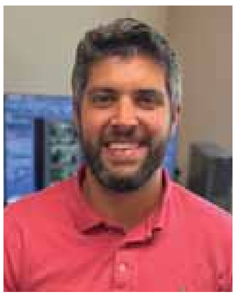
In order to solve the problems of traditional online conferences, such as insufficient communication, difficulties in posters and exhibitions, and single sensory experience, with the support of the ZJU Information Technology Center and Alibaba Cloud for the cloud service, the local organizers cooperated with NetEase and customized a newly developed virtual meeting platform on Yaotai. The attendees could roam freely in the form of virtual characters in the virtual meeting scenes, including a virtual theater hall, three lecture rooms, and two multi-functional exhibition halls. Plenary talks, oral presentations, poster presentations, exhibitor exhibitions, etc. (the elements which are necessary for large-scale international conferences) were all available just like one would have at an in-person event. The interesting, immersive virtual meeting mode greatly stimulated the enthusiasm for online communication. During the conference, attendees traveled around the virtual rooms and conducted lively discussions and idea exchanges on cutting-edge research.

As the first group of people who dared to eat the "crab" of the immersive international academic conference, the organizers at ZJU found a way to integrate the virtuality and reality together for a brand-new meeting experience, and a long list of praises from worldwide attendees were given to them. As the first virtual event in the ICEC-ICMC history, the organizers, attendees and sponsors made this conference a complete success.

YOUNG PROFESSIONALS 2022: Part 2

The Next Generation in Cryogenics and Superconductivity

This feature introduces outstanding young professionals (under 40 years of age) who are doing interesting things in cryogenics and superconductivity and who show promise of making a difference in their fields. Debuted in the Summer 2006 issue, the feature has presented many young persons whom we are proud to see have indeed lived up to that promise.



Eric O'Connell, 31

My educational and professional background: I earned my BS in Mechanical Engineering in 2012 from the University of Massachusetts Dartmouth.

How I got into cryogenics: My introduction to cryogenics was somewhat of a coincidence. For my senior capstone project in college, my team and I designed a high temperature, magnetic thermal annealing oven used for processing silicon wafers for semiconductors. This experience with high vacuum environments and heat transfer led me to Vacuum Barrier Corporation. During a facility tour, I was exposed to the everyday uses of cryogenics in the food and beverage industry — from utilizing the expansion of liquid nitrogen when vaporized to pressurize water bottles, to purging food containers, and to increased shelf life. My interest was sparked. I joined the Vacuum Barrier engineering team in 2012, just a few weeks after graduation.

My mentor(s) and my experience with them: Jack Ross, vice president of engineering, and Erik Showers, product development manager, have both been excellent mentors over my almost ten years at Vacuum Barrier Corporation. With over 50 years of cryogenic experience, they have been great professional resources every step of the way.

My current company/position: I am a mechanical engineer at Vacuum Barrier Corporation.

Awards/honors I received: I placed first in my Senior Capstone Project.

Some of my contributions to the cryogenic field: At Vacuum Barrier Corporation, we strive to provide the highest quality products and constantly aim to improve our liquid nitrogen transfer and injection equipment. Recently, I led the effort to design and implement a high pressure cryogenic static seal on our main line cryogenic piping connections. The cryogenic seal significantly decreases the heat loss at these connections and improves the efficiency of the entire piping system.

What are the most important developments in cryogenics? The COVID-19 pandemic has proved that liquid nitrogen can benefit various industry sectors more than ever. Cryogenic preservation using low pressure liquid nitrogen is vital to preserving many medical materials including vaccines, blood and biological tissues.

What advances do you hope to see in the future? Everyone has experienced how vulnerable supply chains are, currently and over the past few years. Inerting fresh food and drink packages extends the product shelf life significantly, allowing products to survive transit through today's delayed supply chains. Expanding liquid nitrogen applications throughout the food and beverage, biotech and pharmaceutical industries benefits end customers greatly.

Where can readers find out more about your projects? www.vacuumbarrier.com

Ronit Patil, 27

My educational and professional background: I have a master's degree in Mechanical Engineering from Drexel University in Philadelphia and a Bachelor of Engineering in Mechanical Engineering from the University of Mumbai.

How I got into cryogenics: I got into cryogenics when we decided to enhance our offering to customers. Our company, Penflex, works with compressed gases and cryogenic liquids, like liquid helium, and has strict leak testing and cleanliness requirements. We wanted to provide a comprehensive report of testing and cleaning that had been carried out on the hoses our customers were purchasing, so we brought these processes in-house. While there certainly were design requirements that I had adhered to in building hoses for cryogenic applications previously, I would consider the time spent researching, testing and learning about leak testing and cleanliness standards for cryogenic service to be when I truly entered the field.

My current company/position: I am a sales engineer at Penflex Corporation in Gilbertsville, Pa. I look after our customers in the Northeast, many of whom are involved in the cryogenics space.

My mentor(s) and my experience with them: I would say that someone who shares my attention to detail, and perhaps even exceeds me in his desire for exactitude, is Dave Gregor, Penflex's Level II non-destructive examiner. Dave is also our certified welding instructor and examiner and has great experience in teaching people new processes and committing those processes to paper. He was my guide for developing the specifications that would govern the use of the helium mass spectrometer we purchased, as well as those which would ensure we meet our customers' cleanliness requirements. Penflex now has an in-house standard for hoses that have a requirement of helium mass spectrometry testing. I'm happy to report that these documents have been useful in training newcomers and ensuring consistency across our cryogenic products.

Some of my contributions to the cryogenic field: I think bringing cryogenic leak testing and cleaning in-house is a contribution to the cryogenic field. In doing so, we have added another informed supplier to the list of those offering these important services. For instance, some of our cryogenic hoses are used to move liquid helium through MRI machines, and contaminants in the hoses could impact the level of superconductivity needed for the machines to run properly. Bringing things into a tighter focus, I think the investment in our mass spectrometer and learning more about preparing hoses for cryogenic service is a value-add for our customers. We can now, with more confidence than ever before, provide an accurate representation of what has been done.

What are the most important developments in cryogenics? Power generation is a key market for Penflex, so I'm quite familiar with it. I think the way cryogenic technologies have helped to diversify usable energy sources is significant. Just think of LNG's trajectory over the last century. Not only did cryogenics enable the development of large-scale liquefaction processes, but it also fueled advances in storage and transfer that allowed for its commercialization. The "cleanest burning" fossil fuel is now a mainstay in supplying electricity needs around the world.

The kinds of products I work on support this supply chain. Our hoses and expansion joints are made using the 300 series austenitic steels or other high-nickel alloys, often termed "cryogenic steels" because, by design, they will not become brittle and crack at low temperatures. Most other materials will. Liquified natural gas is just one example of how cryogenics has helped this industry evolve. Liquid air could soon become the newest renewable energy to make headlines, and the list goes on. Our job as a supplier to businesses pushing the field of cryogenics forward is to keep current on developments and recognize how advancements in metallurgy, welding and testing could deliver a better product. At times, customers come to us with prototyping requests, and I always enjoy those kinds of opportunities.

What advances do you hope to see in the future? The field of quantum computing is fascinating, and I think, while it may still be a few years out, we'll be seeing some major developments in this arena before too long. I'd love to see whether there's an overlap between such cutting-edge technology and the work we do. Perhaps the refrigeration systems needed to support the computers' operation are an opportunity—something to keep an eye on!

Where can readers find out more about your projects? Penflex Cryogenic Transfer Hoses (with videos featuring Dave Gregor and myself): **www.penflex.com/cryogenic-hose-and-braid-solutions-liquid-transfer**, Penflex (General Resources): **www.penflex.com**, and LinkedIn: **www.linkedin.com/company/7237893**

≈In Memoriam≈

The Return on Investment of One Man's Vision

by Dr. Christopher M. Rey, Founder & President of Energy to Power Solutions (E2P)

Carl H. Rosner

1929-2022

General Electric researcher Carl H. Rosner demonstrates the power of supercooled superconducting magnets in 1965 at the GE Research lab in Niskayuna. *Credit: MISCI*

When I was first asked by the CSA to write a brief missive about my perspective on Carl Rosner's enormous impact and entrepreneurial spirit on the cryogenics and applied superconductivity community, it was difficult to know where to even begin. So, I decided to start with my first introduction to Carl back in the mid-1990s while I was working on my first post-graduate school job at BWX Technologies in Lynchburg, Va.

I first met Carl Rosner at the Department of Energy's High Temperature Superconducting (HTS) Annual Peer Review, which was often held in the summer in Alexandria or in subsequent years at the L'Enfant Plaza in Washington, D.C. I remember that, despite the sweltering summer heat and humidity, Carl was always impeccably dressed in his dark blue, tailored business suits, which was quite a contrast to the numerous academic/scientist types in the more common (and tacky) short-sleeves-and-tie attire.

Carl Rosner was a quiet but imposing figure in every meeting and discussion that took place during the early days of HTS wire fabrication. It was not uncommon back then to speak of HTS wire critical currents (Ic) in the 20-40 A range (77 K, self-field); nor was it uncommon to present HTS wire lengths less than 10 meters. Despite the too often lackluster I_c's and production lengths, Carl always remained both optimistic and a pillar of reassurance about the prospects of HTS wire performance and production capacities. Although he rarely spoke during the many lively discussions about HTS wire progress to-date and future paths of the HTS community, when he did finally comment, his opinions and comments carried an incredible gravitas.

Interestingly, one thing that struck me was that he always carried a newspaper everywhere he went and would occasionally start reading the newspaper during some of the presentations and subsequent HTS-related discussions. Once during a coffee break, I overheard one of the previous speakers commenting to one of Carl's colleagues that, depending upon how intently he was reading his newspaper, he could always tell when Carl was bored or uninterested in the topic. Carl's colleague immediately quipped, "You're quite mistaken. When Carl is reading his newspaper is when he is listening with the most intensity and curiosity." That little verbal exchange between Carl's contemporaries taught me a great deal, not only about Carl, but also the need for understated emotions in an emerging business market.

One of my last memories of Carl Rosner was in the early 2000s when he was giving a visionary talk about the need to fund a major effort in excess of $10 billion in HTS, as had been done in the previous decades for the semiconductor industry. It is interesting to observe that while a government-sponsored program of that funding magnitude never did materialize, over the past few years, the HTS community has seen an enormous fiscal investment from public and private sources in the field of HTS-enabled fusion. As it turns out, Carl Rosner's vision for HTS development is slowly being realized, and we all eagerly await the fruits of this investment.

Product Showcase

This Product Showcase is open to all companies and related manufacturers offering new or improved products for cryogenic applications. We invite companies to send us short releases (150 words or fewer) with high resolution JPEGs of their products to editor@cryogenicsociety.org.

JEV Instruments

I-Liquefier40 Portable Compact Helium Liquefier

I-Liquefier40 Portable Compact Helium Liquefier integrates two sets of GM cryocoolers as a cold source, which has a standard feature in which the cold head inserts into the dewar directly. The helium compressor and the liquefier cold box are installed together and mounted on a small skid-like platform. Such design allows for the liquid helium to be transferred into the customer's device directly and easily without the need of a transportation dewar, so as to avoid liquid helium consumption. **www.jevinstruments.com**

Gas Equipment Co., Inc.

BLD Series

BLD Series cryogenic pressure regulators provide high flow and shut off quickly at the desired set pressure. The regulator design is a non-balanced, spring reference, reducing-type regulator and comes with PTFE seals for cryogenic use. These regulators are optimized for use in pressure-build applications. The solid (non-tied) metal diaphragms provide long-lasting, leak-free performance. The springs for BLD Series regulators have been designed for optimized flow within the set pressure range. All BLD Series regulators are supplied cleaned for oxygen service. **www.gasequipment.com**

Meyer Tool & Mfg.

HURCO VMX24i with 4th Axis

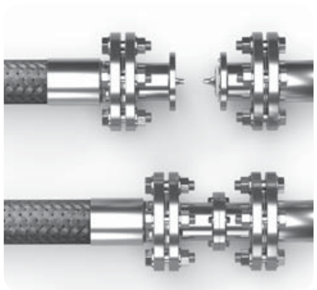
Achieving higher productivity with less human resources requires the leveraging of technology. Meyer's HURCO VMX24i with 4th axis provides advanced controls that seamlessly integrate their CAD/CAM software, addressing the latest paradigm, minimum dimensioned drawings with 3D models. The new mill's control features are ideal for the lower volume part counts of precision cryogenic components. This investment in the latest CNC technology reduces production bottlenecks by increasing capacity, but also by decreasing programming, setup and cycle times. **www.mtm-inc.com**

Cryoguard LLC

M-25 Cryoguard™ Thermal Exposure Indicator

The new M-25 Cryoguard™ Thermal Exposure Indicators are used at or below -50 °C to continuously monitor cryopreserved materials such as laboratory specimens, vaccines, frozen blood samples, biologics, clinical products, pharmaceuticals, medication and other heat sensitive materials. The M-25 indicator signals thermal exposure at or above -25 °C by irreversibly changing color from green to red within two hours. An activated M-25 indicator remains green at or below -50 °C. At 20 °C, an activated M-25 indicator changes color within minutes. The distinct real-time signal allows recipients and users of perishable cryopreserved materials to quickly and reliably verify that the cryo-environment was maintained at or below -50 °C.

With a dimension of approximately 1" in length and 0.5" in diameter, the M-25 indicator fits inside freezer box partitions, on cryovials and freezer canes for continuous monitoring of frozen materials during shipping, storage and handling by personnel. **www.cryoguard.com/m-25**



Stäubli Corporation

High-Performance Safety Breakaway Coupling for Cryogenic Media

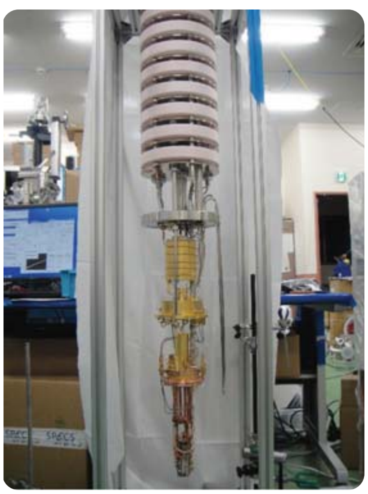
The process of loading and unloading fluids already requires a high safety standard under normal conditions. If the temperature factor is added with cryogenic media, for example, the safety requirements become critical. For cryogenic applications, the Stäubli KBH breakaway coupling provides a safe solution for temperatures ranging from -196 °C to +65 °C. Thanks to break-pin technology, the KBH disconnects the line at a defined tensile load. Non-return valves on each side immediately seal the line tightly and reliably during disconnection. This prevents the liquid from escaping, thus protecting the operator, plant and environment. **www.staubli.com**

m-tech gmbh

LCV – Cryogenic Ball Valve

The complete valve assembly series, LCV, is designed for cold service applications. The standard bonnet length complies with relevant cryogenic standards (DIN EN 1626 & BS 6364), which allows safe and efficient use of this valve at low temperatures. The valves are suitable for handling cryogenic liquefied gases such as LIN, LAR, LOX and LNG. The LCV product range covers DN15 to DN50 (1/2" to 2") and is optimized for both on/off and control applications. The finned bonnet design ensures efficient heat transfer, allowing reliable sealing of the stem packing.

The m-tech standard connection (three pieces of metal connection) enables easy installation and maintenance. No valve disassembly is required by welding/brazing to the pipeline, which minimizes the labor of installation. The connections are available in both brass for copper and stainless steel for stainless steel pipework. **www.m-tech-gmbh.com**



JanisULT

Model HE-3-TLSUHV-STM

Model HE-3-TLSUHV-STM is a top-loading He-3 cryostat with sample in UHV space for STM application. With standardized unique design, this He-3 cryostat generates next-to-zero acoustic noise and mechanical vibration. This cryostat is dedicated to STM applications.

Typical vibration noise level: Typical performance from the users report tip-to-sample vibration level is less than 1pm; Vibration noise detected with RF cable for STM signal: 10pA-1pA

With 10 STP liter He-3 gas, this He-3 cryostat holds approximately 100 hours at base temperature below 280 mK. It is suitable for long time scanning measurements. It can be operated without pumping the 1K pot but keeping the 1K pot approximately 4.5K, called 4K operation mode. With 10 STP liter He-3 gas, the 4K operation mode maintains base temperatures near 310 mK for approximately 50 hours with zero noise. **www.janult.com**

Fluoramics

HinderRUST

HinderRUST provides a long-lasting boundary film between metal and moisture during inside/outside storage, for any stage of construction, installation and ongoing maintenance. It is easily applied by sprayers, aerosols, rollers or brushes. Fluoramics offers several versions of HinderRUST including R2.0, a short-term, removable version, ideal for metal parts that are manufactured and waiting for shipment or service; S4.0, the standard version for use on metals under cover and perfect for equipment maintenance, electronics protection, for pre-assembly protection and weld-through approved; HV100, a heavy-duty version, convertible to a wax film over time and providing a robust barrier of protection; and HV500, a heavy-duty liquid-to-wax black formula that stops and covers unsightly rust and prevents new rust from starting. To reduce inspection failures on cryogenic tanks, use HinderRUST after installation on condensation areas that are prone to corrosion. As an added benefit, HinderRUST keeps nuts/bolts, anchor bolts and other hardware workable while waiting to be installed. **www.fluoramics.com**

Air Liquide Advances Toward Sustainable Objectives with New Air Separation Units

A world leader in gases, technologies and services for industry and health, Air Liquide's ambition is to deliver long-term performance and contributions to sustainability, with a strong commitment to climate change and energy transition at the heart of its strategy. Since its founding in 1902, the essential need for oxygen, hydrogen, and nitrogen has been at the core of Air Liquide's scientific activities. Air Liquide's commitment to these molecules for life has prompted its expansion of services throughout the world. Air Liquide has seen recent growth in their air separation units (ASU), most recently introduced in Egypt and India.

In April 2022, Air Liquide announced its investment in a new ASU in Ain Sokhna, Egypt, to supply industrial gases to EZZ Steel. This new ASU will have an oxygen production capacity of 770 tonnes per day. As well as supporting EZZ Steel, the new site will also support the development of the Ain Sokhna area, one of the country's major basins for heavy industries within the Suez Canal Economic Zone. Air Liquide will connect the new plant to its four other existing ASUs in the country to expand its existing pipeline network in Ain Sokhna.

"Air Liquide is pleased to collaborate with EZZ Steel, accompanying the growth of the Egyptian steel industry through the establishment of one of the largest industrial basins in Egypt. The investment in this ASU and pipeline infrastructure will further enhance Air Liquide's network capabilities, allowing us to meet the growing industrial gas demands of our customers," said Pascal Vinet, senior vice president and a member of the Air Liquide Group's executive committee, supervising European industry activities, and Africa, the Middle East and India.

Preceding their investment in Egypt, Air Liquide invested in another new ASU, one dedicated to industrial merchant activities in Kosi, in the state of Uttar Pradesh in northern India. That unit will have a production capacity of 350 tonnes per day, with a maximum of 300 tonnes of oxygen. Air Liquide India will build, own and operate the ASU, which is planned to start operating by the end of 2023.

Used in a wide variety of fields, large air separation units (ASUs) produce high purity oxygen, nitrogen, argon and rare gases through a combination of adsorption purification, cryogenic distillation and internal compression of high pressure products.
Credit: Air Liquide North America

The new Kosi plant will support small- and medium-sized customers of liquid and packaged gases in northern India and will allow Air Liquide to meet the growing demand of the automotive, metal fabrication, heat treatment, photovoltaic and electronics industries, as well as local hospitals requiring high-purity medical gases. When commissioned, Air Liquide's site in Kosi will become the largest liquid gases plant in the state of Uttar Pradesh.

In line with Air Liquide's sustainability objectives, which include reaching carbon neutrality by 2050, the plant has been designed to contribute to a successful energy transition by India. The new unit is planned to fully operate on renewable energy by 2030 and will contribute to Air Liquide's expansion strategy in India, where the group has been present for more than 30 years. It already owns and operates four ASUs in North India and West India and will finalize the construction of a fifth ASU in Nagpur (West India) in 2022.

"The construction of a new plant in Uttar Pradesh is a very important milestone for Air Liquide in India. This significant new investment will give us the ability to better serve our customers, while also investing in the long-term growth opportunities of this key state. It also shows our confidence in the sustained growth of Indian industry. This investment is in line with Air Liquide's sustainable objectives, as this ASU is meant to ultimately solely run on renewable energy," said Vinet.

Air Liquide is present in 78 countries with approximately 64,500 employees and serves more than 3.8 million customers and patients. **www.airliquide.com**

People, Companies in Cryogenics

NASA recently inducted **Martha K. Williams**, **Ph.D.** into NASA's National Inventors Hall of Fame. Williams, who retired from NASA in 2018 and joined GenH2's leadership team as senior technical advisor when the company was founded in 2020,

Credit: NASA

was recognized for her 29-year career at NASA where she served as the lead polymer scientist/principal investigator and inventor at NASA, Kennedy Space Center, Florida. Williams, who was also featured in this year's "Women in Cryogenics" in *Cold Facts*, joins a select group of 40 inventors and legends across the decades and the NASA centers.

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Fermi National Accelerator Laboratory (Fermilab) was given the green light to start building a new linear accelerator that will help scientists in their quest to better understand our universe. The Proton Improvement Plan II accelerator project at the Fermilab campus in Batavia, Ill., has received full approval for construction from the US Department of Energy, which oversees Fermilab, and will include a new superconducting radio-frequency linear particle accelerator. Construction on the accelerator is expected to start this fall.

....

Bharat Heavy Electricals Limited's (BHEL) Boiler Auxiliary Plant (BAP) inaugurated the newly installed **Cryogenic Oxygen Plant** in Ranipet, Tamilnadu, India. While generating oxygen from atmospheric air with a purity of 99.5% for industrial purposes, the oxygen plant of 50 cubic meters-per-hour capacity can also generate and fill cylinders with oxygen for medical use. BAP is the 13th manufacturing unit of BHEL at Ranipet and is a spin-off plant for the manufacture of boiler auxiliaries like electrostatic precipitators, air pre-heaters and fans.

....

The **U.S. National Science Foundation** (NSF) announced the 2022 awardees of the Expeditions in Computing Awards. The two awardees plan ambitious undertakings to explore emerging and transformative computing technologies to innovate superconducting materials, devices and circuits, and to develop organic, neuron-based computing systems.

The first awardee was **Expeditions: Mind in Vitro**: **Computing with Living Neurons** led by the University of Illinois, Urbana-Champaign team. The Mind in Vitro Expedition will develop science and technology to fabricate, model, program, scale and embody biological processors. The second awardee, **Expeditions: DISCoVER**: **Design and Integration of Superconducting Computation for Ventures beyond Exascale Realization**, is led by a University of Southern California team. DISCoVER Expedition will explore novel superconductor electronics as a viable post-complementary metal oxide semiconductor computing technology.

....

Credit: ICEC28

At **ICEC28**, the International Cryogenic Engineering Conference, **Dr. Ray Radebaugh** received The Mendelssohn Award for his long-standing contributions to cryogenic engineering. Until his retirement in March 2009, Dr. Radebaugh was a physicist with the National Institute of Standards and Technology in Boulder, Colo. He has conducted and supervised research on measurements and models for cryogenic properties and processes, such as refrigeration and heat transfer, and he has published over 160 papers and has five patents.

....

Since its arrival on April 29, the **Psyche** spacecraft has moved into the **Payload Hazardous Servicing Facility** at **NASA's Kennedy Space Center** in Florida, where technicians removed it from its protective shipping container, rotated it to vertical, and began the final steps to prepare the spacecraft for launch. The Psyche spacecraft will explore a metal-rich asteroid between Mars and Jupiter, made largely of nickel-iron metal. The mission is targeting an August 1 launch atop a SpaceX Falcon Heavy rocket from Launch Complex 39A at Kennedy.

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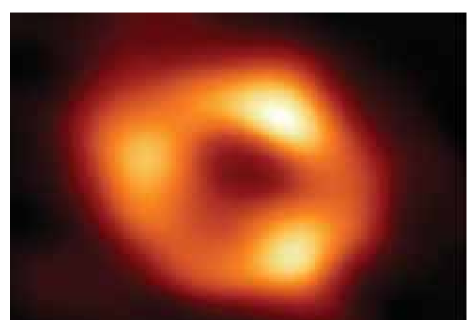

Credit: EHT collaboration

A bright ring of plasma orbits Sagittarius A*, the supermassive black hole at the center of the Milky Way.

Meetings & Events

Cryogenic Engineering and Safety Course
August 1-5, 2022
Golden, CO
https://cryocourses.com

29th International Conference on Low Temperature Physics
August 18-24, 2022
Sapporo, Japan
http://2csa.us/ha

CryoCourse 2022 – European intensive course on Advanced Cryophysics and Cryogenics
September 9-21, 2022
Heidelberg, Germany
http://2csa.us/l5

National Symposium on Cryogenics and Superconductivity 28
October 18-21, 2022
Kharagpur, India
http://2csa.us/kw

ASC 2022
Oct 23-28, 2022
Honolulu, HI
http://2csa.us/ko

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