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* New member since last issue

Inside This Issue

FEATURES

COLUMNS

ON OUR COVER

Boeing engineers loaded a 30-foot-long composite cryotank into a NASA testing trench where composite fuel-tank technology will be studied. The findings may extend beyond space travel and into applications where large amounts of cryogenic fuels need to be stored, like future hydrogen-powered aircraft. The result could increase the possibility of cleaner fuels that curb the carbon impacts of aviation. *Credit: Boeing*

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SPOTLIGHTS

Cold Facts

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From the Executive Director

In this month's issue of *Cold Facts*, we are honored to recognize numerous talented women working in the fields of cryogenics and superconductivity. This feature is always such a pleasure to read – especially as a woman who is new to the field. It's inspiring to see the growth the industry has experienced as more and more women are recognized each year, but I think we can all agree that there is still work to be done to close the gender gap. I encourage you to read this feature and pay close attention to the question we asked each honoree: "What would be the best approach to getting more women into our field?"

This past month, CSA had the pleasure of attending the APS March Meeting in Chicago, IL. I want to give a big shout-out to our friends at Cryomech who sponsored our attendance at the event. We thoroughly enjoyed getting to see many of our valued Corporate Sustaining Members in person!

We are also excited to see more of the cryogenics community in person at the upcoming International Cryocooler Conference in June. CSA will be hosting the Foundations of Cryocoolers Short Course on Monday, June 27, prior to ICC. The Short Course will be instructed by Dr. Ray Radebaugh, consultant emeritus, NIST Boulder, and Dr. Ralph Longsworth from Sumitomo Cryogenics of America, Inc. Registration is now open! Take advantage of early bird rates by registering prior to May 27. Both in-person and virtual attendance is being offered. For full details and registration, visit the CSA website at **www.cryogenicsociety.org**.

Speaking of the CSA website, I want to remind everyone that CSA launched our new website earlier this year! If you haven't done so already, we encourage you to click around and take advantage of the different cryo resources it offers. We hope that you will find the site more functional, easier to navigate, and a useful source of information for the cryogenics community as a whole.

Make sure to check out the Awards page, where you can find all the details for nominating a colleague or peer for the Roger W. Boom Award, named for the late emeritus professor from the University of Wisconsin. Dr. Boom's career spanned more than thirty 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 the 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." Nominations are now open through August 26, 2022. The Boom Award will be presented at the Applied Superconductivity Conference in Honolulu, HI, October 23-28, 2022. For full details regarding the Boom Award, visit the CSA website at **www.cryogenicsociety.org/awards-and-recognitions**.

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

WOMEN in CRYOGENICS and SUPERCONDUCTIVITY

Akanksha Apte

Who is your present employer?
Stanford National Accelerator Laboratory (SLAC)

What is your title?
Cryogenic Process Engineer for LCLS-II project

What projects are you working on now?
LCLS-II is an upgrade to the existing Linac Coherent Light Source (LCLS). LCLS-II will add a superconducting accelerator, which will generate an almost continuous X-ray laser beam. LCLS-II requires a powerful cooling plant that produces refrigerant for the superconducting accelerator. At SLAC, I am a part of the cryogenics team responsible for the operation of the helium refrigeration cryoplant for the LCLS-II project. Currently, we are in the commissioning phase of the LCLS-II project; however, I am also involved in the new project, LCLS-II HE, which will be an upgrade of LCLS-II. It is projected to deliver two to three orders of magnitude increases in average spectral brightness by increasing the energy of superconducting LINAC to 8 GeV.

What accomplishment are you most proud of?
We achieved a major milestone at SLAC for the LCLS-II project in March 2022. We have cooled down LCLS-II LINAC from 300K to 4.5K for the very first time. This is an important step towards our final goal of operating LCLS-II LINAC at 2K. I am proud of being one of the functional members of the team behind this success.

What advancements in cryogenics are you hoping to make in the future?
I am excited for all the new projects that are planned at SLAC, which are vital to the scientific community. Findings from operating cryoplants for LCLS-II will help me to investigate design optimization aspects for the new upcoming projects.

What advances for women would you like to see in the fields of cryogenics and superconductivity?
I am always amazed to see many women in the scientific community of superconductivity, but not so much in cryogenic engineering and operations. More diversity in the workforce is something lacking in the field of cryogenics. I am grateful for the wonderful team members at SLAC for always focusing on equal opportunities and encouragement in the workplace.

What would be the best approach to getting more women into your field?
Early on in my career, I had the opportunity of working under strong female leadership, and the one thing I have learned from them is that it's very important for women to lift up other women; and the best way to do that is to lead by example and encourage others. SLAC, along with other Department of Energy labs, conducts a yearly program for high school girls known as SAGE. This one-week camp provides a platform for female high schoolers to interact with the scientists and engineers working at SLAC. They have the opportunity to interview them and gain hands-on experience with prototype projects during the course. This is a very fun way of exposing young women to the world of cryogenics and superconductivity.

Kayleigh Byrns

Who is your present employer?
Cryomech Inc.

What is your title?
R&D Design Engineer

What projects are you working on now?
I am currently working on several custom cold helium circulation systems, including a project for two systems that utilize a cryofan to circulate the cold gas. I'm also working on various 1 K and 4 K low vibration cryostats. These cryostats feature a sample space vacuum chamber with associated shielding and thermometry. Cryostats also contain various customer-specific

modifications, which can include bolt patterns, optical windows, specific instrumentation and equipment stands.

What accomplishment are you most proud of?
As part of a collaborative team that works directly toward both customer-specific application needs and new product development, I'm most proud of my work across departments and with our customers and vendors to fully design a concept model, source design-specific material and manage the project timelines required to make our concept production-ready. We face many challenges in designing and manufacturing both product prototypes and custom modifications for customer-specific applications. Cryomech's ability to meet these challenges time and again, under any circumstances, is due to our company's tenacious culture of finding solutions to support our customers' successes. I'm proud to be a part of this team where contributions come from everywhere and pride is felt collectively.

What advancements in cryogenics are you hoping to make in the future?
I strive to keep learning and growing as a professional. I hope to continue working with and learning from today's pioneers in cryogenics and to contribute to Cryomech's continued success at the forefront of new product development for existing and emerging cryogenic markets.

What advances for women would you like to see in the fields of cryogenics and superconductivity?
I'd like to see more women highlighted for their achievements in cryogenics, whether in popular publications, academic publications, documentaries, etc. Visibility leads to awareness; awareness leads to curiosity and interest. Ultimately, the more visible women are in these fields, and in all STEM fields, the more women will be drawn to these fields in the future. Highlighting women for their achievements empowers all women to think of their possibilities.

What would be the best approach to getting more women into your field?
I believe the best approach to getting more women into the field is to begin building that exposure and interest early on through robust local and community-based STEM programs for children and adolescents. I was fortunate enough to be approached by a local company while in high school to participate in a program specifically for children interested in engineering. That program is the reason I became an engineer.

Yulia Gitter

Who is your present employer?
Hydrogen Properties for Energy Research Lab (HYPER) at Washington State University.

What is your title?
Graduate research assistant

What projects are you currently working on?
Additive manufacturing has provided a unique opportunity to increase the variability in form, function and materials used in cryogenics, but there is little to no data on material behavior due to thermal stresses experienced by these anisotropic materials with complex geometries. To address this gap in understanding, I am developing a cryogenic dilatometer to characterize the Coefficient of Thermal Expansion (CTE) of 3D-printed parts down to 20 K. This data will allow for more accurate modeling of thermal stresses in additively manufactured parts utilized in the aerospace and aviation industry.

What accomplishments are you most proud of?
The challenge was developing the world's most compact, field-deployable hydrogen liquefier. Led by a master's student and one other undergraduate, it ended up being a dream team of go-getters, a model for future teams. The system consisted of a dual stage cryocooler, 3D-printed AlSi10Mg heat exchanger and a hydrogen level sensor with eight temperature sensors, superconducting wires and a heater block. The most difficult part was the electrical work and plumbing due to spatial constraints in the dewar. Luckily, because of meticulous planning, steady hands and a lot of patience, we were successful when we plugged the internals in on the first round. We have since completed over 40 fills of our tanks with this liquefier at multiple field locations.

What advancements in cryogenics are you hoping to make in the future?
I have completed hundreds of one-way plane rides as a skydiving instructor and have always had the persistent question: "Why is this Cessna not fueled with a renewable?" Liquid hydrogen has a significantly higher specific energy and is lighter than conventional fuel sources. It is the logical next step towards the goal of zero-emissions in the aviation industry. One of the limiting factors is storage due to liquid hydrogen's boiloff at such a low temperature. There are many gaps in understanding the materials, mechanics and manufacturing of novel geometries. Determining more optimal fuel storage tanks that can be integrated into turboprop aircraft is the ultimate goal.

▶ *continues on page 10*

What advances for women would you like to see in the fields of cryogenics?
The advances necessary for women in cryogenics are simply more women, but not just any women; they need to be gritty go-getters with ambition. They cannot be afraid to try something new, and most importantly, they cannot be afraid to fail.

What is the best approach to getting more women into your field?
What if the process for selecting candidates for STEM positions in academia, whether it be a student, researcher or faculty, took out the name and candidate photo? What if the hiring process was solely based on merit? It all comes down to the fact that we do not want to be known solely for being a woman in engineering because then that is all we are. Accolades are immediately discounted because of an unnecessary pronoun. This sets the tone for the infamous impostor syndrome — a huge factor for leaky pipelines in STEM. If we reduce the bias in hiring, merit will speak for itself. Omitting this distinction is how you get more women in the field and, more importantly, more women to stay in the field. We are not accomplished female engineers. We are accomplished engineers.

Lana Grimsley

Who is your present employer?
GenH2

What is your title?
Communications and Marketing Specialist

What projects are you working on now?
I'm working on liquid hydrogen infrastructure supply.

What accomplishments are you most proud of?
Being part of an organization dedicated to making liquid hydrogen more accessible. I truly believe liquid hydrogen is the answer to our cleaner energy needs, and to make that goal obtainable, liquid hydrogen needs to be more widely available. GenH2's mission is to advance the hydrogen economy by accelerating infrastructure buildout to support the energy needs for land, air, sea and space.

What advancements in cryogenics are you hoping to make in the future?
I hope to bring recognition to the GenH2, CTO and Cryogenics teams who are providing game-changing liquid hydrogen and liquefaction technologies. I hope these efforts inspire others to find interest in this field.

What advances for women would you like to see in the fields of cryogenics and superconductivity?
I believe women have all the capabilities in this field to go as far as they desire. It would be great to see more spotlight articles from women in the profession that could be distributed to high school and college campuses to help inspire other females to pursue these types of careers.

What would be the best approach to getting more women into our field?
When I was younger, I would participate in bring-your-daughter-to-work days at NASA with my grandfather, Irby Moore, and my current co-worker, James Fesmire; both are incredibly talented in their trade and focused on encouraging educational experiences for our youth. During these daughter-to-work events, we would participate in hands-on lab experiments and tours of the entire facility. In my opinion, there is no better way to encourage and inspire young minds than to immerse them in hands-on, rich opportunities such as those I was fortunate to be a part of as a child at NASA.

Exposing our youth to workspaces and environments, such as cryolabs, where they can see firsthand how experiments are performed and what results they produce, is an excellent way to embed excitement and passion for this field. Putting programs like this back into our work environment would be a beneficial approach to getting more women into our field.

Ajchariya Harrison

Who is your present employer?
Bionetics Corp., Kennedy Space Center

What is your title?
R&D Engineer for Cryogenic Test Lab

What projects are you working on now?
I'm currently developing a cryo-capacitor module for use in liquid oxygen life support. We are utilizing the benefit of the high surface, area matrix structure of an aerogel composite material to produce the cryo-capacitor that will be used to charge (immerse) with liquid nitrogen for experimentation. The capacitor should be capable of capturing carbon dioxide during exhale and supplying oxygen during inhale.

What accomplishment are you most proud of?
I'm proud of all the projects I've worked on, especially the cryo-capacitor. I was involved in all aspects of the experiment, including the test setup. It was a great feeling, seeing the first result that proved our cryo-capacitor could sequester carbon dioxide — even if it was only for about 15 minutes at first. We kept remodeling and are now at around 50 minutes with the same volume of aerogel.

▶ *continues on page 12*

What advancements in cryogenics are you hoping to make in the future?
I'm hoping for the success of commercial liquid hydrogen storage and transportation. I also hope to see a significant cost reduction in hydrogen production with lowest or near net-zero emissions. Then it will be affordable to everyone, making it common enough to be utilized as an energy source everywhere, even in your house.

What advances for women would you like to see in the fields of cryogenics and superconductivity?
I'm not sure about the advancements, but I want to see more men and women work together as a team. Now that women are more accepted, it should be easier for them to take initiative, speak out, share their opinions and give suggestions to a team than it was previously.

What would be the best approach to getting more women into your field?
I think what would be easiest would be to introduce cryogenics to women early (in childhood) and show them some engaging experiments. Having a female engineer as the speaker at childhood events (like career days) could potentially inspire other young girls/women to consider cryogenics as a future career.

Beth McCall

Who is your present employer?
Chart Industries

What is your title?
Engineering Manager

What projects are you working on now?
I'm honored to be in a position where I lead a team of talented engineers who work on a wide array of exciting projects that support hydrogen and cryogenic mobile equipment for Chart Industries. Our projects include the development of hydrogen trailers for the Republic of Korea and supporting Chart's Orca™ MicroBulk Delivery Systems. We have also developed equipment to support the hydrogen fuel and mobility market.

What accomplishment are you most proud of?
Meeting the rapidly expanding global demand for hydrogen distribution equipment is a significant challenge. Our team in Theodore, AL has transformed their facility to become a high throughput, hydrogen transport manufacturing facility. This change has required significant restructuring of daily processes in all areas, including within my team, all while taking on new design and engineering work to support our customers and while developing new products and training new team members.

Each member of the team has had opportunities through this transformation to demonstrate their strengths through collaborations with different departments in the plant. It has been incredibly rewarding to witness the growth in talent from everyone – from customer-facing roles in product management through development, training manufacturing personnel on standard work processes, and working with other Chart engineering experts in other facilities on tackling complex mathematical analyses and code interpretation. I'm incredibly proud of the way this team has adapted to the changes in the facility and the consistently positive and collaborative attitude they have taken with the transformation.

What advancements in cryogenics are you hoping to make in the future?
I look forward to making a big impact through developing new products for the hydrogen and mobile market. In particular, the hydrogen fuel and mobility markets are expanding quickly, with significant opportunities to support growth in alternatives to fossil fuels. Working with my team to develop new products in this space will establish the infrastructure to provide alternatives to transportation powered by nonrenewable fuel sources.

What advancements for women would you like to see in the fields of cryogenics and superconductivity?
More representation! It's an honor to work for a company that is led by a woman (Jill Evanko, CEO); however, the field of engineering is still dominated by male voices. We collectively have better ideas, collaborate better, and are better innovators when we are comprised of more diverse and equitable teams.

What would be the best approach to getting more women into your field?
There are many ways to approach this. In the past, I've enjoyed partnering with female-focused organizations, such as the Society of Women Engineers (SWE) who focus on developing female engineering talent and partnering with companies to recruit and place female talent into their organizations. I also believe that men play an important role as allies in supporting women in our field by acting on biases that they perceive in addition to voicing their support of initiatives to bring more diversity into the workplace. Supporting and engaging women into engineering starts in school but extends throughout every woman's career.

Martha K. Williams

Who is your present employer?
GenH2

What is your title?
Ph.D., Scientist, Researcher, and Inventor; Senior Technical Advisor; Supports the Chief Technology Officer (CTO) / Chief Architect and Co-Founder

What projects are you working on now?

Currently, I am working on multiple projects:

- I am supporting GenH2's CTO in a broad range of technologies to address its mission of providing liquid hydrogen infrastructure solutions for the marketplace and spanning across different scales and capabilities.
- I am supporting GenH2's CTO with a comprehensive, big picture approach to technology development and invention in order to implement prior art and emerging and new technologies so we can meet GenH2's vision.
- I serve as a technical manager, a liaison for NASA-licensed technologies and as an inventor of some of the licenses that are slated for implementation and technology advancements.
- I am the technical advisor and editor for technical blogs and e-books.

What accomplishment are you most proud of?

Since GenH2 is a young company, the accomplishment to date that stands out to me is being part of the founding team in 2020. Quoting the CTO, "Hydrogen is hard; liquid hydrogen is even harder." Being part of the GenH 2 visionary team that is addressing the big challenges of providing valuable solutions for the hydrogen economy's current and future needs is rewarding and welcomed.

My other important accomplishments (at NASA) before coming to GenH2 were inventions in hydrogen sensing technologies and multiple low temperature, cryogenic thermal insulation and storage systems. Some cryogenic insulation systems concepts were utilized to address the space shuttle Columbia's return-to-flight, including the external tank, liquid hydrogen insulation and liquid oxygen piping experimental investigations. Innovative insulation systems approaches were needed, and investigations led by the NASA Cryogenics Test Laboratory included the development and testing of advanced foam and aerogel hybrid systems. My work was recognized by achievement awards from both NASA and the NASA Engineering Safety Center.

What advancements in cryogenics are you hoping to make in the future?

I'm hoping to support GenH 2's CTO and Cryogenics team in providing game-changing liquid hydrogen and liquefaction technologies — system(s) that are multiple scaled and can be mass-produced for land, air and sea markets. I'm also looking forward to new intellectual property in energy storage systems and innovative, insulating conductive composites for cryogenic systems that we anticipate achieving.

What advances for women would you like to see in the fields of cryogenics and superconductivity?

I would like to see more women in science and engineering be interested in, become involved with and be welcomed in the diverse area of cryogenics by using their interdisciplinary skills to bring major strides, advances and innovation to this essential area for a cleaner energy economy.

What would be the best approach to getting more women into your field?

Mentorship is an important approach to getting more women, especially early career women, into the cryogenics discipline. Furthermore, earlier exposure to specialty training in cryogenics will help women be able to realize how their specialty skills or backgrounds can add value to this challenging and exciting area of research and work. Collaboration and partnerships across disciplines are another great approach to transitioning into this field.

Emily Zhang

Who is your present employer?

East Far Materials

What is your title?

Sales manager

What projects are you working on now?

I am selling and promoting East Far Materials and CryoMLI series products for the cryogenic industry, particularly those in cryogenic transport and storage equipment.

What accomplishment are you most proud of?

I am learning and understanding a whole new industry and enjoy growing in the profession of cryogenics. My leader and friends have helped me a lot, taking me step-by-step, like a family, into the big field of cryogenics. Starting with little knowledge about cryogenics and still learning English, with the help of my coworkers, I have become a sales manager at East Far Materials. A sapling has grown into a big tree. I will continue to sow more saplings in return for the company.

What advancements in cryogenics are you hoping to make in the future?

I hope to grow in this profession by understanding the needs of our customers and being able to provide them with the best advice. When you see me, you can trust me. I hope that translates to our customers, and that I can participate more in the cryogenic industry and contribute to cryogenics, clean energy and the low carbon cause.

What advances for women would you like to see in the fields of cryogenics and superconductivity?

Women are a new force. I look forward to seeing more women in cryogenics, superconductivity, materials, devices, R&D and laboratories.

What would be the best approach to getting more women into your field?

Women do not need to be afraid and shouldn't resist this industry. They should befriend it. Here are some of my practices for reference by peers:

- Cooperate with experts and companies in the industry.
- Strive to learn the knowledge needed in the cryogenic field.
- Participate in industry seminars and exhibitions.
- Get to know more people in the industry.

Emission-Free Flying on the Horizon

Boeing's groundbreaking cryogenic fuel tank and Airbus's hydrogen-powered jet engine bring promise to the future of aviation.

A new type of cryogenic tank, designed and manufactured by Boeing, completed a critical series of tests at NASA's Marshall Space Flight Center at the end of 2021. The successful test campaign advances the large, fully composite, linerless tank for safe and ready use in aerospace vehicles. The reusable tank shell was originally constructed as flight hardware for the Experimental Spaceplane Program of the Defense Advanced Research Projects Agency (DARPA).

Boeing's all-composite cryogenic fuel tank undergoing pressure testing at NASA's Marshall Space Flight Center. *Credit: Boeing*

The 4.3-meter-diameter composite tank is built upon composite cryotank technology that NASA developed and proved efficient through their composite cryotank technology development program and other efforts. It is similar in size to the propellant tanks intended for use in the upper stage of NASA's Space Launch System (SLS) rocket, which is the foundational capability in NASA's Artemis lunar and deep space human exploration program. If the new composite technology were implemented in evolved versions of SLS's Exploration Upper Stage, the weight savings technology could increase payload masses by up to 30%.

"Composites are the next major technological advancement for large aerospace cryogenic storage structures," said Boeing Composite Cryotank Manufacturing Lead Carlos Guzman. "And while they can be challenging to work with, they offer significant advantages over traditional metallic structures."

During the testing, which was funded by DARPA and Boeing, engineers from Boeing and NASA filled the vessel with cryogenic fluid in multiple test cycles, pressurizing the tank to expected operational loads and beyond. In the final test, which was intended to push the tank to failure, pressures reached 3.75 times the design requirements without any major structural failure.

"NASA's support through this testing has been invaluable," said Boeing Test Program Manager Steve Wanthal. "We were able to use their technical expertise and investments made in the testing infrastructure at the Marshall Space Flight Center to continue to advance this technology, which will ultimately benefit the entire industry."

Applications for the technology expand beyond spaceflight. The test, which amplifies Boeing's extensive experience with the safe use of hydrogen in aerospace applications, will greatly benefit the company's ongoing studies of hydrogen as a potential future energy pathway for commercial aviation – a goal the company has already invested in by completing five flight demonstration programs with hydrogen in addition to their space program tests.

"Boeing has the right mix of experience, expertise and resources to continue to advance this technology and bring it to market in a variety of applications across aerospace and aeronautics," Guzman added.

As growing pressure mounts on the aviation industry to achieve emission-free flying, cryogenic storage tests on commercial airplanes will become more prevalent, as evidenced by European-based aircraft manufacturer Airbus's announced plans to test a hydrogen-powered jet engine by the middle of the decade as it pushes to meet its 2035 deadline to build a zero-emission aircraft. Airbus's plan calls for the first flight of an A380, the world's largest passenger aircraft, to be powered by a modified GE Passport turbofan by the end of 2026. To achieve this, they have teamed up with CFM International, the world's leading supplier of jet engines for commercial airplanes.

As the flying testbed, the prototype will be equipped with four tanks holding 400 kilograms of liquid hydrogen stored near the back of the airplane's interior. (The four hydrogen tanks will be surrounded by a hermetically sealed container for safety.) On their part, Airbus will define the hydrogen propulsion system requirements, oversee flight testing and provide the A380 platform to test the hydrogen combustion engine in the cruise phase. CFM has agreed to modify the combustor, the fuel system and the control system of the GE Passport turbofan, which will run on hydrogen.

The physical size and light weight of the engine, as well as its turbomachinery and fuel flow capability, made the engine an ideal choice for the partners. Additionally, its size allows flexibility for installing all the various systems and pipes needed for

A rendering of Airbus's planned A380 hydrogen-powered flight demonstrator shows placement of a modified GE Passport turbofan on the upper fuselage near the tail of the airplane. *Credit: Airbus*

efficient conversion of liquid hydrogen to gas. The engine will be mounted on the upper fuselage of the A380, just ahead of the tail, to allow for monitoring of emissions separately from those of the engines powering the aircraft. But first, CFM will execute an extensive ground test program ahead of the A380 flight test.

"Hydrogen combustion capability is one of the foundational technologies we are developing and maturing as part of the CFM RISE Program," said CFM chief executive Gael Meheust. "Bringing together the collective capabilities and experience of CFM, our parent companies [GE and Safran] and Airbus, we really do have the dream team in place to successfully demonstrate a hydrogen propulsion system."

According to Airbus Chief Technical Officer Sabine Klauke, some technical hurdles the project will face center on the fact that hydrogen burns 10 times faster than jet fuel, raising challenges involving the stability of the flame. Subsequently, Michel Brioude, chief technical officer of Safran, explained that additional challenges involve the need for cryogenic fuel pumps and new piping and seals to accommodate the very cold temperatures (as low as -250 °C) at which the hydrogen must be stored in its tanks. Prior to combustion, the hydrogen will be converted from liquid form into gas. As hydrogen gas burns at a higher temperature than kerosene, the plane must be adapted to withstand the extreme heat.

"There are many technical issues, but I can tell you we are committed and confident that we will address them," said Brioude. "During the flight test program, what we want to characterize are the condensation trails produced by the engine in different atmospheric conditions. Hydrogen does not produce CO_2, but it produces three times more water emissions. So those kinds of condensation trails might be a contributor to the greenhouse effect. Today, we don't know how long it lasts in the atmosphere, so we need to do the tests and collect the data to be able to know the effect on climate change."

GE Aviation Engineering Division Vice President and General Manager Mohamed Ali spoke of the need for partnerships across the industry, including with regulators, to build a framework to meet safety standards expected by the public. To date, GE has collected more than 8 million hours of experience running ground-based hydrogen gas systems. "So, we know how to put the safety precautions around that, and all of these findings would be taken into the future testing of this program," Ali explained.

Technical challenges will undoubtedly be the biggest hurdle the project will face, but Brioude is optimistic because the partners have already reached out to the European Union Aviation Safety Agency and the Federal Aviation Administration for better understanding of the regulatory requirements for ensuring the platform can fly safely and to start to define the key points for earning certification.

"We have data and we have experience we can share with them," Brioude noted. "And they are very open-minded about working with us."

Energy Evolution LLC President and former CSA President James Fesmire is excited to see liquid hydrogen gaining momentum and application in these industries. "It is great to see this latest accomplishment from Boeing, undoubtedly building on the data and lessons from the last three decades and now providing a foundation for future application for a significant advance in aerospace vehicles. With the plans for liquid hydrogen aircrafts and a path to clean aviation around the Earth, this technology could see application of significant advancement as well."

Elements of this story are attributed to Josh Barrett, Boeing Global Media Relations, and Gregory Polek, AIN Online.

World's Largest Liquid Hydrogen Tank Nears Completion

by Adam Swanger, NASA-KSC, adam.m.swanger@nasa.gov

Construction of the world's largest liquid hydrogen (LH_2) storage tank is almost complete at launch pad 39B at NASA Kennedy Space Center (KSC) in Florida. With a usable capacity of 4,732 m^3 (1.25 Mgal), this new vessel is roughly 50% larger than its sister tank, which is located 170 m (550 ft) to the southeast. Once the new sphere is fully commissioned, these two tanks will provide a combined LH_2 storage capacity of 7,950 m^3 (2.1 Mgal) to fuel the new Space Launch System rocket supporting future Artemis exploration missions to the moon and Mars.

As with its sister tank, which was erected during the 1960s as part of the original construction of the launch pad to accommodate the Saturn V moon rocket, Chicago Bridge & Iron Company (CB&I — now a part of McDermott International) played a central role in the design and construction of the new LH_2 sphere. It is similar in design to the legacy tank, as well as being double-walled and vacuum insulated, though it has a larger outer diameter of 25 m (83 ft) versus 21.4 m (70.2 ft). Where it does make substantial departures from the old design, however, is in the inclusion of two new technologies pioneered by the Cryogenics Test Laboratory at KSC (CSA CSM): glass bubble bulk-fill insulation as a replacement for the more traditional perlite, and an Integrated Refrigeration and Storage (IRAS) heat exchanger[1] for future controlled storage capability.

Over the past 20 years, NASA has extensively tested glass bubbles for insulating LH_2 tanks, focused primarily on the K1-type product from 3M Corporation. Field testing of a 190 m^3 (50,000 gal), perlite-insulated LH_2 storage tank at NASA Stennis Space Center in Mississippi, which was retrofitted with K1 glass bubbles in 2008, yielded a 44% reduction in boiloff and improved over time to around 48% in 2015.[2] Taking advantage of this substantial performance benefit that glass bubble provides, it is estimated that the

Figure 1. New NASA LH_2 storage tank during painting. *Credit: CB&I*

Figure 2. Cutaway of the new NASA sphere showing the IRAS Heat Exchanger Support Tower. *Credit: CB&I*

new sphere will have a normal evaporation rate (or boiloff rate) on par with that of the perlite-filled legacy tank (around 0.03% per day), even though it is significantly larger. Filling of the annular space with an estimated 1.3 quadrillion individual K1 bubbles, roughly 2,000 m^3 (537,000 gal) worth, was completed in early January 2022, at which point the focus turned to pumping down the annular space to its operational warm vacuum pressure in anticipation of the initial chilldown.

Inclusion of the internal IRAS heat exchanger as part of the intrinsic tank design was crucial to accessing all the benefits of "full control storage" in the future, such as zero-loss tank chill-down from ambient temperature, tank thermal cycle management (i.e., isothermalization between fill/drain cycles), zero-loss LH_2 tanker offloads, long duration zero-boiloff, in-situ hydrogen liquefaction and liquid densification (i.e., increased energy density). Economic analysis of zero boiloff testing on a smaller scale IRAS system at KSC in 2015-16, known as the Ground Operations Demonstration Unit for Liquid Hydrogen,[3] revealed that for every dollar spent on electricity to power the system, roughly \$7 worth of LH_2 was saved (based on \$0.06/kWh electricity cost and \$5.20/kg LH_2 cost) – a fact that played an important role in infusing the technology into the new launchpad sphere.

The heat exchanger is American Society of Mechanical Engineers code compliant and constructed of 43 m (141 ft) of fully welded, 38 mm (1.5 in) diameter, 316L stainless steel tubing with round coils located at the 75% and 25% fill levels. Total heat transfer area in contact with the hydrogen is roughly 5.2 m^2 (56 ft^2). Gaseous helium refrigerant supplied by a future closed-loop external refrigeration system will be routed to and from piping interfaces located on the lower part of the external tank, and piping within the annular space makes the connection between the external interfaces and internal coils. The entire heat exchanger is supported by an internal tower suspended from the upper dome of the inner sphere. Helium supply will be split into parallel paths upon entering the heat exchanger, travel through either the upper or lower coil first, depending on the desired flow path, and make its way vertically to the other coil before collimating at the annular piping interface and returning to the refrigeration system.

Overall construction of the new LH_2 sphere and ancillary systems is now complete, with coating of the outer vessel completed in February 2022. Final checkouts are currently underway, including a warm vacuum retention test, and initial LH_2 loading is scheduled to begin in September 2023.

More information about the design of the new tank, glass bubbles and IRAS can be found through reference 4.

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SINTEF/ECONNECT's New Tool Predicts LNG, Ammonia and Liquid CO_2 Flow Rates in Floating Cryogenic Pipes

SINTEF Energy Research and ECONNECT Energy have developed a novel computational fluid dynamic (CFD) modeling tool to predict liquefied natural gas (LNG), ammonia and liquid carbon dioxide flow rates in floating, flexible cryogenic pipes. The tool will increase understanding of flow rates in floating pipe technology with various pressure and temperature parameters to better inform the cost for end users and to increase gas value chain efficiency. This unique project establishes the optimal configuration of floating pipes by combining fluid dynamic modeling by SINTEF with data from ECONNECT Energy's operations.

Floating, flexible pipes for new SINTEF/ECONNECT technology. *Credit: SINTEF/ECONNECT*

With additional support from Innovation Norway and the Norwegian Research Council, the Innovation Project for the Industrial Sector (IPN) project contributes to a body of fluid dynamics research, addressing the heat and mass transport phenomena required to improve the process configuration and control for floating gas distribution systems. This is the first reliable modeling tool available to predict the flow rates for floating, flexible cryogenic pipes accounting for diameter, corrugation profile and insulation level that simulates leading floating pipes on the market.

A key component of the new modeling tool is its ability to address methods that stabilize the friction factor of LNG and other non-aqueous fluids to increase the throughput capacity and decrease boiloff effects, which effectively reduces costs and increases system efficiency. Relating to scaling up cargo deliveries and predicting the behavior of large volumes of fluid, this model will have significant commercial value because higher volumes of fluid can affect the velocity, and pressure and can contribute to a higher friction factor.

Stian Magnusson, ECONNECT Energy CIO, praises the project for its impact on clean energy. "The competence generated in the project will help to scale jettyless distribution technology and lower the barrier to cleaner energy substantially by making these energy feedstocks more available. This will enable industries and other users such as marine transport in Norway and abroad to make a switch from heavier fuels to LNG and ammonia."

The proprietary CFD models were validated with data from ECONNECT Energy's cargo deliveries to improve the process configuration and control for technologies using floating, flexible cryogenic pipes. Findings using data from a 2021 LNG operation demonstrate a lower-than-anticipated friction factor, further proving system efficiency and capacity for increased liquid volume. ECONNECT Energy input data allows for benchmarking the operational performance of ECONNECT Energy's jettyless system against traditional jetty solutions.

The CFD models can also be used to estimate the friction factor for other diameters and pipes for future technologies, hastening jettyless applications for zero carbon fuels and carbon capture.

New Rupture Disk Assemblies Provide Added Protection for Cryogenic Systems

by Jeff Elliott, a Torrance, California-based technical writer

Today, cryogenics is used to provide convenient storage of large quantities of industrial gases, such as nitrogen, oxygen, carbon dioxide, argon, helium and hydrogen, which can be vaporized from liquid to gas for uses ranging from steelmaking to medical systems and welding. Additionally, cryogenic equipment provides stable, cold temperatures required to preserve biological samples, supports superconducting magnets like those used in medical imaging systems and particle physics experiments, and provides support for novel surgical procedures and materials research.

Within these systems, liquefied gases are kept at very low temperatures because the boiling points for these gases are very low, ranging from -78.5 °C (-109.3 °F) for liquid carbon dioxide to -269 °C (-452.2 °F) for liquid helium. Due to its physical properties, as temperature rises, a small amount of liquid can expand rapidly into a large volume of gas. For example, the expansion ratio of nitrogen is 694 – with 1 liter of liquid nitrogen becoming 694 liters of gaseous nitrogen at standard temperature and pressure (ambient conditions). If the insulation or other cooling methods used to maintain cryogenic temperature conditions for a liquid are lost, a rapid buildup of pressure will occur in any closed tank or vessel in which the liquid is contained.

For these reasons, cryogenic systems are equipped with pressure relief devices, such as rupture disks, to protect against rapid pressure rise caused by a sudden increase of heat into cryogenic systems, cryogenic shippers, cryostats, canisters and associated piping. For applications that utilize superfluid helium to cool superconducting magnets used in magnetic resonance imaging equipment, particle accelerators (and for semiconductor processing, rupture disks) protect against the sudden catastrophic loss of insulating vacuum or insulating nitrogen in the storage vessel or experimental enclosure.

Several connection types can be used to attach the rupture disk assembly to the medical application.
Credit: BS&B Safety Systems

The rupture disk, which is a one-time-use membrane made of various metals including exotic alloys, is designed to activate within milliseconds when a predetermined differential pressure is achieved. However, given the critical reliability of the equipment in operation and during storage/transport, this demands high integrity pressure relief technology.

As a result, OEMs are increasingly turning to integrated rupture disk assemblies with all components combined by the manufacturer, as opposed to loose rupture disk and holder devices that leave much to chance. These assemblies are being tailored to the application, miniaturized and designed to utilize a wide range of standard and exotic materials, as required. This approach ensures the rupture disk device performs as expected, enhancing equipment safety, reliability and longevity while simplifying installation and replacement.

Separate Components Versus Integrated Assemblies

Traditionally, rupture disks began as standalone components that are combined with the manufacturer's separate holder device at the point of use. The installation actions of the user contribute significantly to the function of the rupture disk device. When installed improperly, the rupture disk may not burst at the expected set pressure. There is a delicate balance between the rupture disk membrane, its supporting holder and the flanged, threaded or other fastening arrangement used to locate the safety device on the protected equipment.

For this reason, an integrated rupture disk assembly is often a better choice than separable parts. Available ready-to-use and with no assembly required, integrated units are certified as a device to perform at the desired set pressure. The one-piece design allows for easier installation and quick removal if the rupture disk is activated.

The assembly includes the rupture disk and housing and is custom engineered to work with the user's desired interface to the pressurized equipment. The devices are typically threaded or flanged, or even configured for industry-specific connections such as CF/KF/Biotech industry clamp connections and VCR couplings. The rupture disk and holder are combined by the manufacturer by welding, bolting, tube stub or crimping, based on the application conditions and leak tightness requirements.

There are additional advantages to this approach. Integrated assemblies prevent personnel from utilizing unsafe or jury-rigged solutions to replace an activated rupture disk to save a few dollars or rush equipment back online. The physical characteristics of increasingly miniaturized rupture disks as small as 1/8" can also make it challenging for personnel to pick up the disk and place it into a separate holder.

"Cryogenic equipment OEMs are driven to deliver the safest operation as well as the longest life and lowest cost of ownership to their customers," says Geof Brazier, managing director of BS&B Safety Systems Custom Engineered Products Division. "The use of an integral assembly maximizes the longevity, proper function and trouble-free service of the pressure relief technology."

Integrated Assemblies – Rupture Disk Design

According to Brazier, the most important considerations in rupture disk device design are having the right operating pressure and temperature information along with the expected service life, which is often expressed as the number of cycles the device is expected to endure during its lifetime. Since pressure and cycling varies depending on the application, each requires a specific engineering solution.

"Coming up with a good, high reliability, cost-effective, and application-specific solution for cryogenic equipment involves selecting the right disk technology, the correct interface (weld, screw threads, compression fittings and single machined part) and the right options, as dictated by the codes and standards," says Brazier.

Because user material selection can also determine the longevity of rupture disks, the devices can be manufactured from metals and alloys such as stainless steel, nickel, monel, inconel, and hastelloy.

According to Brazier, for a wide range of industries, it can be important for rupture disks to have a miniaturized reverse buckling capability in both standard and exotic materials. "Where economics is the driver, reverse buckling disks are typically made from materials such as nickel, aluminum and stainless steel. Where aggressive conditions are required, more exotic materials like monel, inconel, hastelloy, titanium and even tantalum can be used," he says. In almost all cases, "reverse buckling" rupture disks are utilized because they outperform the alternatives in respect to service life.

In a reverse buckling design, the dome of the rupture disk is inverted toward the pressure source. Burst pressure is accurately controlled by a combination of material properties and the shape of the domed structure. By loading the reverse buckling disk in compression, it can resist operating pressures up to 95% of minimum burst pressure, even under pressure cycling or pulsating conditions. The result is greater longevity, accuracy and reliability over time.

"The process industry has relied on reverse buckling disks for decades. Now the technology is available to OEMs in miniature form as small as 1/8" burst diameter from BS&B. Until recently, obtaining disks of that size and performance was impossible," says Brazier.

However, miniaturization of reverse buckling technology presents its own unique challenges. To resolve this issue, BS&B created novel structures that control the reversal of the rupture disk to always activate in a predictable manner. In this type of design, a line of weakness is also typically placed into the rupture disk structure to define a specific opening flow area when the reverse type disk activates and also prevents fragmentation of the disk "petal."

"Reverse buckling, and therefore having the material in compression, does a few things. Number one, the cyclability is much greater. Second, it allows you to obtain a lower burst pressure from thicker materials, which contributes to enhanced accuracy as well as durability," says Brazier.

Small nominal size rupture disks are sensitive to the detailed characteristics of the orifice through which they burst. This requires strict control of normal variations in the disk holder.

"With small size pressure relief devices, the influence of every feature of both the rupture disk and its holder is amplified," explains Brazier. "With the correct design of the holder and the correct rupture disk selection, the customer's expectations will be achieved and exceeded."

Due to cost, weight and other considerations, Brazier says that BS&B has increasingly received more requests for housings made from plastics and composites.

Because customers are often accustomed to certain types of fittings to integrate into a piping scheme, different connections can be used on the housing. Threading is popular, but BS&B is increasingly utilizing several other connection types to attach the rupture disk assembly to the application. Once the integral assembly leaves the factory, the goal is that the set pressure cannot be altered.

"If you rely on someone to put a loose disk in a system and then capture it by threading over the top of it, unless they follow the installation instructions and apply the correct torque value, there is still potential for a leak or the disk may not activate at the designed burst pressure," explains Brazier. "When welded into an assembly, the rupture disk is intrinsically leak tight and the set-burst pressure fixed."

While OEMs have relied on rupture disks in their cryogenic equipment, the availability of integrated, miniaturized rupture disk solutions tailored to the application in a variety of standard and exotic materials can significantly enhance equipment safety, compliance and reliability – even in extreme work conditions.

Demaco's Hydrogen Distribution System Enables Plans for European Spallation Source

The European Spallation Source (ESS) research facility is currently under construction in Lund, Sweden. ESS is a research center founded on the needs of the European scientific community and marks a partnership of 13 European nations with a collective goal to build and operate the world's leading research facility utilizing neutrons.

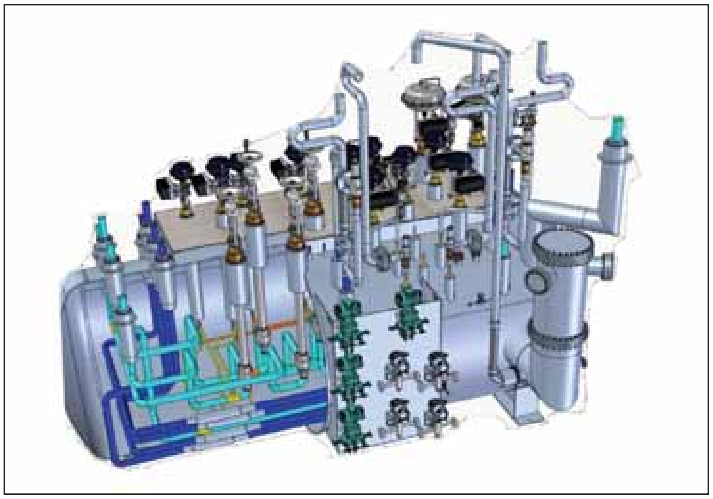
For its research, ESS will convert fast-moving neutrons into slower-moving neutrons. To facilitate this, ESS will provide researchers with a long-pulsed cold and thermal neutron beam. The neutron beam is generated by spallation in a tungsten target wheel. The generated neutrons will be cooled (slowed) down in two cryogenic hydrogen moderators. In the moderators, subcooled liquid hydrogen will absorb the extracted heat in a cryogenic moderator system; it will then be further absorbed by supercritical helium that circulates in the target moderator cryogenic plant. In these systems, subcooled liquid hydrogen will be used as a coolant. Hence, cryogenic systems and liquid hydrogen are vital for ESS.

With three decades of experience in the cryogenic and hydrogen industries, Demaco is well qualified to supply the cryogenic equipment that is needed to enable the aim of the ESS project. Demaco is responsible for designing, producing, testing and installing a cryogenic valve box, the necessary single vacuum insulated transfer lines, and the piping that, together, will form a part of the ESS cryogenic system. Valve boxes are specific devices that are essential for a cryogenic system. The main challenges of implementing the valve boxes are caused by the lack of space to incorporate the many necessary instruments like temperature sensors, flow meters, cryogenic valves and pressure measurement devices.

Hydrogen from the main supply vessel will be distributed by the valve box into the four supply lines that lead up to cryogenic moderators. In the hydrogen return line, the valve box will allow the hydrogen to flow back into the main supply vessel through the various return lines. Next to distributing the back-and-forth flowing hydrogen, the valve box also contains instruments that will measure the ortho-para fraction of the hydrogen as it returns from the moderators.

Demaco's design for the valve boxes goes further in terms of safety than the specified ATEX regulations. It features additional safety provisions to ensure the safe handling of the high pressure in the system and the potentially explosive environment surrounding the cryogenic system. The transfer lines in and out of the ESS valve box have a complex design that cannot be compared with a typical single transfer line. ESS required a shared vacuum for all the transfer lines to optimize overall safety. Designing the lines was complicated because hydrogen is used while pressure drops in the vacuum lines occur. To reduce this problem, the lines were designed with special pressure safety valves, special bellows, flexible components and special Demaco Johnston couplings to ensure the hydrogen would be contained within the system — thus guaranteeing the reliability of the valve box.

▶ continues on page 30



3D illustration of the valve box designed for the ortho-para measurement system (OPMS), as used by ESS. *Credit: Demaco*

AFCryo's New Liquid Oxygen System Provides Remote Capabilities

AFCryo, a New Zealand-based company specializing in small to medium cryogenic and liquefaction systems, has developed a fully mobile, high purity (99.5%), aviator-grade human medical liquid oxygen system. What makes this project unique is it is the only system that is fully portable, relocatable and remotely controlled, and at the same time meets the international standards for a high purity, liquid oxygen system (LOX).

This product is a result of an international tender for the design and build of the system to be owned by a European defense organization. AFCryo was selected over other suppliers due to its design, customer engagement and system reliability. Known for its containerized solutions, AFCryo's services are used around the world, within several different applications and among numerous industries.

"The biggest challenge to overcome was to design a system that was transportable and would fit into a single 20-foot ISO container and provide safe and reliable operation," says Christopher Boyle, managing director of AFCryo. "We were intrigued by the challenge that we knew we could resolve for the customer. AFCryo specializes in reliable liquefaction technologies that can be used in challenging environments and can also be transportable. We have developed several liquefaction gas units and CryoCubes that are now producing cryogenic liquids and gases around the world, often in remote locations and complex environments like, for example, 2 km underground or in extreme high temperatures and dusty conditions. We solved the problem others could not solve."

AFCryo's customer has procured the unit to enable them to conduct international peacekeeping and humanitarian projects. The unit will provide aviator and medical oxygen for field hospital applications, usually in remote locations, and can be transported by land, sea and air. For this project, the client will transport the unit

Containerized, high purity (99.5%) aviator grade and human medical liquid oxygen (LOX) system, designed and developed by AFCryo. *Credit: AFCryo*

using a C-130J Hercules aircraft to any destination in the world; it can then be connected to a generator or power supply in a field environment. The LOX CryoCube can produce up to 150 liters of LOX per day or up to 120,000 liters of oxygen gas per day.

"A power source is the only input required to have the unit ready to produce high purity liquid oxygen. After installation we can remotely control and monitor the system from our facilities or from our customer's facilities as well," adds Boyle.

The unique system uses Dual-Polarized Slot Antenna (DPSA) technology to produce oxygen gas to the desired purity, 99.5%. AFCryo's large linear pulse tube cryocooler is liquefying the gas at 90 K for storage in an appropriate dewar. The CryoCube is fitted with medical gas analysis equipment to continuously monitor the oxygen composition of trace gases and dewpoints.

"We are seeing interest from other global organizations. Our experience in building containerized, deployable CryoCubes means that we can design a liquid oxygen CryoCube that meets the strict international standards required for production of Aviator Liquid Oxygen and its required medical standards, as well as being mobile and relocatable," concludes Boyle.

This project is a game changer for a lot of organizations that are struggling to get supplies of medical quality, aviator standard liquid and gaseous oxygen. Having a solution that can be easily transported to any location, as well as one that can also be accessible on site, will be a big relief for many who are facing short supplies and long waiting times for distribution and delivery, and for those based in rural districts. **www.af-cryo.com**

Jobs in Cryogenics

Spacecraft Systems Engineer
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Cryogenic Test Engineer
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Mechanical Project Engineer/ Cryogenic Engineer
AFCryo - Christchurch, Canterbury

Mechanical Cryogenics Engineer
Lawrence Berkeley National Laboratory - Berkeley, CA

Cryogenic Engineer
Technifab Products, - Brazil, IN

Senior Mechanical Engineer & Project Manager
Ability Engineering Technology Inc - South Holland, IL

Job openings from CSA Sustaining Members and others in the cryogenic community are included online, with recent submissions listed above. Visit **https://cryo.mcjobboard.net/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.


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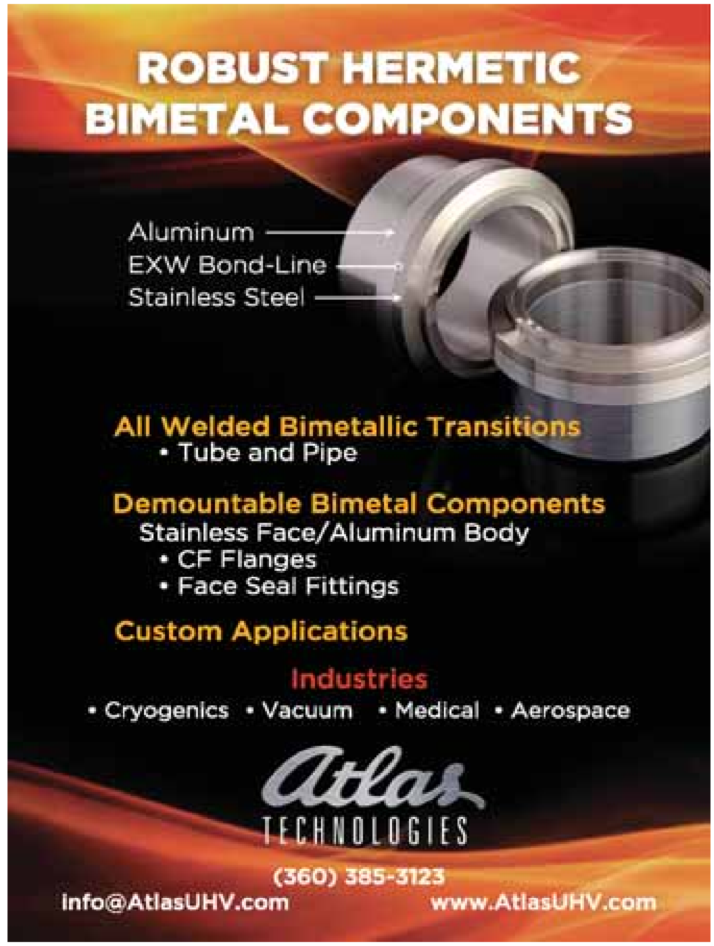
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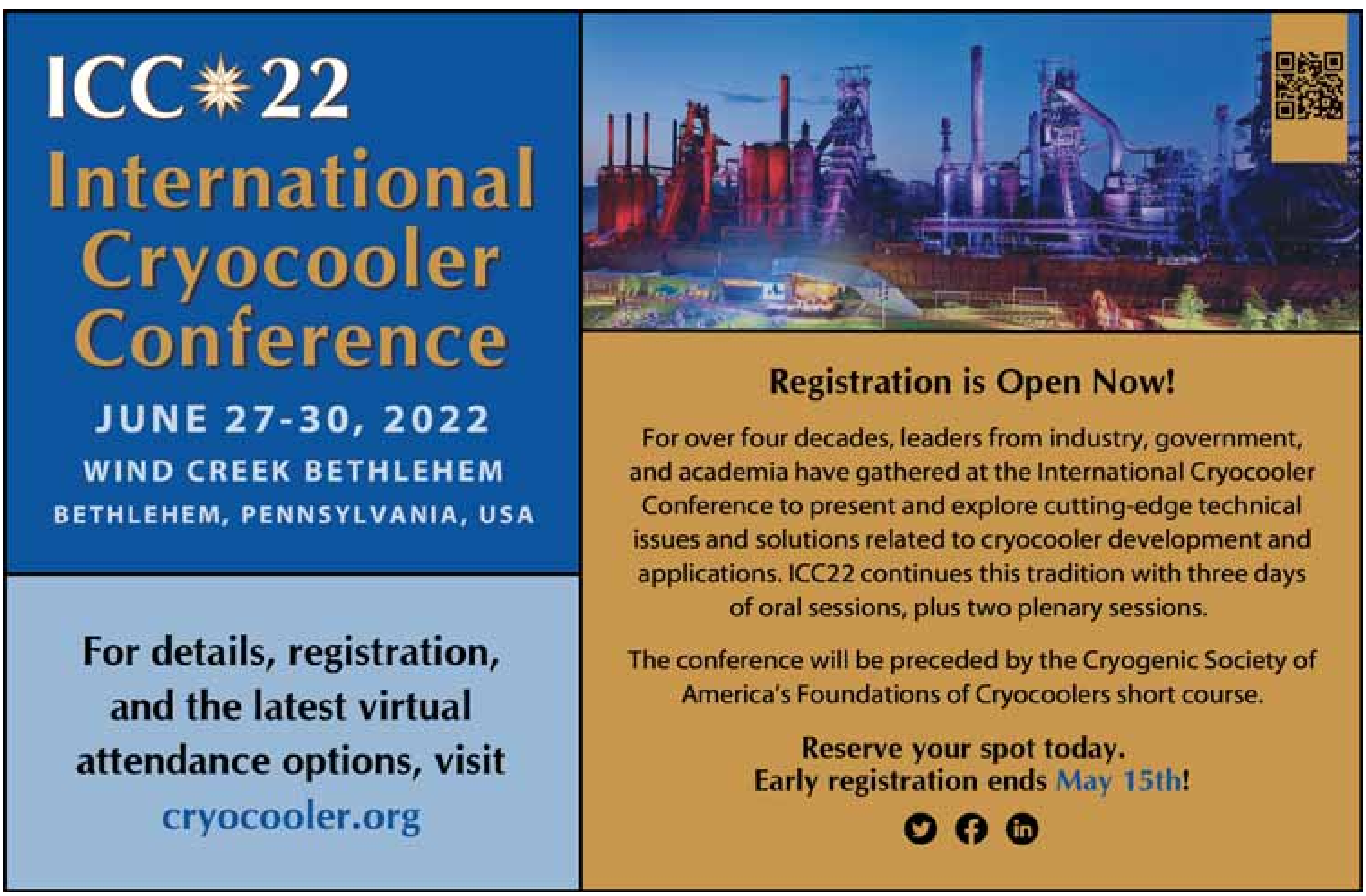
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Cryo Bios

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

Louis Paul Cailletet

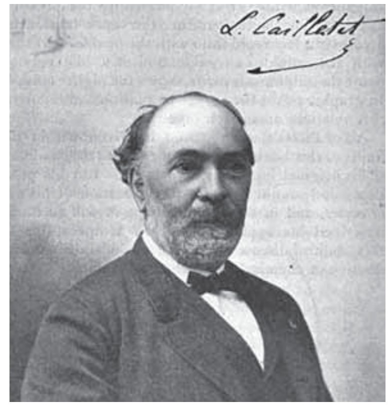
There was once a time when we spoke of permanent gases. Louis Paul Cailletet, born in Chatillon-sur-Seine, France in 1832, would go on to change how we speak of gases with the first liquefaction of oxygen. Louis Paul Cailletet was born in Chatillon-sur-Seine, France. His father owned and operated an iron and steel works. Cailletet attended secondary school in Paris and then audited classes for two years at the Ecole des Mines in Paris. While in Paris, he developed both a friendship and a professional collaboration with the chemist Henri Saint-Claire Deville.

In 1855, Cailletet returned to his father's iron and steel works, where he had access to large blast furnaces operating at extreme temperatures. In a loose collaboration with Deville, Cailletet investigated metallurgy and chemistry at high temperatures. For example, Deville had shown experimentally that gaseous compounds would disassociate into their constituent elements at high temperatures. Cailletet was able to verify this result by measuring gases emitted from the blast furnaces.

Cailletet then began to study the chemistry of gases at high pressures, which was a precursor to his liquefaction of oxygen and brings up the idea of permanent gases. Throughout the 19th century, scientists started to liquefy gases (both compounds and elements) at room temperature by subjecting them to very high pressures. However, there were several gases including air, oxygen, nitrogen, hydrogen and carbon monoxide that couldn't be made liquid even at pressures exceeding 1000 bar. These gases were referred to as permanent gases; and at the time, they were not thought to be condensable. Of course, today we know that the reason for this behavior is that the critical temperature of these gases is below room temperature, and above the critical point no amount of pressure will cause a gas to liquefy. (Note that the list of permanent gases above does not include helium, neon, krypton or argon. This is because these elements weren't discovered until later.)

Cailletet began by measuring the compressibility of gases at high pressures and investigated the effect of high pressures on chemical reactions. This work allowed him to develop techniques to both create and measure high pressures. He then turned to liquefying gases, and during one of his attempts to liquefy acetylene, the high-pressure glass cylinder sprung a leak, causing a sudden drop in both pressure and temperature and the condensation of the acetylene into droplets. Cailletet adopted the sudden expansion and subsequent cooling of gases into his approach for liquefying oxygen and other gases. His apparatus for liquefying oxygen consisted of a glass tube into which the oxygen is placed. The tube was surrounded by a bath of evaporating sulfur dioxide, which cooled the tube to 244 K. An elaborate hydraulic pump pushed liquid mercury into the bottom of the tube, compressing the oxygen to high pressures. Next, a valve in the hydraulic system opened, releasing the pressure on the mercury and causing the oxygen to suddenly expand as it pushed the mercury out of the tube. This produced a mist of liquid oxygen droplets in the tube. This first liquefaction of oxygen was reported by Cailletet in late 1877. A few days after this report, Raoul Pictet from Geneva, Switzerland, also reported that he had liquefied oxygen using a cascade refrigeration technique.

After these results were reported, scientists raced to liquefy the remaining "permanent gases." These included nitrogen (1883, Z. Wroblewski and K. Olszewski, *Cold Facts* Vol 35, No. 1), argon (1895, K. Olszewski), hydrogen (1898, J. Dewar, *Cold Facts*, Vol 34, No. 4) and helium (1908, Kamerlingh Onnes, *Cold Facts*, Vol 35, No. 2). Cailletet provided an oxygen compressor and other equipment to Wroblewski and Olszewski, and they were the first to create a boiling bath of liquid oxygen rather than just mist in a tube. These liquefaction efforts were really the start of the field of cryogenics, and because the boiling point of oxygen is 90 K, Cailletet's liquefaction of it could be considered the first experiment in cryogenics well before the term cryogenics was coined.



Louis Paul Cailletet

Born September 21, 1832

Died January 5, 1913

Paris, France

Louis Paul Cailletet had other intellectual interests. He did numerous studies on plant physiology, but a particular interest of his was aeronautics. The Wright brothers' first flight was in 1903, so for most of Cailletet's life, aeronautics was based on balloon flight. Cailletet studied the air resistance on falling bodies, invented an altimeter and, as an extension of his development of pressure-measuring devices, installed a manometer at the top of the Eiffel Tower. He also developed a sophisticated automatic camera system for use in reconnaissance with unmanned balloons. His interest and contributions to aeronautics led him to be elected president of the Aero-Club de France.

Both Cailletet and Pictet were awarded the Davy Medal by the Royal Society of England for their liquefaction of oxygen. Cailletet was elected to the French Academy of Sciences in 1884. A good overview on the race to liquefy "permanent gases" is *The Quest for Absolute Zero* by K. Mendelssohn (1966).

Cool Fuel

by Dr. Jacob Leachman, Associate Professor, Washington State University, jacob.leachman@wsu.edu with Reece Adams, Team Lead, Cryogenic Accelerated Fatigue Tester (CRAFT) Team, reece.adams@wsu.edu

Could Zero-Boiloff Storage Be Easier Than We Think?

I'm throwing in the towel on academia and starting my own bank. Let's call it the First Hydrogen Bank. You invest your money, and I'll bank it as pure hydrogen energy for later use. It's not only the coolest bank around, but it will be the greenest, fastest (10×), largest (10×), and have the lowest exchange rate among energy banks. Standard terms and fees apply:

- Open an account for as little as $500,000
- Reserve limits up to $50,000
- Compounding losses near 3% per day
- Transfer fee, only 10%
- Zero-balance reactivation fee of $10,000
- Apply now to start in 2023!

Jokes aside, those are some hefty terms and fees. Such is the predicament of organizations looking to bank or store energy in the form of liquid hydrogen. No matter how hard you try, you can't stop heat transfer in cryogenics. Heat boils cryogenic fluids that are stored, causing tank pressure to increase and pressure relief valves to vent. This results in daily losses. These losses are coming under increased scrutiny, not just for the economic losses as above, but because a new study in preprint indicates hydrogen leakage may contribute to short-term global warming.[1] While these side effects may be smaller than other fuels, and the long-term benefits of hydrogen still far outweigh the short-term setbacks, the negative results could become significant because of the required scale of hydrogen. Regardless of economic or environmental reasons, we need to get serious about reducing liquid hydrogen storage losses.

Zero-boiloff (ZBO), a.k.a. no-vent storage, is achieved through combinations of effective insulation, passive cooling and active cooling. Industry has settled on a baseline configuration of 4,300 kg cylindrical, liquid hydrogen storage tanks with vacuum-jacketed insulation achieving daily boiloff rates near 3%.[2] For reference, 4,300 kg of hydrogen has a raw energy equivalent to 143 megawatt-hours. With this insulation, the heat load on the liquid is near 500 W, depending on fill percentage. It's difficult to improve upon vacuum-jacketed superinsulation. Let's consider what we can do with passive and active cooling.

Passive cooling utilizes cool hydrogen boiloff vapors to intercept heat on the way to the liquid. If we are very good at utilizing cold hydrogen vapors to intercept incoming heat, we will warm hydrogen all the way to room temperature before exiting the tank. This hydrogen carries a total cooling capacity of up to 4,500 kJ/kg for a total of 7,800 W of cooling power at a similar venting rate caused by the heat inflow of just 500 W. Yes, you read that right. Passive cooling has incredible potential to reduce the heat load, which results in hydrogen

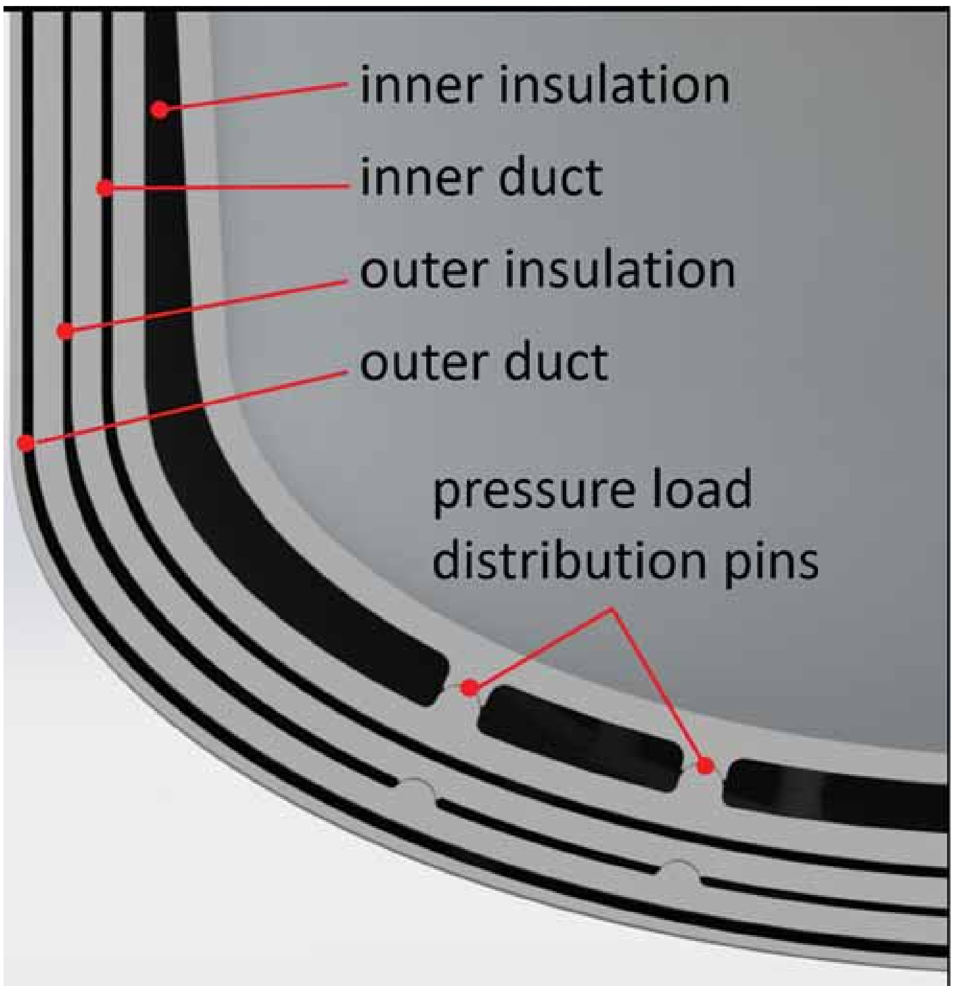


Figure 1. *Credit: Jacob Leachman*

venting. We've developed small-scale 3D-printed tanks designed with two full vapor shrouds (shown in Figure 1) to demonstrate this concept. However, these small-scale tanks are nowhere near the scale needed for bulk storage. It is expensive to manufacture large-scale tanks with four to five fully nested shells for passive cooling, as each vapor shroud should be insulated from the next. As 3D printing technologies continue to advance, however, you can imagine a future where multiwalled monolithic tanks are printed with vapor shrouds (at scale) in rapid succession.

Wouldn't it be nice if nature collected the energy coming into the liquid hydrogen tanks and concentrated it somewhere small for efficient removal? Surprisingly, it does! Heated hydrogen rises quickly to the top of the vapor ullage space within tanks. Wes Johnson's recent SHIIVER Report from the NASA-Glenn Research Center[1] shows that the temperature of hydrogen within the ullage space can easily be 50 to well over 100 K higher in temperature than the liquid below.[3] A boiloff gas (BOG) compressor can be used to extract this concentrated high temperature hydrogen. If we assume an extraction temperature near 77 K, such a compressor would lift 1,100 kJ/kg of thermal energy with hydrogen from the tank. This means that just 0.45 g/s of hydrogen out of the tank is enough to balance the 500 W incoming heat load. If para-orthohydrogen conversion is completed before the hydrogen leaves the tank, the required mass flow rate is 0.35 g/s. We can scale up compressors to meet this demand, provided we have either a high-pressure storage area to accumulate the hydrogen or a fuel cell to utilize the hydrogen, for example.

All passive cooling approaches require continuous boiling and extraction of hydrogen. What if we simply wanted to bank the hydrogen over summer without losses for use during winter? Active cooling is required to intercept the 500 W of heat load with no-venting and ZBO. Cooling to 20 K is incredibly limited by a poor Carnot Coefficient of Performance near 0.07. This implies that 14 W of electrical energy must be input for every 1 W of heat lifted at 20 K for an ideal refrigerator. Sadly, even our very best refrigerators are only operating near 30 to 40% of their ideal efficiency. A power input of 23.8 kW is required to run such a refrigerator. While this may seem considerable, a 20×10 m solar array shielding the storage tank from the sun could output up to 30 kW. If you're not a fan of solar, you can use the extra hydrogen from the BOG compressor and a 60% efficient fuel cell to produce 25.5 kW, also enough to run a cooler.

What can be seen from this simple analysis is that we have several tools at our disposal to dramatically reduce and potentially eliminate venting from liquid hydrogen storage facilities. The challenge quickly becomes which path, or combination of paths, yields the quickest return on investment. I'd very much enjoy the opportunity to develop such a research facility here on WSU's campus for freight and logistics refueling. With your help, maybe we really will start a hydrogen bank.

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[2] **https://files.chartindustries.com/21746492_LH2Trailer.pdf**

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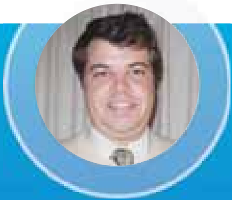
Footnotes

[1]The Structural Heat Intercept, Insulation, and Vibration Evaluation Rig (SHIIVER) is a large-scale cryogenic fluid management (CFM) test bed designed to scale CFM technologies for inclusion on large, in-space stages.



Space Cryogenics

by Wesley Johnson

James Webb Space Telescope Successfully Launches, Deploys and Prepares for Operations

The James Webb Space Telescope (JWST) launched on December 25, 2021, from Kourou, French Guiana (Figure 1). JWST is intended to replace the Hubble Space Telescope by exploring the infrared radiation that shifted from the initial ultraviolet radiation emitted directly after the Big Bang and in the early formation of the universe. It took 30 days for the telescope to arrive at the second Lagrange point (L2) in the earth-sun system, which is approximately a million miles from the earth.

L2 places the earth between JWST and the sun and allows a singular sun shield (essentially five layers of widely spaced MLI between the sun and the telescope that is the size of a tennis court) to shield the telescope from both the earth and the sun while the rest of the telescope is facing deep space. Lagrange points are unique locations within a "three-body system" (sun-earth-spacecraft) where the gravitational forces of the sun and the earth are balance[1], causing JWST to orbit the sun in the same amount of time that Earth does (approximately 365.25 days). By shielding from both the earth and the sun with large areas able to radiate heat to deep space (at approximately 2 K), the main telescope will be able to reach temperatures between 35 and 40 K. With this location and low temperatures, the JWST will be able to survey the sky with higher sensitivities than previous telescopes. It will look back in time at the formation of the first stars and galaxies to help understand the formation of the early universe. By detecting wavelengths in the infrared regime, it will be able to look through clouds of dust that shield the inner workings of the stars and galaxies. Additionally, it will be able to provide insight into the atmospheres of planets that orbit other stars to help determine if they would be habitable for the building blocks of life.[2]

For the telescope to fit in the fairing (or payload volume) of the Ariane 5 launch vehicle, the primary mirror for the JWST was designed to have 18 foldable, hexagonal segments. (Figure 2 is an image showing the JWST operational configuration.) These segments were folded up during launch and then deployed en route to the telescope's orbital destination. Before the deployment of the mirror segments, the sun shield, which was also folded up within the spacecraft, was deployed and tensioned. The deployment phase took seven days for the sun shield and ten days for the mirror segments as the engineers slowly moved them into place. With the segmented mirror, the JWST has a 6.5-meter diameter (as opposed to the Hubble Space Telescope, which has a diameter of 3 meters) allowing it to absorb more radiation and observe fainter sources. Each of the 18 mirror segments has actuators that allow for the continued tuning of the mirror after deployment. These actuators must continue to function even in the cold operational temperatures of the main telescope.[3]

Once JWST reached its intended orbit in late January, it began the process of cooling down its instruments. In addition to the passive cooling provided by the sun shield, the Mid-InfraRed Instrument (MIRI) located within the Integrated Science Instrument Module has a cryocooler that cools at both 18 K and at 6.2 K. Here, the 18 K load is a shielding of the 6.2 K load.[4-6] The cryocooler is a hybrid Pulse Tube/Joule-Thompson (JT) system consisting of a helium circulation loop powered by a room temperature

Figure 1: JWST launch on an Ariane 5 launch vehicle.
Credit: NASA/Chris Gunn

circulator with a three-stage pulse tube pre-cooler and a JT final stage.[5-7] With the helium circulator being at approximately room temperature, the three-stage pulse tube system cools three recuperative heat exchangers in the JT refrigerator to reach the desired 6.2 K target temperature after expansion.

One of the largest challenges in the system design was enabling the cooldown of the system. (This is more thoroughly discussed in references 5 and 6.) The addition of a bypass valve within the JT cryocooler loop, just before expansion, allowed for the cooldown to be achieved. Another interesting challenge within the JWST/MIRI cryocooler system was the cryocooler's distribution tubing lines that connect the J-T portion of the cryocooler system at the MIRI instrument optics to the cryocooler compressors which are located

▶ continues on page 30

Clean Energy Future

by James E. Fesmire, President, Energy Evolution LLC, james@321energy.us

Cryogenic Liquid Transfer

Cryogenic liquid transfer is the piping, distribution or similar conveyance of a cryogenic liquid from point A to point B. Normally, the cryogenic liquid is stored at or near the atmospheric pressure so that it is close to its normal boiling point (NBP). If the storage tank is kept at some higher pressure (say 5 or 10 bar), then the liquid is “warm,” relative to its NBP, and cannot be simply transferred out of the tank to another receptacle where the pressure is atmospheric. The liquid will flash to vapor, two-phase flow will dominate, and little to no liquid will be transferred. For the tank kept vented to the atmosphere, the vent can be closed, the tank ullage space pressurized, and then the liquid can be transferred from the tank. But from the moment the tank is pressurized, the liquid is warming up, and the transfer must take place right away.

The goal is to move the liquid before too much heat comes into the piping (into the liquid) and causes problems like two-phase flow and vapor lock. Think of moving ice cubes on a conveyor belt inside an oven at 280 °C. That is about the same situation (same ΔT) as trying to move liquid hydrogen through a piping in the ambient environment. The melting of the ice cubes can be minimized by a combination of three ways: insulate the ice cubes, sub-freeze the ice cubes or move them really fast!

Since the 1960s, this process of storage and transfer has worked out well for cryogens like liquid nitrogen, liquid oxygen, liquid hydrogen and others. Each cryogen has its issues. Liquid oxygen is extremely heavy, but it doesn’t boil readily. Liquid hydrogen is extremely light, but it does boil readily. Transfer can be done by pumped or pressurized means, but in either case, it is the starting point of a NBP liquid that is required for traditional (passive, non-controlled) storage and transfer. New technologies today afford the capability for active, controlled storage

Figure 1. Concept of liquid hydrogen infrastructure for an airport. *Credit: Hamburg Aviation*

and transfer by starting with densified liquid. In this case, the densified liquid can absorb the heat gain from the surroundings into the piping and allow the liquid to remain a liquid and not flash to vapor. This controlled transfer, more akin to the flow of water, can be designed to enable cryogenic transfer that is quick, safe and efficient.

What is the problem with cryogenic transfer today? It gets the job done for today but tends to be cumbersome and time-consuming with many limitations. Let’s take a look at the basic steps in the process of cryogenic transfer by pressurized means. We’ll use liquid hydrogen as our example, as the more complex one, but most steps will be similar for any cryogenic liquid. These are the basic steps where the tank and piping are already connected as part of the whole system:

1. Vent the storage tank to ambient pressure (in advance or normal standby condition).

2. Purge/inert the transfer line. Clean out the internals of the piping circuit by evacuation and/or purge with helium gas.

3. Backfill the line. Fill the line with gaseous hydrogen or helium.

4. Verify: analyze to make sure the line is free of air or moisture.

5. Pressurize the storage tank with gaseous hydrogen or helium.

6. Cool down the line. Partially open the upstream and downstream valves and allow the line to begin to cool down. (Watch out for pressure excursions, pipe bowing, leaks due to stresses on mechanical joints, etc.)

7. Transfer: when the internal flow line is cooled to 20 K, perform the main transfer of the liquid.

8. Warm up the line. Close the valves in the required sequence and allow the line to begin to warm up.

9. Purge/inert the line as before.

10. Vent the storage tank to ambient pressure.

Altogether, it is time-consuming and there are also significant losses in product.

To put liquid hydrogen to work in the hydrogen economy to come, the cryogenic transfer processes must be improved to reduce the time, complexities and losses involved. Controlled storage can be tapped as part of the solution, but high-performance and practical transfer systems are still needed for utility for infrastructure across the board. For example, Airbus has set ambitious goals for developing an LH_2 aircraft and the necessary infrastructure by 2035. Cryogenic transfer (or transport) has to happen from production to airport, from airport to tarmac, from tarmac to aircraft tanks, and from aircraft tanks to engines. That is a lot of transfer, and the latter two are likely interconnected networks of piping.

Transfer of cryogenic fluids will be a vital part of the clean energy future, putting liquid hydrogen to work and a host of other uses from testing to manufacturing to transportation.

10 meters away on spacecraft bus. The lines had to be thermally isolated from the surrounding environment to keep the cryocooler performance requirements within the cryocooler's design capability. With such low environmental temperatures around the tubes (none expected higher than 120 K), a simple gold plating was able to provide sufficient thermal protection for the tubing runs; however, the process for coating the tubes with gold turned out so well that now the Oscars are coated using the same methodology.[8,9]

A total of six months of "commissioning" or checking out JWST is planned before operations. The cooldown of the MIRI and other operations on the telescope can be followed on the NASA website.[3] Initial images are already being taken to help with the process of aligning the mirror and checking out of the instruments. As of the writing of this article, the launch, deployment and activation of the James Webb Space Telescope have gone as planned with enough fuel on board for a full mission.

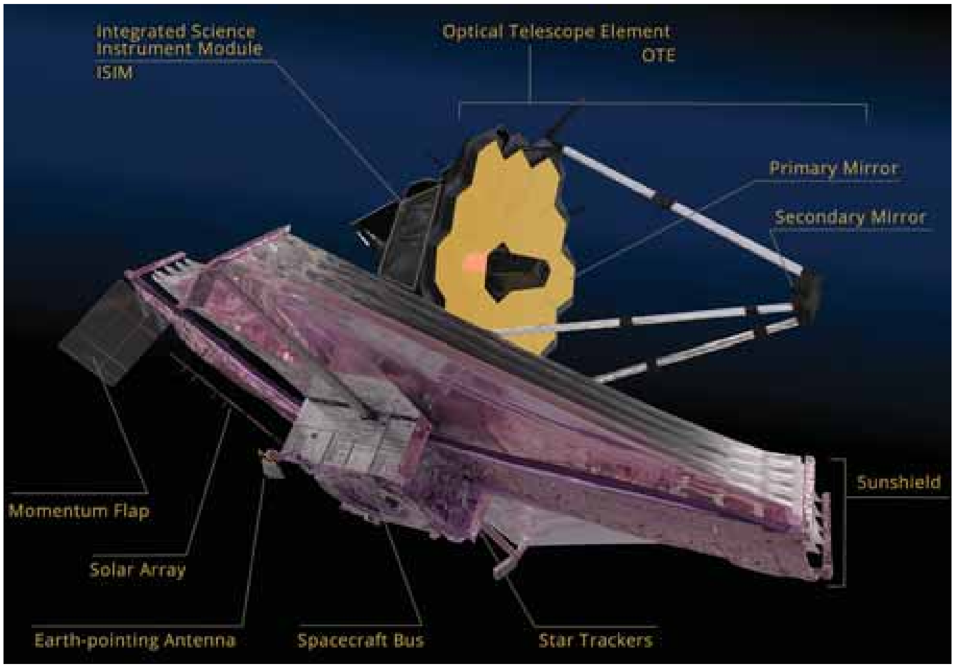


Figure 2. JWST spacecraft image. *Credit: NASA*

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Demaco's Hydrogen Distribution System... Continued from page 20

Another critical point is the connection of the vacuum line to the monolith vessel where the equipment is exposed to the external vacuum and ionizing radiation levels in the area. To safeguard the reliability of the equipment, further analysis must be conducted. Additionally, 100% X-ray inspection of all piping welds and the vacuum jacket must be performed (standard at 10%) to guarantee the quality of the infrastructure through which hydrogen is transferred from and to the main vessel.

Demaco, involved and integrated

Demaco's field engineer involved in the construction and installation of the valve box, Marco van der Walle, reports: "We start our week with the day-to-day planning for the coming week, and we share this planning with our counterparts at ESS. To minimize on-site surprises, we regularly meet to discuss any issues that might jeopardize or interfere with our jointly agreed planning. Whenever we require equipment like scaffolding or aerial platforms, they take care of it instantly."

Regarding the planning of hoisting the equipment, van der Walle says that Demaco found hoist teams standing ready on every occasion. "After we had mounted the process lines, the pipes were welded together. All welds are bi-weekly checked by X-ray inspection, which is done after production hours. Currently, we are hoisting and mounting the piping of the shaft. The next step will be hoisting and positioning the valve box. We will install the last part of the installation during our next tour to Lund and finish up by conducting the necessary checks and tests. Through our efforts and the excellent cooperation with the ESS crew, I can state that installing the valve box at ESS, which is our part of the project, is progressing smoothly and as planned. **www.demaco-cryogenics.com**

Bioresearch Merger Brings Productivity to Bio-Operations

IC Biomedical, founded in 2020 through the merger of International Cryogenics, Inc. and Worthington's Life Sciences Cryogenic Equipment division, brings a 65-year legacy of design and manufacturing cold chain storage and transport technology to today's cryogenic market.

The company traces its roots back to 1957 when the growing need for liquefied oxygen and nitrogen led Taylor-Wharton to develop the first insulated liquid cylinders. This product line, eventually branded in the early 2000s as CryoScience by Taylor-Wharton, brought high-quality, organized cryogenic storage to research labs and biorepositories and became the standard for vessels in this growing market. For 58 years, Taylor-Wharton perfected its product designs for longer holding, more durable cryogenic tanks and bulk sample storage freezers. In 2015, the product line's assets, along with intellectual property and a manufacturing facility in Theodore, AL, were acquired by Worthington Industries, where it was sold under the Life Sciences brand. Today, IC Biomedical is the only company in the world producing Taylor-Wharton-designed aluminum vessels and stainless steel bulk freezer systems. As a tribute to this lineage, the company's newly designed aluminum small freezer product line is sold under the TW brand.

In 1980, International Cryogenics, Inc. (ICI) was formed in Indianapolis, Indiana to design and manufacture high quality, custom cryogenic storage and transfer applications. Custom equipment manufactured by ICI was used in highly demanding applications such as the space shuttle, solar eclipse infrared camera equipment, liquid helium transfer lines and storage containers used in supporting MRI equipment. In the 1990s, ICI developed a line of aluminum liquid nitrogen cryobiological containers with extended holding times. These tanks were used for many specialized purposes, including on African safaris to collect semen from endangered species and for the collection and storage of specimens used in laboratories and research centers.

IC Biomedical is committed to providing Made-in-the-USA, high-quality, reliable cryogenic storage and transport vessels for artificial insemination / animal husbandry operations. *Credit: IC Biomedical*

When IC Biomedical was formed in November 2020, the company had acquired facilities in Indiana and Alabama and was building two types of dewars, small freezers, shippers and vial storage. At the end of its first year of operation, the company consolidated its products into a single, updated design based on the best features from its legacy companies. In the last six months, the company has introduced 10 newly designed products in the shipper and small freezer category that are in more agreement with end user-specific requirements.

Establishing a new company during the COVID pandemic was extremely challenging. The first big breakthrough for IC Biomedical came in June 2021, when its new medical-grade manufacturing facility in Cartersville, GA began production. The older facilities were sold, and the company consolidated its headquarters in Cartersville. Since then, the 75,000 sq. ft. facility has earned its ISO 13485:2016 certification and is in the process of adding another 30,000 sq. ft. of space.

IC Biomedical is managed by a highly experienced group of cryogenic industry veterans led by CEO Steve Shaw, who has more than 27 years of cryogenic biomedical market experience that includes serving as president of Chart Industries' former Biomedical Group, MVE and Caire. In September 2020, the group was joined by Chief Commercial Officer Ian Pope, who is an industry thought leader and acknowledged expert in cryogenic and ultracold storage and transport. Pope has previously served in high-level management positions at Brooks Life Science Systems, Cryo Associates and Chart Biomedical.

"As global bioresearch and IVF procedures continue to evolve, IC Biomedical is committed to continuous improvement in product quality and performance," says Pope. "Ensuring the quality systems within the organization stay one or two steps ahead of regulatory requirements and remain proactive in continuous development will ensure our products are appropriate for the current and future critical application needs of our end users."

Cryogenic products remained fundamentally unchanged since 1957. While many of these products are ideal, fit-for-purpose vessels, in many cases, the end user had to adapt their processes and procedures to available products. With new design and manufacturing technology, high-tech insulation materials, and developments in telemetry plus advanced temperature sensors and controls, IC Biomedical is now designing products that are more application-specific to deliver maximum productivity for bio-operations.

IC Biomedical's leadership sees the future of cryogenics as having more regulation, higher audit standards and including application-specific products, as well as being more quality-driven. From durable aluminum dewars, small freezers, vial management lab systems and shippers, to high-tech, fully automated and auditable stainless steel freezer delivery solutions for the most complex cell research, IC Biomedical is committed to the future sustained growth of bioresearch. **https://icbiomedical.com**

Physicists Observe "Quantum Boomerang" for First Time

by Sonia Fernandez, University of California, Santa Barbara, sonia.fernandez@ucsb.edu

Physicists at UC Santa Barbara (UCSB) have become the first to experimentally observe a quirky behavior in the quantum world: a "quantum boomerang" effect that occurs when particles in a disordered system are kicked out of their locations. Instead of landing elsewhere, as one might expect, they turn around and come back to where they started and stop there.

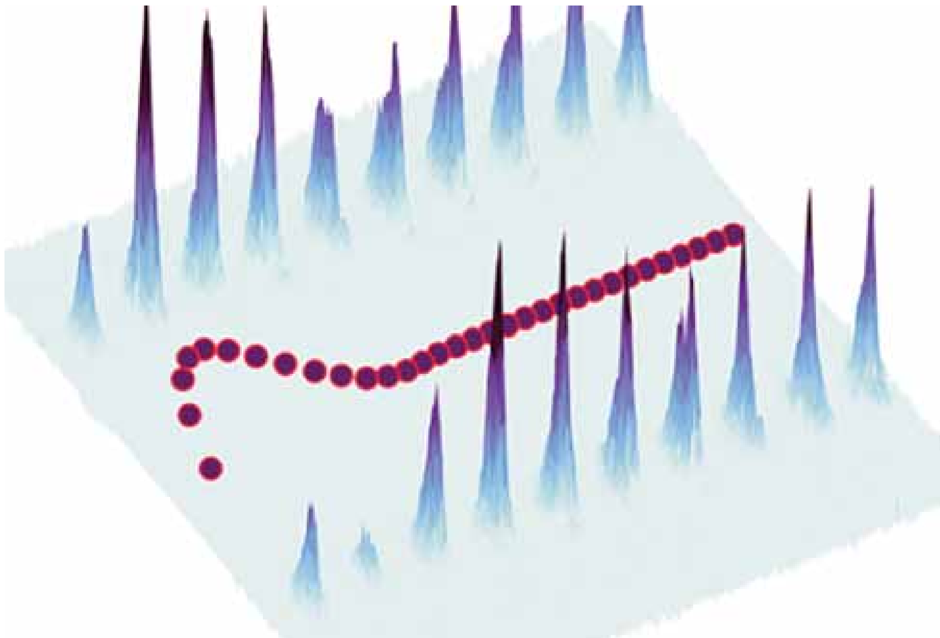
"It's really a fundamentally quantum mechanical effect," said atomic physicist David Weld, whose lab, Weld Lab (an experimental, ultracold atomic physics group at UCSB), produced the effect and documented it in a paper published in *Physical Review X*. "There's no classical explanation for this phenomenon."

The boomerang effect has its roots in a phenomenon that physicist Philip Anderson predicted roughly 60 years ago, a disorder-induced behavior called Anderson localization, which inhibits transport of electrons. The disorder, according to the paper's lead author, Roshan Sajjad, can be the result of imperfections in a material's atomic lattice, whether they be impurities, defects, misalignments or other disturbances.

"This type of disorder will keep them from basically dispersing anywhere," Sajjad said.

As a result, the electrons localize instead of zipping along the lattice, turning what would otherwise be a conducting material into an insulator. From this rather sticky quantum condition, the quantum boomerang effect was predicted to arise a few years ago.

Launching disordered electrons away from their localized position and following them to observe their behavior is extremely difficult, if not currently impossible; however, the Weld Lab had a few tricks up its sleeve. Using a gas of 100,000 ultracold lithium atoms suspended in a standing wave of light and "kicking" them, emulating a so-called quantum kicked rotor ("like a periodically kicked pendulum," both Weld and Sajjad said), the researchers were able to create the lattice and the disorder and observe the launch and return of the boomerang. They worked in momentum space, a method that evades some experimental difficulties without changing the underlying physics of the boomerang effect.



The Weld Lab's quantum boomerang showed a lithium atom's initial departure and return to average zero momentum despite periodic energy "kicks" from their quantum kicked rotor. *Credit: Weld Lab, UCSB*

"In normal, position space, if you're looking for the boomerang effect, you'd give your electron some finite velocity and then look for whether it came back to the same spot," Sajjad explained. "Because we're in momentum space, we start with a system that is at zero average momentum, and we look for some departure followed by a return to zero average momentum."

Using their quantum kicked rotor, they pulsed the lattice a few dozen times, noting an initial shift in average momentum. Over time and despite repeated kicks, however, average momentum returned to zero.

"It's just a really fundamentally different behavior," Weld said. "In a classical system, a rotor kicked in this way would respond by constantly absorbing energy from the kicks. Take a quantum version of the same thing, and what you see is that it starts gaining energy for short times; but at some point, it just stops, and it never absorbs any more energy. It becomes what's called a dynamically localized state."

This behavior is due to the wave-like nature of quantum systems.

"That chunk of stuff that you're pushing away is not only a particle, but it's also a wave - a central concept of quantum mechanics," Weld explained. "Because of that wave-like nature, it's subject to interference. That interference in this system turns out to stabilize a return and dwelling at the origin."

In their experiment, the researchers showed that periodic kicks exhibiting time-reversal symmetry would produce the boomerang effect, but randomly timed kicks would destroy both the symmetry and, as a result, the boomerang effect. Up next for the Weld Lab: if individual boomerang effects are cool, how much more of a party would it be to have several interacting boomerang effects?

"There are a lot of theories and questions about what should happen — would interactions destroy the boomerang? Are there interesting many-body effects?" Sajjad said. "The other exciting thing is that we can actually use the system to study the boomerang in higher dimensions."

Research on this project was also conducted by Jeremy L. Tanlimco, Hector Mas, Eber Nolasco-Martinez and Ethan Q. Simmons at UCSB; Tommaso Macri at Universidade Federal do Rio Grande do Norte in Brazil and Patrizia Vignolo at Universite Cote d'Azur in Nice, France.

Tiny Materials Lead to a Big Advance in Quantum Computing

by Adam Zewe, Massachusetts Institute of Technology

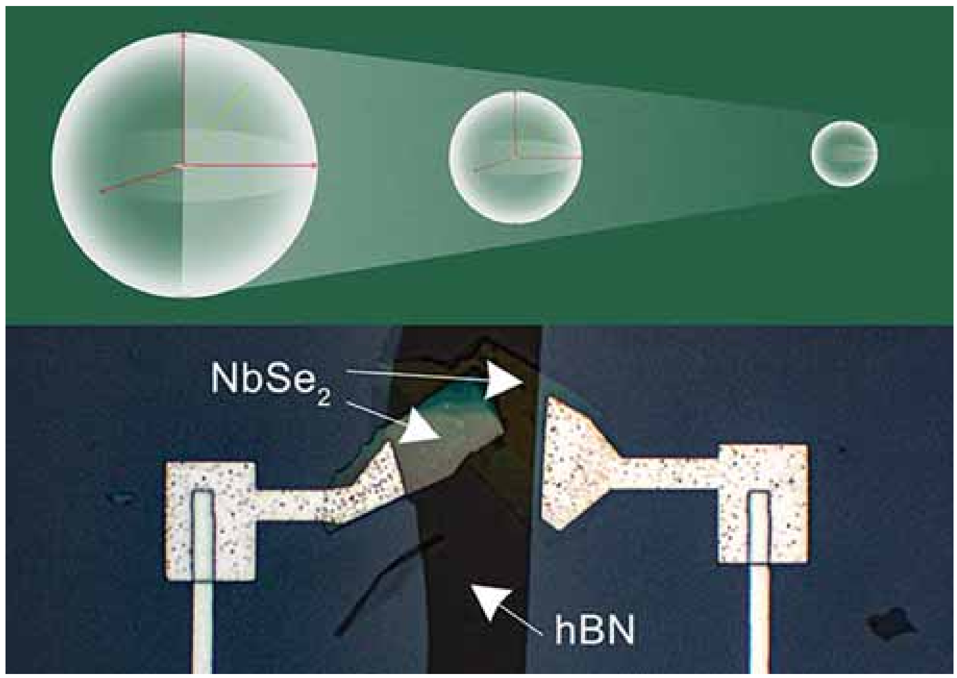
Like the transistors in a classical computer, superconducting qubits are the building blocks of a quantum computer. While engineers have been able to shrink transistors to nanometer scales, however, superconducting qubits are still measured in millimeters. This is one reason a practical quantum computing device couldn't be miniaturized to the size of a smartphone, for instance.

MIT researchers have now used ultrathin materials to build superconducting qubits that are at least one-hundredth the size of conventional designs and suffer from less interference between neighboring qubits. This advance could improve the performance of quantum computers and enable the development of smaller quantum devices.

The researchers have demonstrated that hexagonal boron nitride, a material consisting of only a few monolayers of atoms, can be stacked to form the insulator in the capacitors on a superconducting qubit. This defect-free material enables capacitors that are much smaller than those typically used in a qubit, which shrinks its footprint without significantly sacrificing performance.

In addition, the researchers show that the structure of these smaller capacitors should greatly reduce cross talk, which occurs when one qubit unintentionally affects surrounding qubits.

"Right now, we can have maybe 50 or 100 qubits in a device, but for practical use in the future, we will need thousands or millions of qubits in a device. So, it will be very important to miniaturize the size of each individual qubit and at the same time avoid the unwanted cross talk between these hundreds of thousands of qubits. This is one of the very few materials we found that can be used in this kind of construction," says co-lead author Joel Wang, a research scientist in the Engineering Quantum Systems group of the MIT Research Laboratory of Electronics.



MIT researchers used the 2D material hexagonal boron nitride to build much smaller capacitors for superconducting qubits, enabling them to shrink the footprint of a qubit by two orders of magnitude without sacrificing performance.
Credit: MIT

Wang's co-lead author is Megan Yamoah, a former student in the Engineering Quantum Systems group who is currently studying at Oxford University on a Rhodes Scholarship. Pablo Jarillo-Herrero, MIT's Cecil and Ida Green Professor of Physics, is a corresponding author, and the senior author is William D. Oliver, a professor of electrical engineering and computer science and of physics, an MIT Lincoln Laboratory Fellow, director of the Center for Quantum Engineering, and associate director of the Research Laboratory of Electronics. The research is published in *Nature Materials*. This research was funded, in part, by the

▶ *continues on page 36*

U.S. Army Research Office, the National Science Foundation, and the Assistant Secretary of Defense for Research and Engineering via MIT Lincoln Laboratory.

Qubit quandaries

Superconducting qubits, a particular kind of quantum computing platform that uses superconducting circuits, contain inductors and capacitors. Just like in a radio or other electronic device, these capacitors store the electric field energy. A capacitor is often built like a sandwich, with metal plates on either side of an insulating, or dielectric, material.

But unlike a radio, superconducting quantum computers operate at super-cold temperatures — less than 0.02 degrees above absolute zero (-273.15 °C) — and have very high frequency electric fields, similar to today's cell phones. Most insulating materials that work in this regime have defects. While not detrimental to most classical applications, when quantum-coherent information passes through the dielectric layer, it may get lost or absorbed in some random way.

"Most common dielectrics used for integrated circuits, such as silicon oxides or silicon nitrides, have many defects, resulting in quality factors around 500 to 1,000. This is simply too lossy for quantum computing applications," Oliver says.

To get around this, conventional qubit capacitors are more like open-faced sandwiches, with no top plate and a vacuum sitting above the bottom plate to act as the insulating layer.

"The price one pays is that the plates are much bigger because you dilute the electric field and use a much larger layer for the vacuum," Wang says. "The size of each individual qubit will be much larger than if you can contain everything in a small device. And the other problem is, when you have two qubits next to each other, and each qubit has its own electric field open to the free space, there might be some unwanted talk between them, which can make it difficult to control just one qubit. One would love to go back to the very original idea of a capacitor, which is just two electric plates with a very clean insulator sandwiched in between."

So, that's what these researchers did.

They thought hexagonal boron nitride, which is from a family known as van der Waals materials (also called 2D materials), would be a good candidate to build a capacitor. This unique material can be thinned down to one layer of atoms that is crystalline in structure and does not contain defects. Researchers can then stack those thin layers in desired configurations.

To test hexagonal boron nitride, they ran experiments to characterize how clean the material is when interacting with a high frequency electric field at ultracold temperatures, and found that very little energy is lost when it passes through the material.

"Much of the previous work characterizing hBN (hexagonal boron nitride) was performed at or near zero frequency using DC transport measurements. However, qubits operate in the gigahertz regime. It's great to see that hBN capacitors have quality factors exceeding 100,000 at these frequencies, among the highest Qs I have seen for lithographically defined, integrated parallel-plate capacitors," Oliver says.

Capacitor construction

The researchers used hexagonal boron nitride to build a parallel-plate capacitor for a qubit. To fabricate the capacitor, they sandwiched hexagonal boron nitride between very thin layers of another van der Waals material, niobium diselenide.

The intricate fabrication process involved preparing one-atom-thick layers of the materials under a microscope and then using a sticky polymer to grab each layer and stack it on top of the other. They placed the sticky polymer, with the stack of 2D materials, onto the qubit circuit, then melted the polymer and washed it away. Then they connected the capacitor to the existing structure and cooled the qubit to 20 millikelvins (-273.13 °C).

"One of the biggest challenges of the fabrication process is working with niobium diselenide, which will oxidize in seconds if it is exposed to the air. To avoid that, the whole assembly of this structure has to be done in what we call the glove box, which is a big box filled with argon, an inert gas that contains a very low level of oxygen. We have to do everything inside this box," Wang says.

The resulting qubit is about 100 times smaller than what they made with traditional techniques on the same chip. The coherence time, or lifetime, of the qubit is only a few microseconds shorter with their new design. And capacitors built with hexagonal boron nitride contain more than 90 percent of the electric field between the upper and lower plates, which suggests they will significantly suppress cross-talk among neighboring qubits, Wang says. This work is complementary to recent research by a team at Columbia University and Raytheon.

In the future, the researchers want to use this method to build many qubits on a chip to verify that their technique reduces cross talk. They also want to improve the performance of the qubit by fine-tuning the fabrication process, or even building the entire qubit out of 2D materials.

"Now we have cleared a path to show that you can safely use as much hexagonal boron nitride as you want without worrying too much about defects. This opens up a lot of opportunity where you can make all kinds of different heterostructures and combine them with a microwave circuit, and there is a lot more room that you can explore. In a way, we are giving people the green light — you can use this material in any way you want without worrying too much about the loss that is associated with the dielectric," Wang says.

Open Sourced Control Hardware for Quantum Computers

by Monica Hernandez and Joe Chew, Lawrence Berkeley National Laboratory

The Advanced Quantum Testbed (AQT) at Lawrence Berkeley National Laboratory (Berkeley Lab) has open sourced a new electronics control and measurement system for superconducting quantum processors, making the engineering solutions for the emerging hardware more accessible. Researchers Gang Huang and Yilun Xu from Berkeley Lab's Accelerator Technology and Applied Physics Division (ATAP) led the AQT superconducting qubit control system (QubiC) design, leveraging a robust technological legacy in research and development for particle accelerators. Funded by the Advanced Scientific Computing Research program in the US Department of Energy Office of Science, AQT's QuibiC is unique because of its customizable and modular capabilities. With superconducting circuits being one of the leading quantum computing technologies seeking to solve complex problems beyond the reach of classical computers, such adaptable application is crucial to broaden quantum computing usage.

The need for more affordable qubit control

Quantum information processors require expensive electronic controls that can manipulate qubits with precision. However, it is both a theoretical and experimental challenge to develop the control hardware that maximizes quantum computers' performance. Furthermore, current coherence times are short-lived, and most commercially available electronic equipment is designed as general-purpose for nonquantum systems. The cost, size, and complexity of control and measurement hardware increases with a growing number of qubits. This presents a significant roadblock for startups and junior academic research groups worldwide.

AQT's researchers at Berkeley Lab are tackling these control challenges by designing modular control hardware for current and future superconducting processors and open sourcing the system's full-stack code so it can be accessed, improved and leveraged by the broader quantum information science community.

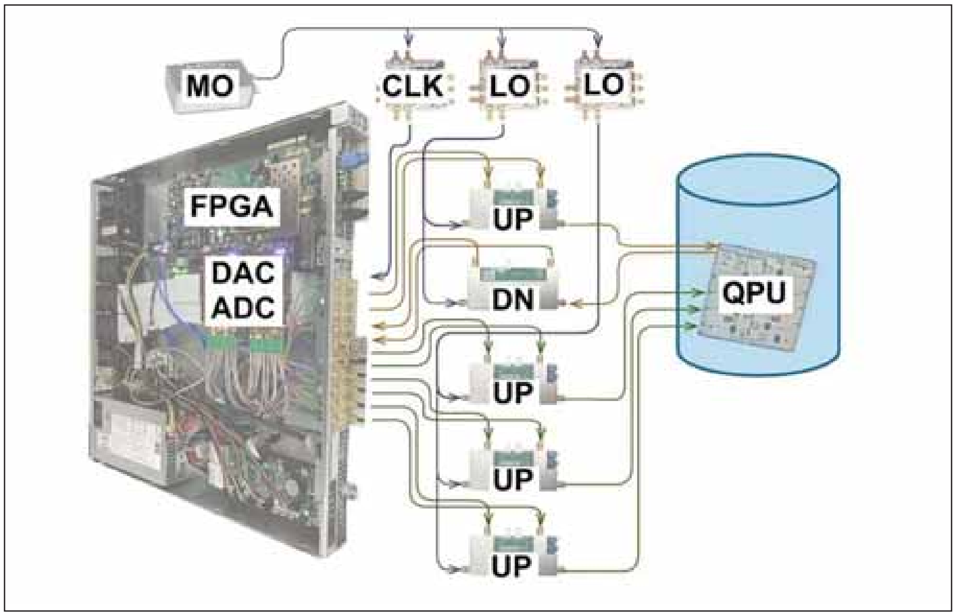


Diagram of QubiC prototype showing room temperature electronics hardware. *Credit: Gang Huang and Yilun Xu/Berkeley Lab*

"Newer control electronics systems are not tailored for quantum control systems," explained Huang. "So quantum researchers need to make the control system bigger by purchasing more instruments as the processors become more complex. But the cost for control hardware should not be linear or exponential, and that's where we try to come in. By building this as a more accessible and affordable system from the ground up, we really know what happens underneath – [something we can use] for further integrations and to try to scale the design."

QubiC integrates a field-programmable gate array (FPGA) radio frequency (RF) system, which modulates the signals at room temperature to manipulate and measure the superconducting qubits cooled down to cryogenic temperatures. AQT's cryogenic dilution fridge, "Blizzard," reaches very low temperatures, close to absolute zero.

QubiC's Python-based software and firmware implement the control and measurement protocols to characterize and benchmark the quantum chips, optimize one- and two-qubit gate algorithms and mitigate errors. Experimental results have demonstrated that QubiC executes quantum algorithms with promising synchronicity and speed, delivering results similar to commercially available systems at less cost.

"We're working on providing a more modular and affordable hardware control solution that performs equal to or slightly better with the added benefits," emphasized Huang. "But we cannot do everything by ourselves, so by open sourcing the code, we can find a community willing to support, contribute to and develop [the technology]."

QubiC is compatible with commercial and custom-designed electronics. As a result, testbed users from a variety of national laboratories, startups and companies

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have shown strong interest in deploying their projects using QubiC's customizable interface.

"Open sourcing the full stack of the QubiC systems benefits the community because more people can contribute, customize and improve it. And as an early career researcher involved in its design from the start, I have learned to integrate different disciplines from engineering to physics to experiments," Xu elaborated.

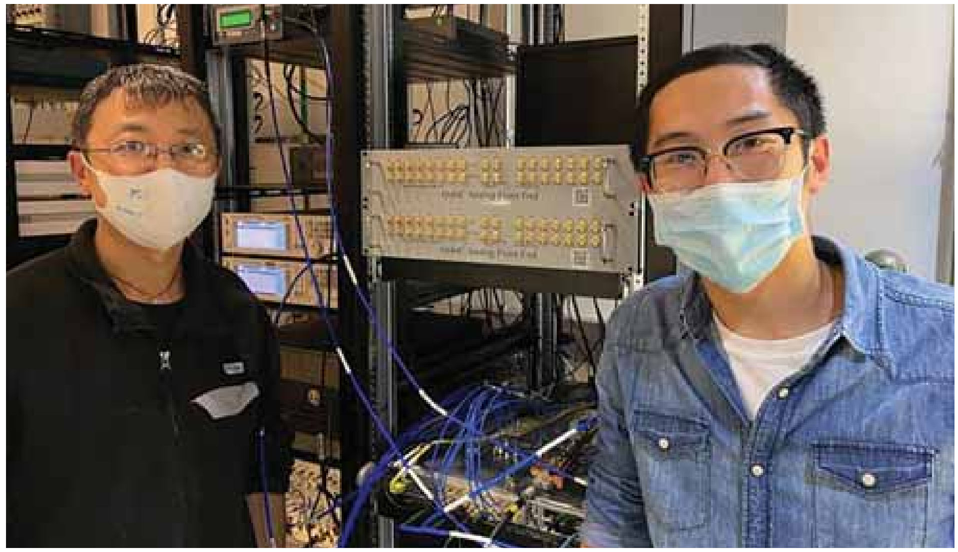
Leveraging the legacy of particle accelerators

The research and development of AQT's control hardware comes from a seemingly unlikely source, but it expands on Berkeley Lab's origins and 91-year history in particle accelerators. Across their many sizes and purposes – ranging from compact medical treatment machines to extensive research facilities like the Large Hadron Collider – accelerators speed up charged particles and funnel them into a controlled beam to explore matter and energy.

As particle accelerators grow more powerful, the need for state-of-the-art instrumentation and control systems increases. It's critical to precisely stabilize particle beams and the sophisticated equipment that produces them. The resulting technology and know-how can benefit many other fields, such as quantum computing.

Huang and Xu are members of the Berkeley Accelerator Controls and Instrumentation (BACI) Program, where expertise in these control systems is a common resource and crucial to the varied efforts of the ATAP Division. BACI, supported by the General Accelerator R&D program in the DOE Office of High Energy Physics, has a decades-long history of developing precision control and feedback systems for particle accelerator projects.

"I am very happy to see that previous investment for accelerator controls now can be further developed and used for qubits controls," said BACI Program Head Derun Li.



Researchers Gang Huang and Yilun Xu led the QubiC design, leveraging robust research and development for particle accelerators at Berkeley Lab. *Credit: Christian Jünger/Berkeley Lab*

Researchers designed and open sourced a modular field-programmable gate array (FPGA)-based electronics control system. Dubbed QubiC, the system is for superconducting quantum information processors. *Credit: Berkeley Lab*

"Particle accelerators are a vital component of Berkeley Lab's scientific endeavors, so the work with advanced FPGA-based RF control technology and engineering for particle beams helped us streamline the customization for quantum hardware," added Huang. "AQT researchers and testbed users are able to take advantage of the open source toolbox and gain a deeper understanding of flexible control hardware platforms that are both cost-effective and scalable."

ATAP Director Cameron Geddes described the QubiC design for AQT's superconducting processors as "classic examples of how capabilities developed for one area can benefit others in the team-science tradition of Berkeley Lab."

Open-access testbed

Extensible quantum computers will require significant modifications to current tools and standard techniques, which is why AQT researchers have pioneered the open-sourced control hardware used in the Berkeley Lab quantum computing testbed program, inspired by technology transfer of particle accelerators.

By providing AQT users full-stack access to QubiC and its infrastructure, the broader community has access to state-of-the-art superconducting quantum processors and can co-participate in the evolution of quantum processors, potentially making QubiC compatible with other quantum computing technologies in the future.

Rutherford & Titan Expands Service to US

Rutherford & Titan (RT) is a nationwide cryogenic installation and servicing company with a network spanning the US. With experience in the cryogenics industry as well as strategic relationships with key industry partners, RT provides solutions that give unique opportunities for clients to not only save money, but also find a robust approach to safety.

According to Chief Executive Officer Amir Amirsadeghi, running a business that utilizes cryogenics is complicated enough, but RT is committed to a promise to its clients: a clear-sighted perspective and a guiding hand when choosing the right machines, piping or safety systems for their business. "Clients deserve a partner who has seen it all — an experienced, trusted pro who can guide them through the tough days and steer them toward success. Every day, we strive to be that partner," says Amirsadeghi.

From selecting and installing a machine to performing ongoing maintenance and sourcing replacement parts, RT provides a comprehensive range of services for its clients. Whether those services include industrial gas piping, safety systems, finding efficiencies in existing systems or replacing entire systems, the team has led multiple projects across the US. "We do not shy away from finding solutions in complex environments and are always looking to grow assets in those categories that support our customers," adds Amirsadeghi. "One of our fastest-growing segments has been reviewing machinery for end manufacturers, combining the manufacturing and service aspects of our business, and giving actionable insights to end producers.

In 2018, RT went from a network of three to 1,900 technicians across the US. With a primary focus in industrial gas piping applications and generators, the company has become adept in all primary skills surrounding cryogenics to offer a broader solution set to customers. "Either directly or through our network of trusted partners in our space, if we cannot execute, we know someone within our network who can," boasts Amirsadeghi.

Looking ahead, the company's focus is on liquid nitrogen generators and the company's ability to scale them, from a manufacturing standpoint and within a serviceable scale. "Offering small and large-scale generators for applications such as dermatology and aerospace has allowed us to develop a suite of services for each segment offering. We plan to continue to expand our network and supplier partners, so we can provide the best comprehensive solutions," elaborates Amirsadeghi.

RT is excited about its new goal to start manufacturing its suite of smaller units onsite in the US. By 2023, RT hopes to start manufacturing liquid generators that produce between 8-10L per day. Over time, the focus will expand, bringing production to the US market segment-by-segment.

On-site picture of 480L-per-day unit. *Credit: RT*

"It has been one of our biggest goals to vertically integrate production and service within the US landscape; alongside everything else we offer to customers, we feel this will reduce the logistical burdens that we have all faced since the start of the pandemic," concludes Amirsadeghi. **www.rutherfordtitan.com**


Dr. Jack DaGrave
FormFactor
Dr. Philip Krantz
Keysight

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.

Montana Instruments

Cryogenic Nanopositioner

Montana Instruments announces the Spring 2022 release of their new cryogenic nanopositioner, The Rook™. "The Rook has the lowest 3-axis vibrations to keep samples in focus," said Product Manager Sal Guarnieri. Other features include a three-axis design for optimal sample temperature and motion control, a robust, reliable design, fully integrated plug-and-play control, galaxy software control, remote monitoring and scripting, and best-in-class thermal links. Performance for The Rook is specified at the top of the 3-axis stack, providing the user with clear expectations of what is happening at the sample in terms of temperature, vibrations and bi-directional run-out. It is specifically designed for use in Montana Instruments' CryoAdvance™ workhorse cryostat (released in September 2021), a low-vibration, cryogen-free system that allows users to access cryogenic temperatures in a 50mm (3.2 K – 350 K) or 100mm (3.4 K-350 K) sample chamber. It can also be utilized in the Cryostation® s200, Montana Instruments' largest and most versatile closed-cycle cryostat, with 200mm of sample space in configuration. **www.montanainstruments.com/the-rook**

attocube

attoDRY800xs

With the attoDRY800xs, attocube takes the revolutionary concept of the attoDRY800 to the next level and introduces a compact standalone platform for quantum optics experiments. The ultra-compact optical cryostat offers the perfect solution for researchers who want to set up quantum optics experiments at cryogenic temperatures but do not have room for a conventional optical table or big cryostats, which occupy several m^3 of precious lab space. With the cold sample space perfectly integrated into an optical breadboard of only 17" x 28" size, it offers both highest compactness and maximum flexibility for the experimental setup and can be equipped with attocube nanopositioners, various customizable cryogenic shrouds like apochromatic objectives, and offers unmatched low vibration performance (less than 5 nm vertical), automated temperature control (between 3.8 K and 300 K), gas handling and remote control. The attoDRY800xs can be used for self-contained experiments directly on its optical breadboard or placed adjacent to existing larger optical tables with fiber coupling between the optical elements. **www.attocube.com**

East Far Materials

EF CryoMLI series material

The CryoMLI series from East Far is a family of cryogenic temperature and lightweight insulating materials designed to prevent heat leakage from vessels inside or outside. Building on their thermal control experience and manufacturing excellence, combined with extensive experience in aerospace, transport cryogenic vessels and medical applications, East Far offers customized solutions for equipment and performance. **www.eastfarcorp.com**

Tempshield®

Cryo-LNG™ Gloves

Tempshield's Cryo-LNG™ Gloves are the gloves of choice when working with LNG or liquid nitrogen in an industrial setting. They provide the same high level of thermal and splash protection as Tempshield's other gloves. The rugged, abrasion-resistant palm offers flexibility and dexterity when function is important and safety is critical. They also have a wicking inner lining to maintain comfort over extended periods. Available in mid-arm and elbow lengths and in colors blue or brown, these gloves replace Tempshield's Cryo-Industrial® Gloves and are certified to EU Cat. III standards: EN 388, EN 511 and EN 420. They are applicable to LNG fueling and delivery, cryogenic gas delivery and servicing, and for the oil and gas and mining industries. **https://tempshield.com**

JanisULT

Cryogen-free sub-K continuous flow cryostat

The JanisULT cryogen-free sub-K continuous flow cryostat for Angle-Resolved Photoemission Spectroscopy (ARPES) is a convenient multifunctional tool suitable for a wide range of research applications, such as the study of the electronic structure of the surface of solids. In the past, ARPES experiments performed in the 2 K to 10 K range due to the larger heat load to the sample. JanisULT delivered the world's first continuous operating high power (wet) He-3 sub-K ARPES cryostat in 2008. The sample on the system with improved design can move with four-degree freedom (X-, Y-, Z- and phi), achieving a base temperature of 0.65 K. Samples in the upgraded sub-K ARPES system move with five-degree freedom (X-, Y-, Z-, phi and theta) and achieves a base temperature of 0.85 K.

JanisULT has also developed the world's first continuous flow, operating high cooling power cryogen-free (dry) sub-K ARPES cryostat. The system can be operated in three distinct modes: 4K operation mode, 1K operation mode and Joule-Thomson (JT) operation mode. **www.janult.com**

Cryoguard LLC

M-15 Cryoguard™ Thermal Exposure Indicator

The new M-15 Cryoguard™ Thermal Exposure Indicators are used at or below -40 °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-15 indicator signals thermal exposure at or above -15 °C by irreversibly changing color from green to red within two hours. An activated M-15 indicator remains green at or below -40 °C. At 20 °C, an activated M-15 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 -40 °C. With a dimension of approximately 1" long and 0.5" in diameter, the M-15 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-15**

Cryomech

PT310 Pulse Tube Cryocooler

The Cryomech PT310 cryocooler delivers optimum heat lift performance at 3 K, which enables dry dilution refrigerators to achieve temperatures down to millikelvin levels. To develop the PT310 cryocooler, Cryomech combined customer feedback with its long history of cryocooler innovation and expertise. The PT310 cryocooler offers game-changing performance of 1W at 3 K and 35W at 35 K. The remote motor version, PT310-RM, offers 0.9W at 3 K and 32W at 35 K. The PT310 sets the standard of the highest heat lift performance at 3 K in the world.

The need for greater heat lift to build more powerful dilution refrigerators resulted in the 2021 launch of Cryomech's PT425 cryocooler, which provides a world-leading performance of 2.7W at 4.2 K. Building on this success, the PT310 cryocooler pushes the heat lift to the next level, increasing it by about 50% at 3 K. With this performance, Cryomech enables its customers to advance their technology, which is at the heart of the quantum computing race. **www.cryomech.com**

SAES

LOTHAR®+

SAES has expanded its getter portfolio with the launch of LOTHAR®+, designed for hydrogen sorption in the vacuum jacket of cryogenic containers. LOTHAR+ absorbs H_2, CO and other reducing gases, thereby improving the reliability and lifetime of super-insulating tanks and pipes. This innovative product does not need an activation. It is provided as loose powder or in ready-to-use porous PET bags. These features allow for the optimization of the cryogenic container production process and lowers the total cost of ownership. LOTHAR+ is not hazardous and does not contain any elements included in the REACH or Proposition 65 declarations. Finally, LOTHAR+ is much less expensive than PdO with equivalent H_2 sorption capacity. SAES provides innovative and efficient solutions based on powerful chemical getters, leveraging a deep understanding of vacuum technology and materials science. **www.saesgroup.com**

People, Companies in Cryogenics


Credit: Fermilab

The Compact Muon Solenoid experiment, which studies particle collisions at the Large Hadron Collider (LHC) at CERN in Switzerland, is heading into a new era of research under the guidance of **Fermi National Accelerator Laboratory** (Fermilab, CSA CSM) scientist **Patty McBride**, who begins a two-year term as deputy spokesperson for CMS on September 1, 2022. She will be serving in the role with Luca Malgeri, also of CERN.

As deputy co-spokesperson, McBride will push to publish new physics results from the most recent LHC run and to prepare the experiment for its next run. She will also help direct the project to upgrade the detector to manage higher intensity collisions that will emerge from a revamped LHC set to come online in 2026. The new and improved High-Luminosity LHC will crank up the number of particle collisions to five to seven times its current rate and generate 30 times the data CMS has collected until recently.

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Credit: Worcester Polytechnic Institute

Laurie Leshin, president of Worcester Polytechnic Institute (WPI), has been named director of the J**et Propulsion Laboratory** (JPL) and vice president of **Caltech**. She joins JPL from WPI, one of the nation's oldest private STEM universities, where she has served as president since 2014. She is the first female president in the university's 150-year history and will also be JPL's first female director. Leshin is an internationally recognized scientist whose career has spanned academia and senior positions at NASA and included two White House appointments. She has been lauded for her barrier-breaking leadership in the space industry and in academia for her accomplishments as a distinguished geochemist and space scientist. She will formally assume her new position on May 16, 2022.

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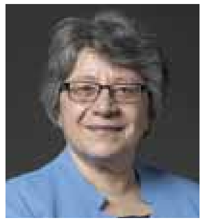
Credit: Allan Johnson, Fermilab

Particle physicist **Lia Merminga** was appointed the first female director of the **Fermi National Accelerator Laboratory (Fermilab)** based in Batavia, IL. She will become the seventh director of the US particle-physics lab. Merminga chaired the Fermilab Accelerator Advisory Committee for the influential Particle Physics Project Prioritization Panel "P5" report, which was released in 2014 and set the future pathway for US particle physics. She also served as project director of the lab's PIP-II superconducting accelerator – a major upgrade to the lab's accelerator complex. When complete in 2028, it will produce the world's most intense beam of high-energy neutrinos for Fermilab's Long-Baseline Neutrino Facility, which involves sending the particles 1,300 km to a detector at the Sanford Underground Research Facility in Lead, SD.

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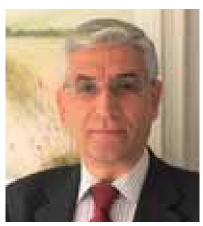
Credit: Intelliconnect

Intelliconnect has appointed **Dr. Ziad Melhem** as a non-executive director of its CryoCoax division. Ziad is the Founder and CEO of **Oxford Quantum Solutions Ltd.**, an independent consultancy business that was launched in February 2021.

Dr. Melhem was previously the strategic business development manager at Oxford Instruments NanoScience, implementing alliances and collaborative R&D projects on quantum, nanoscience and nanotechnology applications. He has over 32 years of experience on new product design and business development activities in applied superconductivity, low and high temperature superconducting materials, and cryogenic, quantum and nanotechnology applications for scientific, medical, energy and industrial sectors.

Intelliconnect Managing Director Roy Phillips said, "We are delighted to welcome Ziad to the Intelliconnect family. He brings a wealth of experience, knowledge and enthusiasm to the Intelliconnect/CryoCoax team. His knowledge of cryogenics, both technically and commercially, is phenomenal, and his input will undoubtedly assist us in serving existing customers and applications and gaining further market penetration."

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Credit: Web Industries Inc.

Web Industries Inc., a leading global provider of contract converting and turn-key manufacturing services, announced that **John S. Madej** has joined the company as president. Madej joins Web Industries from Hollingsworth & Vose (H&V), where he most recently served as chief operating officer and previously as chief financial officer. For more than 24 years, Madej served in a variety of leadership roles at General Electric (GE). He was president and CEO of Exatec LLC, a GE-Bayer joint venture and served as a product general manager based in Tokyo, Japan, for four years.

"I am excited to join the Web Industries team and work together to continue to develop the company and expand the growing business," says Madej. "Working closely with its customers, Web Industries has a successful track record of global growth across diverse markets. I look forward to collaborating with the team, expanding the company's capabilities and delivering improved productivity and performance for our customers into the future."

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Nikkiso Cryogenic Industries' Clean Energy & Industrial Gases Group, a part of the Nikkiso Co., Ltd (Japan) group of companies, announced **Umit Ciftci** as regional business development manager for Turkey and the surrounding areas. Based in Istanbul, Turkey, he will be responsible for the Group's full product line. Ciftci has more than 25 years of experience in compressed air, working in various positions such as sales engineer, marketing and business line manager (in Turkey) and business development manager in the UAE for Atlas Copco.

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The U.S. Department of Energy's **Fermi National Accelerator Laboratory (Fermilab)** is pleased to invite the public back to its Batavia, IL site. Reopened on March 28,

Bison herd on the grounds of Fermilab. *Credit: Fermilab*

2022, the lab grounds are open to the public for outdoor activities such as biking, hiking, running and viewing the bison herd. Indoor access remains limited, and most public events and lectures will continue to be held virtually.

Fermilab's calendar of events and visiting hours can be found on the company website, **www.fnal.gov.**

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The winners of the **2021 Cockcroft Institute Early Career Excellence Awards** announced **Andrew May** of the Accelerator Science and Technology Centre (ASTeC) and **Volodymyr Rodin** of the University of Liverpool as the recipients of the Best

The Cockcroft Institute is devoted to the development and construction of particle accelerators and intense sources of radiation for pure and applied research. *Credit: Cockcroft Institute*

Sustained Contribution Award. **Thomas Heinemann** of the University of Strathclyde was awarded Best Outstanding Single Output. The Cockcroft Institute Early Career Excellence Awards were established to recognize and encourage outstanding research in early career staff or PhD students working at the Cockcroft Institute.

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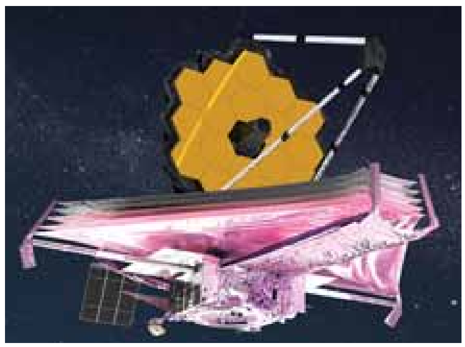
Webb's Mid-Infrared Instrument (MIRI) – a joint development by NASA and ESA (European Space Agency) – reached its final operating temperature, making its mission



In this illustration, the multilayered sunshield on NASA's James Webb Space Telescope stretches out beneath the observatory's honeycomb mirror. The sunshield is the first step in cooling down Webb's infrared instruments. *Credit: NASA GSFC/CIL/Adriana Manrique Gutierrez*

to detect infrared light from distant galaxies, stars hidden in cocoons of dust, and planets outside our solar system possible.

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SIAD Macchine Impianti (SIAD MI) was awarded the **Hydrogen Rising Star**

Siad Macchine Impianti honored as a new emerging company in March 2022. *Credit: Siad Macchine Impianti*

Company of the Year at The Hydrogen Future Rewards (part of Connecting Green Hydrogen MENA 2022) on March 30, 2022, in Dubai, United Arab Emirates.

The award acknowledges SIAD MI's proficiency in the development of new solutions relating to the compression and liquefaction of green hydrogen. Through its parent company, SIAD, which has been producing and distributing technical gases for almost a century, and its direct experience with thousands of customers throughout the world, SIAD MI boasts dedication and expertise in the compression, management and liquefication of hydrogen, particularly green hydrogen.

Meetings & Events

15th Workshop on Low Temperature Electronics (WOLTE-15)
June 6-9, 2022
Matera, Italy
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