Cold Facts

2023 Buyer's Guide | Corporate Directory

The Magazine of the Cryogenic Society of America, Inc. INTERNATIONAL

Products and Services

for Cryogenic and Superconductivity Applications Worldwide

Volume 38 Number 6 2022

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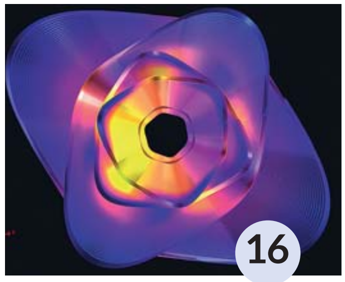

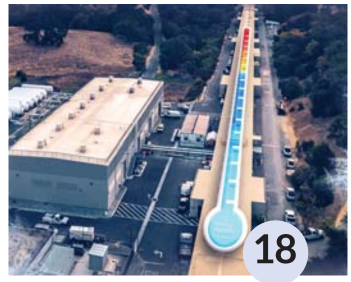

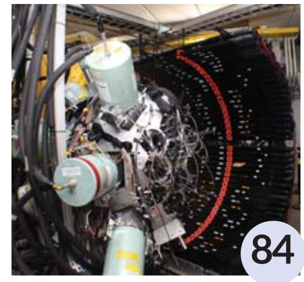

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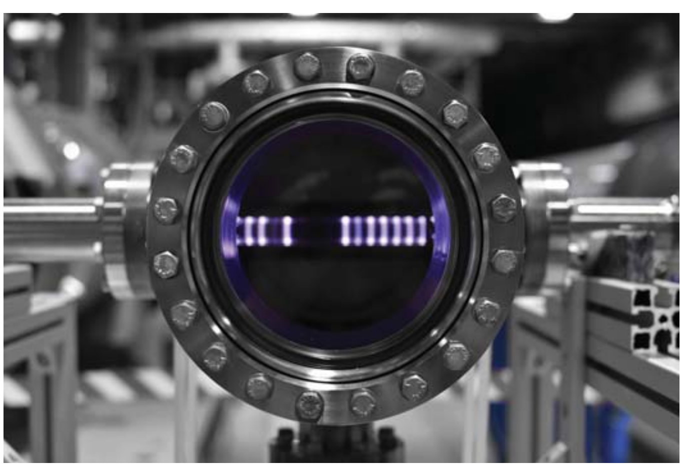

A plasma cell "sputters" carbon on a beam screen in a laboratory. *Credit: CERN*

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SPOTLIGHTS

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From the Executive Director

'Tis the season for hot chocolate, chestnuts roasting on an open fire...and the CSA Buyer's Guide! We are proud to present to you our 2023 edition of the printed Buyer's Guide – a resource of products and services designed for cryogenic applications. We hope you find this year's edition to be a useful tool to meet your needs throughout 2023 and beyond. As a reminder, you can always access the online version of our Buyer's Guide, updated regularly at **www.csabg.org**.

With 2022 coming to a close, I enjoy reflecting on the successes CSA has experienced in the last year. The year began with CSA launching a brand-new website at **www.cryogenicsociety.org**! More than just a website, the system serves as a simple way to interact with CSA by incorporating CSA's membership database, event registration platform, membership dues billing and more. We hope that you have found the site more functional, easier to navigate, and a useful source of information for the cryogenics community as a whole.

In March, we attended the APS March Meeting held in Chicago. For me, this was the first time I was able to meet in person with many of our members. It was a great pleasure after speaking with so many virtually for a full year. In June, CSA attended the International Cryocooler Conference (ICC) which was held in Bethlehem, Penn. CSA also hosted a Foundations of Cryocoolers Short Course the day prior to ICC. We were able to host this event hybrid – with some people attending in person and others virtually. It was a great success with more than 50 registrants. In October, we attended the Applied Superconductivity Conference (ASC) in Honolulu, Hawaii. ASC was a fantastic networking experience, and it was also a great opportunity to discuss ways CSA can continue to provide resources to the cryogenics community. In between all of these exciting events, CSA welcomed nine new corporate sustaining members, 27 new individual members and 32 new suppliers in the Buyer's Guide.

Looking forward to 2023, there are plenty of exciting things coming up very soon. We've announced the 30th Space Cryogenics Workshop (SCW) will take place July 16-18, 2023, at the Outrigger Kona Resort and Spa in Kailua-Kona, Hawaii. By the time you receive this magazine, the call for abstracts will be open. For full details, visit **www.spacecryogenicsworkshop.org**. The week prior to the SCW, CEC/ICMC '23 will be taking place in Honolulu, Hawaii, from July 9-13, 2023. For full details regarding CEC/ICMC 23, visit **www.cec-icmc.org/2023**. CSA plans to host numerous short courses covering different topics on the first day of CEC/ICMC, July 9. These short courses will be held at the Honolulu Convention Center. Full details will be announced soon.

As always, I hope you enjoy this special Buyer's Guide issue of ***Cold Facts***! Happy New Year!

The "New" Space Mission-Cryogenic Bearings

by Jeremy Cole, Design and Applications Engineer – Space, RBC Transport Dynamics, jqcole@rbcbearings.com

Since the late 1990s, advancements in communication technology and the advent of GPS expanded the desire for companies and governments to invest in satellite technologies that operate in higher orbit. Today, companies like SpaceX, Blue Origin, Virgin Orbit, Relativity Space and ULA are developing cost-effective, reusable launch systems.

Manufacturers understand the virtues of investing in engineering solutions with high-performance materials backed by rigorous testing dedicated to the extremes of space travel.

The Difficulties with Bearings in Space

The materials used in space bearing applications, like aero bearings, must be lightweight, stiff and able to resist fatigue failure during high-cycle vibration. However, the temperature ranges between space and aerospace are quite different. Standard operating temperatures for self-lubricated aero bearings range from −65° F (outside air temperature during flight) to 650° F (third stage of a turbine engine). Bearings in reusable launch vehicles must endure the massive thermal gradient occurring from vacuum (-454° F) to the heat of re-entry. The drawback with many conventional bearing materials in space is that they undergo a volumetric phase transformation from a ductile, shock absorbent crystalline structure to a hard, brittle structure, incapable of sustaining bending moments or impact. This is known as the ductile-to-brittle transition and happens to mild steel around -100° F (Figure 1).

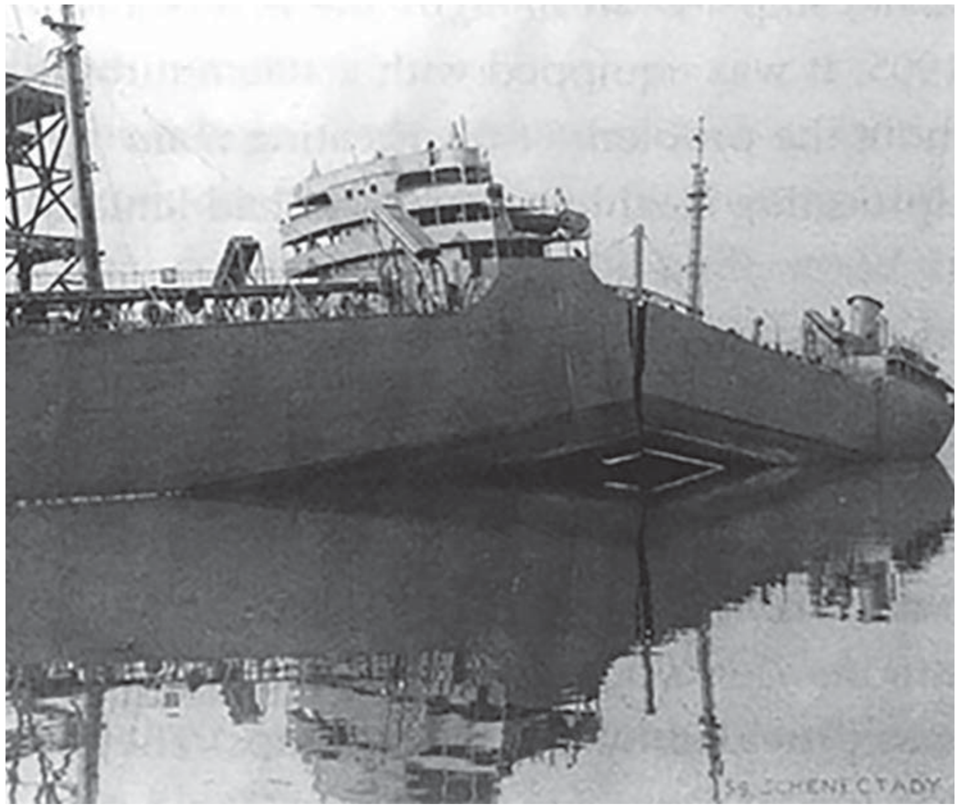
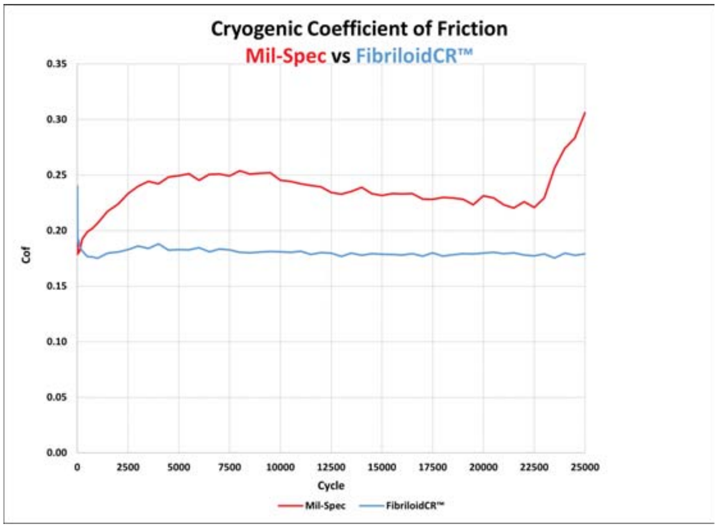


Figure 1. Example of the catastrophic result of ductile-to-brittle transition in steel. *Credit: U.S. GPO*

Figure 2. PTFE transfer film burnished onto a counterface bushing. *Credit: RBC Transport Dynamics*

The next challenge for a space bearing is the functionality of the self-lubricating composite. Like many steels, polymer matrix composites (PMCs) also have a finite temperature performance band. Below the glass transition temperature, molecular mobility drops by several orders of magnitude, leading to significant decreases in damping, toughness, ductility and drawability. While all those qualities are



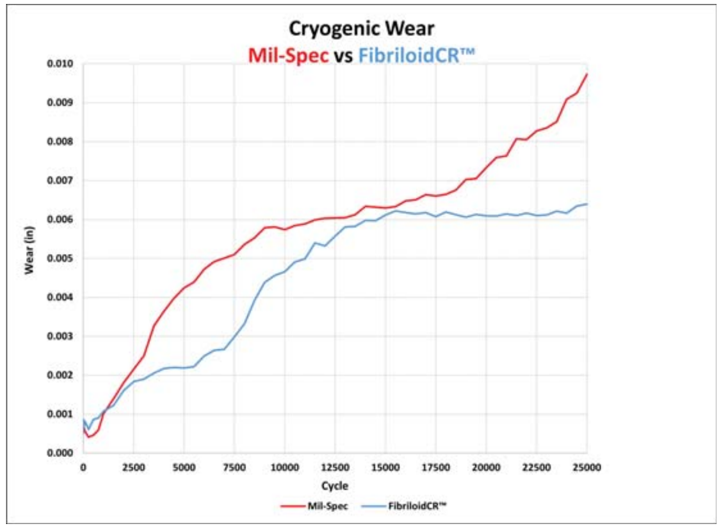


Figure 3. Test data from cryogenic (-300° F) oscillation under radial load, 40 ksi bearing stress, 20 cycles per minute, ±25° angle of oscillation; (left) coefficient of friction data; (right) wear data.
Credit: RBC Transport Dynamics

important in a bearing material, loss of drawability is possibly the greatest drawback; self-lubricating bearings require film-forming elements to be sacrificially pulled from the composite and drawn, via shear stress, into a transfer film (Figure 2).

A transfer film protects both composite and counterface by creating a boundary layer where lubricious material is not lost, but instead moves back and forth across the load zone, preserving both surfaces. But in the cryogenic environment of space, it is difficult to form an adequate transfer film, and the bearing continues to wear abrasively throughout its service life. This requires the material to be preferentially abrasion resistant as well as lubricious.

Testing for Space

Typical plain-bearing and rod-end qualification testing is performed every two years, overseen by Naval Air Systems Command and Airframe Control Bearings Group. This testing defines strict performance criteria regarding oscillatory wear at multiple temperatures, torque, adhesive performance, fatigue and static loading. Despite the rigor of this testing, the space mission requires yet another layer of examination to include contamination concerns and an increased focus on tribology (the study of friction), fatigue and static-loading properties under cryogenic conditions.

Conclusion

The final product, FibriloidCR™, combines cutting-edge, nanocomposites technology, superalloys and specialized processing into the first high-performance bearing dedicated solely to the space industry. When tested against the Mil-Spec bearing under high loads and cryogenic temperatures, the test results confirmed that conventional bearing materials do not suffice in this demanding new environment. Figure 3 illustrates the performance differences between these two systems under the most rigorous conditions: 40 ksi of bearing stress and -300° F.

In Figure 3 (top), the Mil-Spec bearing demonstrates an inconsistent coefficient of friction caused by abrasive wear continually altering the surface finish of the mating couple. This is further evidenced by the shape of the wear curve in Figure 3 (bottom). In this graph, the Mil-Spec bearing remains in the abrasive wear regime (positive slope), never entering the optimal adhesive wear regime and achieving a steady state (horizontal slope). However, under the same test conditions, FibriloidCR™ exhibited a uniform coefficient of friction and achieved adhesive wear (steady state) in about 15,000 cycles.

A post-test examination of the Mil-Spec samples showed both accelerated wear of the composite liner and severe damage to the counterface: as the counterface becomes damaged by abrasive wear, the resultant increase in surface finish synergistically increases the wear rate on the composite. This results in reduced bearing life and increased coefficient of friction (recorded as torque). In contrast, the FibriloidCR™ bearing (composite) retained more than 25% of its usable life, and the metallic counterface remained pristine.

FibriloidCR™ bearings and rod ends meet AS81820 and AS81935 requirements, operate with high-tribological performance under cryogenic conditions (–300° F to 450° F) and excel at both high loads with low-frequency vibration and low loads with high-frequency vibration.

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

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

Airflow North America Corp.

ISO tanks to transport liquid gases in 20, 40 and 45 ft. ISO containers, including tanks for air gases, LNG and LIN, ISO tubes for compressed He and H_2, and ambient vaporizers. Sourcing of industrial and packaged gases for distribution.

CryoEdge™ *

Cryogenic treatment services to increase the life of cutting tools and wear parts for a wide variety of applications, including blades, drill bits and other cutting tools, as well as automotive parts and firearms.

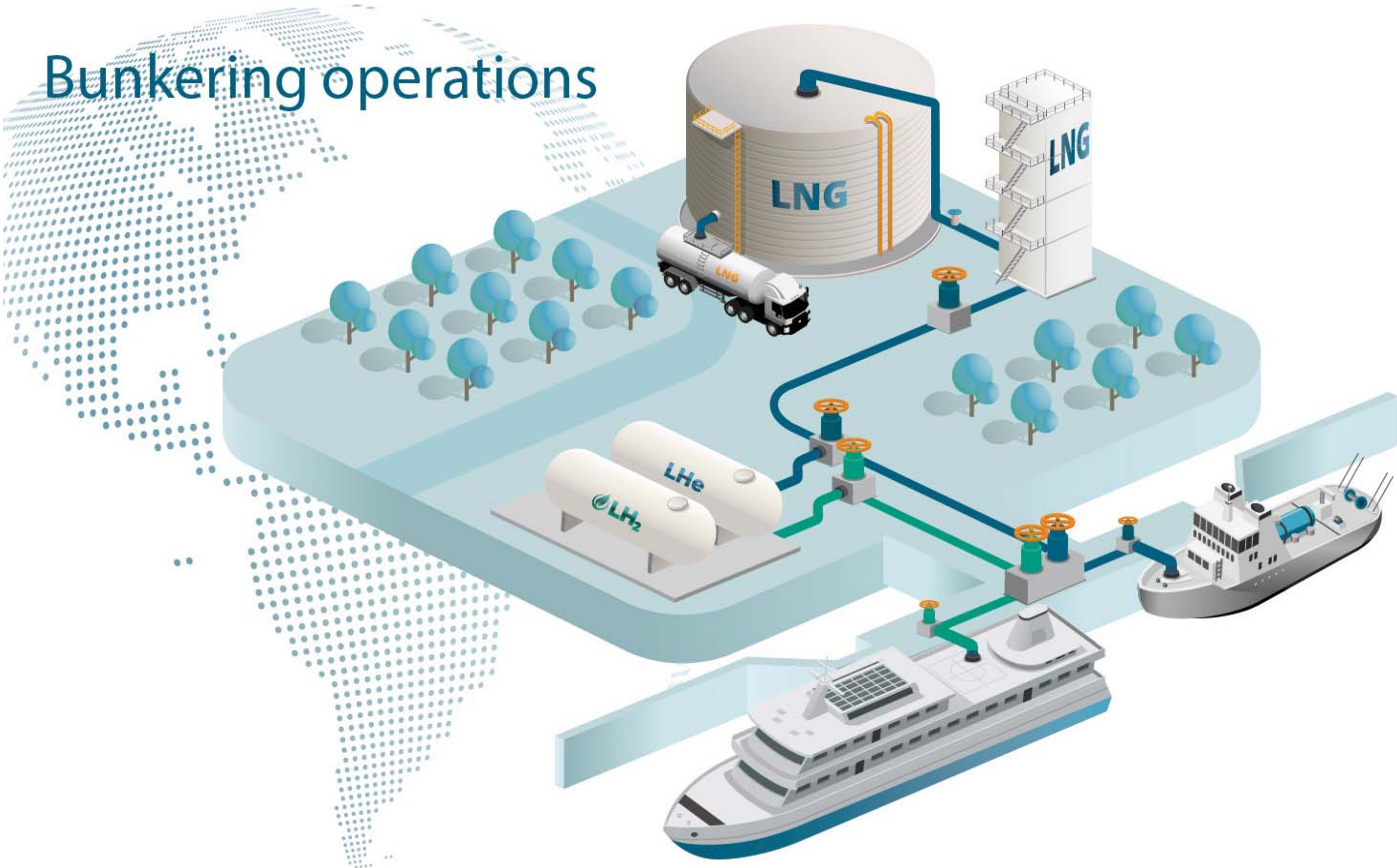
Cryotherapy Repair Service

With a decade of work with cryotherapy equipment manufacturers who have a presence in the US, Cryotherapy Repair Service can repair and maintain a wide range of equipment with the highest industry standards. Also provides assistance with moving equipment.

***CSA CSM**

Why the LNG Retrofit Revolution Has Cryospain at Work Across Land and Sea

by Paul Devlin, Senior Communications Manager, Cryospain



Asian governments are stepping up LNG bunkering operations for the maritime industry. *Credit: Teresa Requena, courtesy of Cryospain*

What is it about liquefied natural gas (LNG) for transport that has Cryospain's teams hard at work across continents and oceans, on existing and brand-new vehicles and all over the world? Within the context of the global challenge of slashing emissions, LNG as fuel is taking a more and more central role: on land, a general shift towards rail for the ever-expanding heavy transport industry is coupled with a mission to make the trains themselves more efficient and environmentally friendly. The European Commission's 2016 energy security package places gas front and center in the transition to a low-carbon economy. Of course, this means new-build natural gas engines, but it also must consider existing vehicles.

Meanwhile, the demand for LNG bunkering infrastructures for shipping has never been so high. This is largely due to the major environmental benefits natural gas provides, especially when compared to the emissions that traditional engines produce. LNG truly is the cleaner choice for shipping. What was already a trend is becoming a revolution, thanks to International Maritime Organization's 2020 regulations that seek to clean coastal air. As a result, LNG installations are spreading fast throughout the world's seaports.

Retrofits: Why and How?

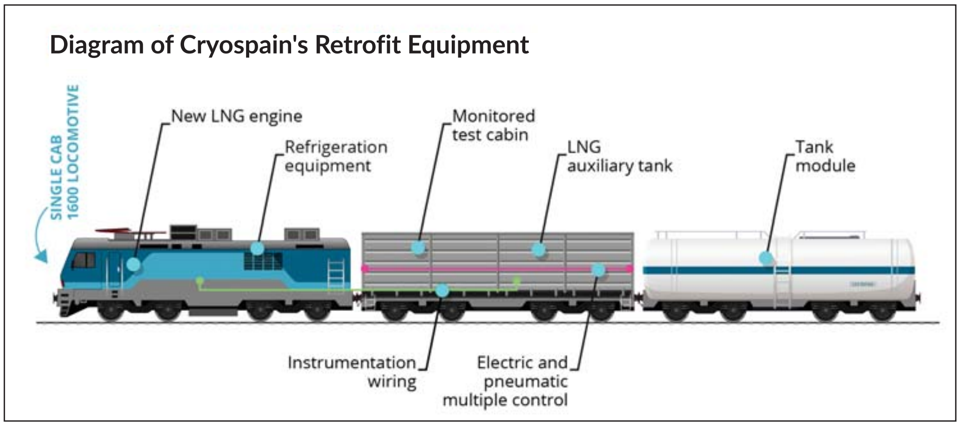
The shift to greener fuels cannot be imagined without taking into account traditionally fueled vehicles currently in operation. Of course, an increasing percentage of new vehicles are being built every year with LNG engines. Cryospain has been involved in the design of brand-new ships that, from conception, have opted for natural gas as a greener fuel choice. However, retrofitting allows for transformations that extend life cycles of existing vehicles, making them far more efficient and reducing the dual impact of building new vehicles and disposing of old ones. Aside from the many non-financial benefits, such as those elaborated on here, from a purely cost point of view, the initial investment is always quickly absorbed and surpassed by year-on-year savings. In other words, retrofitting is a fast and ultimately cost-effective way to make the essential switch to greener fuels.

These projects require a high level of experience and expertise, as well as truly tailored design. Essentially, a cryoline system must be adapted to a structure not originally intended to house it. In most cases, you are retrofitting ships, trains or other vehicles that are in active operation, making the time variable crucial (the longer the retrofit operation lasts, the longer the vehicle is stopped, and the greater the loss for business relying on it).

What Makes LNG Right For Transport?

LNG is a cryogenic product that is transported at approximately 160 degrees below zero. This means we can store more in a given space than with CNG (compressed natural gas). LNG represents a smart choice for transport because it is a clean, accessible fuel, which also makes economic sense.

Compared to fuel oil and diesel, LNG reduces carbon dioxide emissions by 20-25%. LNG also eliminates emissions of solid particles in suspension, reduces emissions of nitrogen oxides by at least 80%, and virtually eliminates emissions of nitrogen dioxide and sulfur oxides. Companies all over the world are realizing the importance of making the switch to LNG, and Cryospain has been proud to answer the call in ten projects across eight different countries, like the ones detailed below.



The equipment Cryospain's team installed for its LNG train retrofit project. *Credit: Teresa Requena, courtesy of Cryospain*

Ship retrofits mean adapting cryoline systems to structures not originally intended to house them.
Credit: Teresa Requena, courtesy of Cryospain

Our Experience: Retrofit for the Rail Industry

It was our honor to help put our native Spain on the cryogenic and LNG map with a pioneering project to test both the economic and technical feasibility of LNG in the railway sector. The project proved a huge success in validating hopes for LNG as a low-emission energy resource against diesel fuel on non-electrified lines. Our team, experts in a vast range of cryogenic systems, drew on their experience to design and install:

- LNG cryogenic tank (LNG requires 600 times less volume than natural gas under normal conditions)
- Vaporizer (necessary for the liquefied gas to be gasified and heated to engine consumption temperature)
- Valves
- Generating set of the tender
- Heat production system (boiler)
- Pneumatic production system
- ATEX declassified electrical and control room
- Electrical and control panel
- Compressed gas conditioning systems

Our Experience: Retrofit for the Maritime Industry

This example takes us from our native Spain's land transport network to the distant seaports of Asia. Asian governments are stepping up and endorsing LNG as a marine fuel. South Korea's government has announced plans to develop LNG bunkering facilities in the country. In 2018, Japan's Ministry of Land, Infrastructure, Transport and Tourism announced its support of the country's first LNG bunker vessels. Singapore, the world's largest bunkering port, granted subsidies to build LNG bunkering infrastructures to its two licensed LNG bunker suppliers.

Our experts travelled to the major port of Shanghai, China, to tackle this retrofit of an existing vessel:

- 50-plus meters of simple cryogenic pipes and 70-plus meters of double-wall cryogenic pipes
- 100-plus meters of double-wall ventilated pipes
- Design and supply of supports between inner and outer cavities of double-wall piping
- 2D and 3D design of the installation
- Fatigue study with finite element analysis programs
- Non-destructive test of all welding
- DNV approval of the manufacturing and testing

Cryogenics: Making the Vital Switch to Greener Fuels Possible

Cryospain has long been a champion of low-emission fuels to replace the traditional diesel and fuel-oil engines. Our hard work to achieve the goal of zero greenhouse emissions will continue. We know that more environmentally friendly transport options are possible and take great pride in the cryogenics industry's pioneering role in the LNG revolution.

NIST's Superconducting Hardware Could Scale Up Brain-Inspired Computing

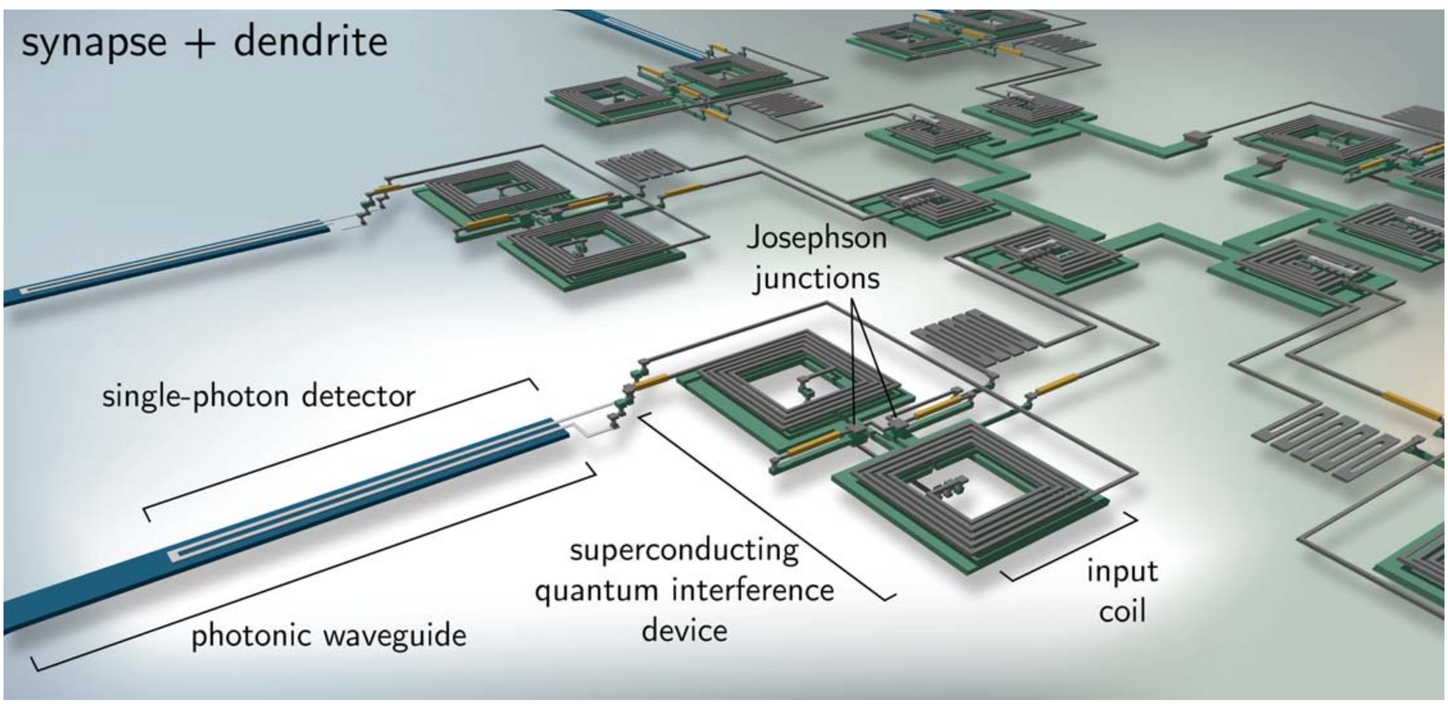
by Ben P. Stein, NIST

Scientists have long looked to the brain as an inspiration for designing computing systems. Some researchers have recently gone even further by making computer hardware with a brain-like structure. These "neuromorphic chips" have already shown great promise, but they have used conventional digital electronics, limiting their complexity and speed. As the chips become larger and more complex, the signals between their individual components become backed up like cars on a gridlocked highway and reduce computation to a crawl. Now, a team at the National Institute of Standards and Technology (NIST) has demonstrated a solution to these communication challenges that may someday allow artificial neural systems to operate 100,000 times faster than the human brain.

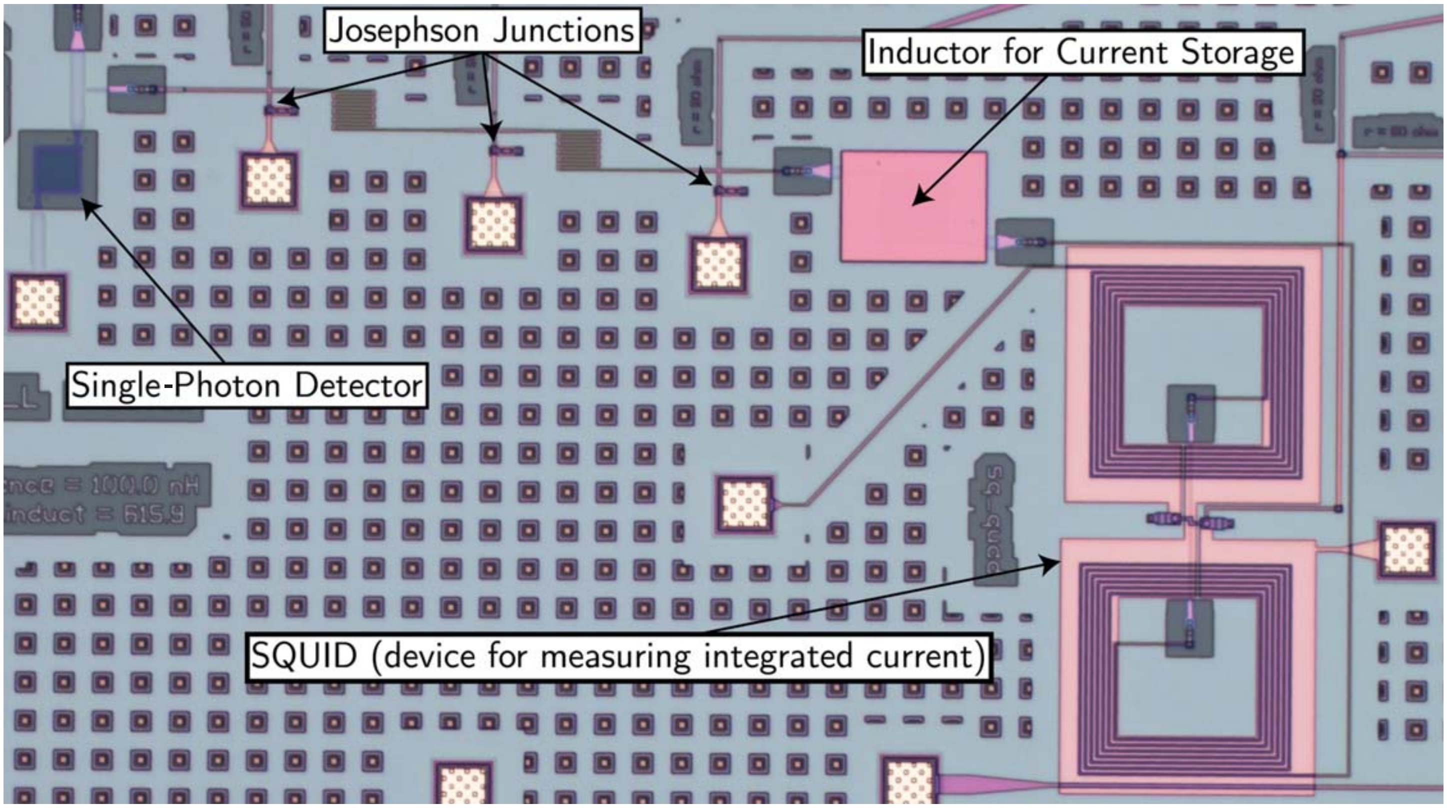
The human brain is a network of about 86 billion cells called neurons, each of which can have thousands of connections (known as synapses) with its neighbors. The neurons communicate with each other using short electrical pulses called spikes to create rich, time-varying activity patterns that form the basis of cognition. In neuromorphic chips, electronic components act as artificial neurons, routing spiking signals through a brain-like network. Doing away with conventional electronic communication infrastructure, researchers have designed networks with tiny light sources at each neuron that broadcast optical signals to thousands of connections. This scheme can be especially energy-efficient if superconducting devices are used to detect single particles of light known as photons – the smallest possible optical signal that could be used to represent a spike.

In a new paper in *Nature Electronics*, NIST researchers have achieved for the first time a circuit that behaves much like a biological synapse yet uses just single photons to transmit and receive signals. Such a feat is possible using superconducting single-photon detectors. The computation in the NIST circuit occurs where a single-photon detector meets a superconducting circuit element called a Josephson junction. A Josephson junction is a sandwich of superconducting materials separated by a thin insulating film. If the current through the sandwich exceeds a certain threshold value, the Josephson junction begins to produce small voltage pulses called fluxons. Upon detecting a photon, the single-photon detector pushes the Josephson junction over this threshold, and fluxons are accumulated as current in a superconducting loop. Researchers can tune the amount of current added to the loop per photon by applying a bias (an external current source powering the circuits) to one of the junctions. This is called the synaptic weight.

This behavior is similar to that of biological synapses. The stored current serves as a form of short-term memory, as it provides a record of how many times the neuron produced a spike in the near past. The duration of this memory is set by the time it takes for the electric current to decay in the superconducting loops, which the NIST team demonstrated can vary from hundreds of nanoseconds to milliseconds, and likely beyond. This means the hardware could be matched to problems occurring at many different time scales – from high-speed industrial control systems to more leisurely conversations with humans. The ability to set different weights by changing the bias to the Josephson junctions



Artistic rendering of how superconducting circuits that mimic synapses (connections between neurons in the brain) might be used to create artificial optoelectronic neurons of the future. *Credit: NIST*



Photograph of a NIST superconducting circuit that behaves like an artificial version of a synapse, a connection between nerve cells (neurons) in the brain. The labels show various components of the circuit and their functions. *Credit: NIST*

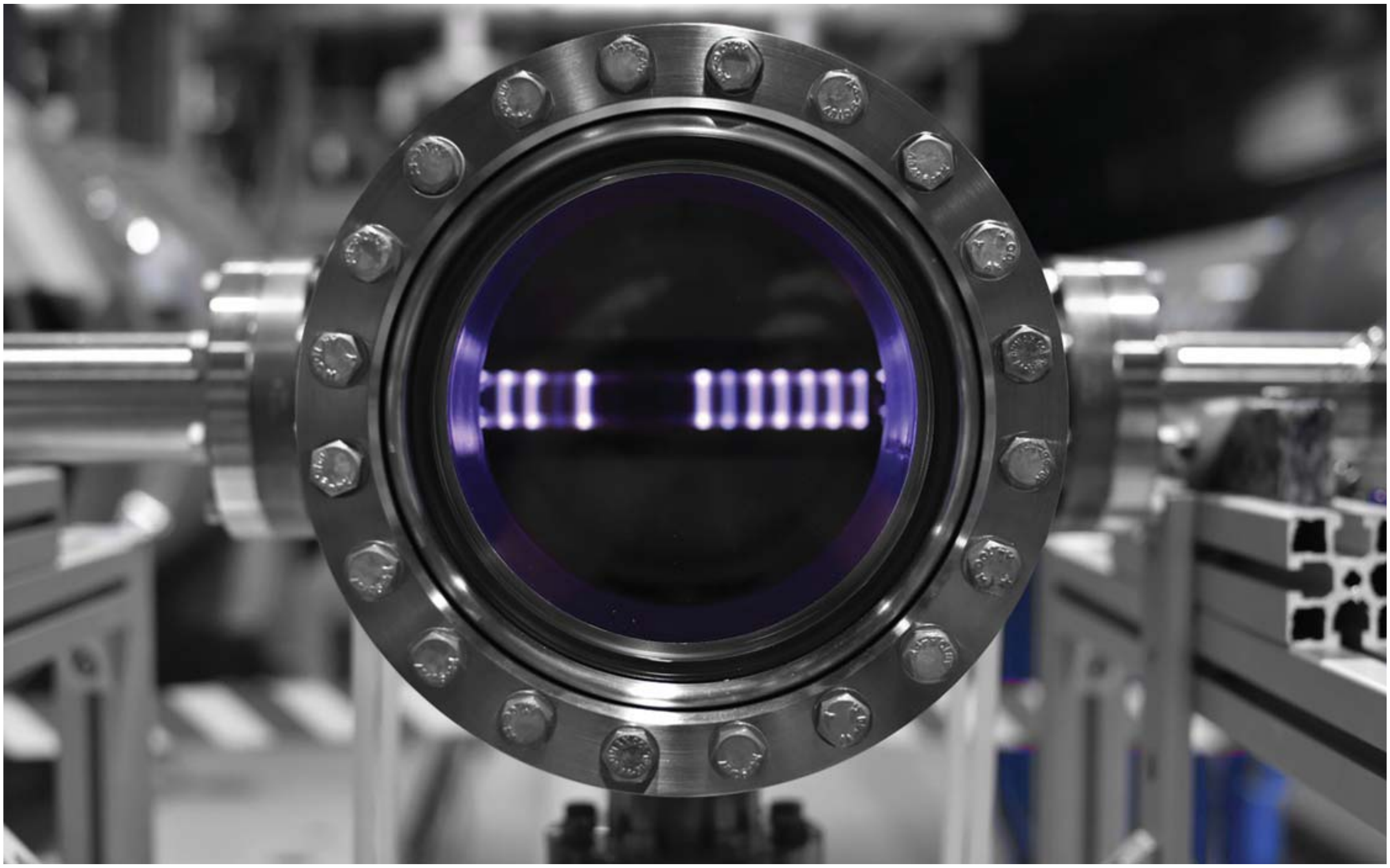
permits a longer-term memory that can be used to make the networks programmable so the same network can solve many different problems.

Synapses are a crucial computational component of the brain, so this demonstration of superconducting single-photon synapses is an important milestone on the path to realizing the team's full vision of superconducting optoelectronic networks. Yet the pursuit is far from complete. The team's next milestone will be to combine these synapses with on-chip sources of light to demonstrate full superconducting optoelectronic neurons.

"We could use what we've demonstrated here to solve computational problems, but the scale would be limited," NIST Project Leader Jeff Shainline says. "Our next goal is to combine this advance in superconducting electronics with semiconductor light sources. That will allow us to achieve communication between many more elements and solve large consequential problems."

The team has already demonstrated light sources that could be used in a full system, but further work is required to integrate all the components on a single chip. The synapses themselves could be improved by using detector materials that operate at higher temperatures than the present system, and the team is also exploring techniques to implement synaptic weighting in larger-scale neuromorphic chips.

This work was funded in part by the Defense Advanced Research Projects Agency. Paper: S. Khan, B.A. Primavera, J. Chiles, A.N. McCaughan, S.M. Buckley, A.N. Tait, A. Lita, J. Biesecker, A. Fox, D. Olaya, R.P. Mirin, S.W. Nam and J.M. Shainline. Superconducting Optoelectronic Single-Photon Synapses. Nature Electronics.



A plasma cell "sputters" carbon on a beam screen in a laboratory. *Credit: CERN*

Remedy Confronts Challenges of Electron Clouds Inside Particle Colliders

by Thomas Hortala, CERN

Electron clouds are the bane of particle accelerators: a few stray electrons in a vacuum chamber, when stirred by a proton beam, can bounce off the walls of the beam screen (the metallic inner surface of the vacuum chamber), multiplying and whizzing around the beam. The resulting "cloud" can lead to a heat load being deposited on the cryogenic circuit and to a significant decrease in the beam quality, especially in areas where bunches are denser, such as inside the focusing triplet magnets surrounding the collision points of the LHC. The production of denser beams is precisely the goal of future accelerator projects such as the High-Luminosity LHC, which aims to achieve a ten-fold increase in integrated luminosity across the collider – making the issue of electron clouds even more pressing. And yet, crippling electron clouds may soon be a thing of the past, thanks to a new method for coating beam screens with a layer of carbon.

While the copper surface of the LHC magnet beam screens can give back up to two electrons for any single one it receives, a carbon surface will yield only one particle at most. With that in mind, spraying LHC magnets with carbon seems like a no-brainer to thwart electron clouds. But, in practice, this is not easily achieved: engineers in TE-VSC-SCC (surfaces, chemistry and coatings) must coat the beam screen with a carbon layer that is fine enough to preserve the resistivity properties of the copper surface without disturbing the fragile environment of the LHC magnet. Thus, they resort to a physical vapor deposition technique called sputtering. A graphite rod inserted inside the vacuum chamber is bombarded with argon ions produced in a plasma. As the ions hit the rod, carbon atoms on its surface are sprayed out, scattering towards the beam screen on which they settle. A carbon layer forms on the copper surface of the screen.

Implementing the principle of sputtering carbon onto a beam screen poses a number of physical challenges, forcing engineers to jump through many hoops. To increase the adhesion of the carbon to the copper (i.e., to make it stick), the native copper oxide must first be removed by bombarding the beam screen with argon ions before coating it with an intermediate titanium layer, which adheres well to both the copper and the carbon. In addition, the titanium removes hydrogen impurities in the plasma that would have caused the carbon to lose its valuable electronic properties.

"Beyond these physical challenges, we are also dealing with significant spatial constraints, working inside the LHC tunnel, on magnets that cannot be taken out of the collider. This made us develop creative ways of treating the surface from a distance," explains Pedro Costa Pinto, the project leader. To combat these constraints, a modular sputtering device has been designed, composed of a titanium rod and a carbon rod enclosing small permanent magnets. This plasma cell can be pulled by a cable along the LHC magnet. The device has already proved its worth on the LHC's Q5L8 quadrupole, which received the carbon treatment before the LHC restart as a first test. The first results are unequivocal: the standalone magnet has received minimal heat load (damage from the electron clouds) compared to all other magnets.

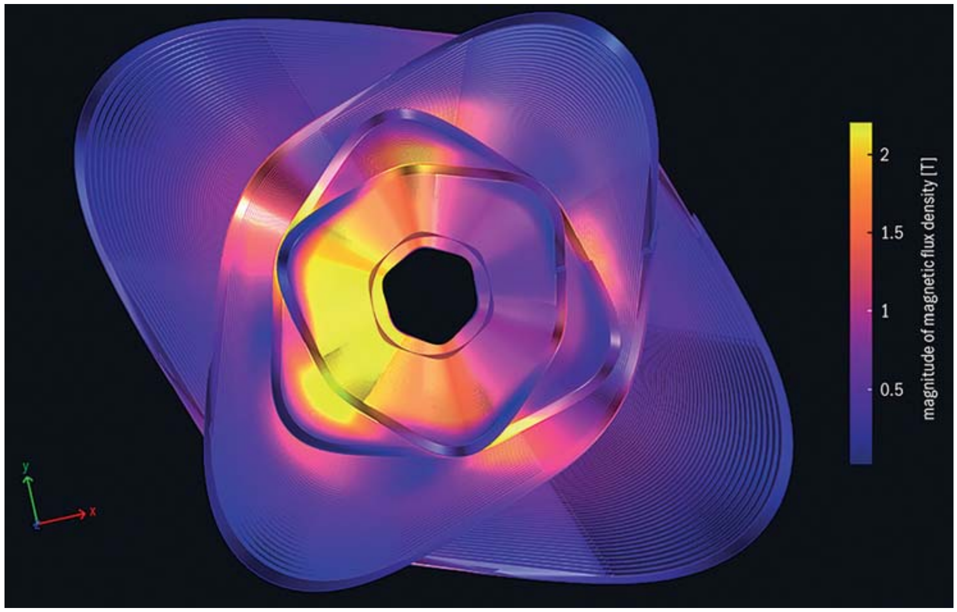
The logical next step will be to apply this technology where it is needed most: on the new triplet magnets surrounding the ATLAS and CMS collision points where the luminosity is particularly high. In parallel, the first HL-LHC magnet beam screens will undergo the same treatment. "The brand-new HL-LHC screens haven't been placed in the accelerator yet, which obviously makes things easier for us because the sputtering can be carried out in the workshop in a controlled environment. However, we need to update both our method and our tools to adapt for the larger, innovative beam screens," says Spyros Fiotakis, who has worked on the carbon-coating method since its inception.

The modular sputtering device, with its carbon rod (left) and titanium rod (right). *Credit: CERN*

"When we presented the project in 2015, few believed we could make carbon-coating work on a magnet in the LHC tunnel. Seven years later, we are ready to apply this technology to more and more machines, with the hope of lifting a long-running limitation on the performance of particle accelerators." adds Pedro. Time will tell whether carbon coating will save accelerators from themselves, but the technology will, without a doubt, be part of the answer.

FCC-ee Designers Turn Up the Heat

by Matthew Chalmers, Editor, CERN Courier



Innovative: The magnetic flux density of a nested main sextupole-quadrupole system for FCC-ee, looking along the direction of the electron beam. *Credit: M Koratzinos/RAT GUI*

The proposed electron–positron Higgs and electroweak factory FCC-ee, a major pillar of the Future Circular Collider (FCC) study, is a leading contender for a flagship project at CERN to follow the LHC. Envisaged to be housed in a 91-km-long tunnel in the Geneva region, and to be followed by a high energy hadron collider utilizing the same infrastructure, it is currently the subject of a technical and financial feasibility study, as recommended by the 2020 update of the European strategy for particle physics.

Maximizing energy efficiency is a major factor in the FCC design. Two new projects backed by the Swiss Accelerator Research and Technology (CHART) collaboration seek to reduce the environmental impact of FCC-ee by exploring the use of high temperature superconductors in core accelerator technologies.

Much like its predecessor, the Large Electron-Positron (LEP) collider, and indeed every lepton collider to date, the main magnet systems in the FCC-ee design are based on normal-conducting technology. While perfectly adequate from a magnetic field point of view, normal-conducting magnets consume electricity through Ohmic heating. The FCC-ee focusing and defocusing elements, comprising about 3,000 quadrupole magnets and 6,000 sextupole magnets, are estimated to consume in excess of 50 MW when operating at the highest energies. This can be reduced if the magnetic systems are made superconducting, and if high temperature superconductors (HTS) are to be used. Whereas conventional superconductors like the niobium-titanium used in the LHC must be cooled to extremely low temperatures (1.9-4.5 K), state-of-the-art HTS materials can operate up to 90 K, significantly reducing the cryogenic power needed to keep them superconducting. The question remains whether high performing HTS accelerator magnets, with all their advantages on paper, can be built in practice.

Turning FCC-ee superconducting not only helps with operational costs and environmental credentials, but the new HTS technology has potential applications in everyday life. In April 2022, the CHART executive board gave the green light to two projects investigating the feasibility of superconducting technology for the main magnet systems of FCC-ee. CHART was founded in 2016 as an umbrella collaboration for R&D activities in Switzerland, with CERN, PSI, EPFL, ETH-Zurich and the University of Geneva as present partners. The larger HTS4 project, involving CERN and PSI, will focus on superconducting magnets, while CPES (Cryogenic Power Electronic Supply) will focus on cryogenic power supplies, with partners ETHZ and PSI.

"The use of HTS-based magnets could dramatically reduce the power drawn by the main quadrupole and sextupole systems for FCC-ee when operating at the highest center-of-mass energies," explains HTS4 Principal Investigator Michael Koratzinos of PSI. According to Koratzinos, because HTS magnets do not need iron to shape the magnetic field, they can be made much lighter and can be nested inside one another to increase performance and flexibility in the optics design. "Turning FCC-ee superconducting not only helps with the reduction in operational costs and the environmental credentials of the accelerator, but it also helps society develop this new and exciting HTS technology with potential applications in everyday life."

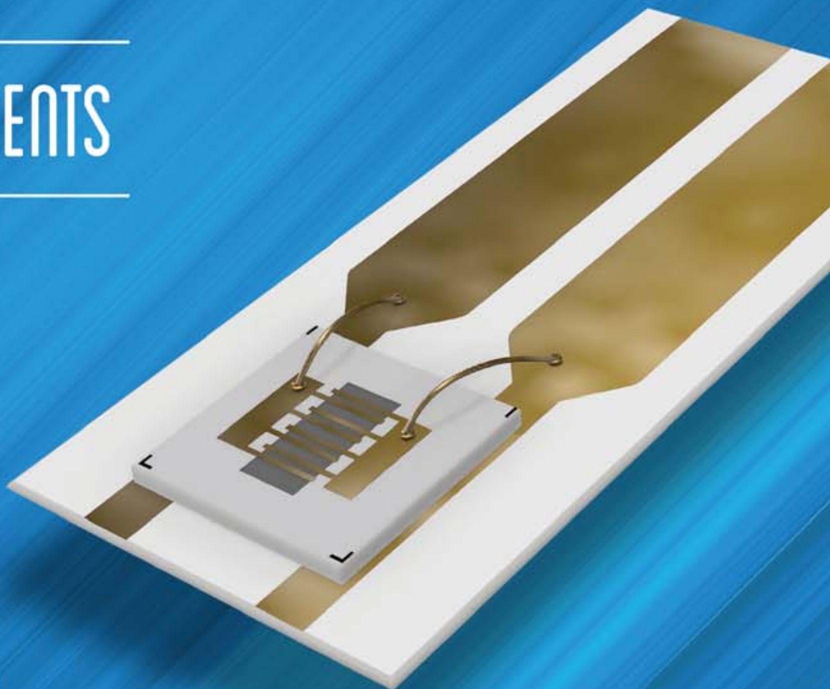
High Demand

HTS conductors are currently in high demand, mainly from a multitude of privately funded fusion projects, such as the SPARC, a tokamak under development by Commonwealth Fusion Systems in collaboration with the Massachusetts Institute of Technology Plasma Science and Fusion Center. Their main disadvantage is their high cost, but this is expected to come down as demand picks up. SPARC needs about 10,000 km of HTS conductor during the next few years, compared to an estimated 20,000 km for FCC-ee, although on a later timescale.

The ultimate goal of HTS4 is the production of a full-size prototype of one of the FCC-ee short-straight sections based on HTS technology. Four work packages will address: integration with the rest of the FCC-ee accelerator systems; enabling technologies on peripheral issues such as impregnation; the conceptual and technical design of a short demonstrator and a prototype; and the design, construction and testing of the full prototype module.

"Any future project at CERN and elsewhere relies on innovative R&D to minimize its electricity consumption," says Michael Benedikt, project leader of the FCC study at CERN. "We are doing our utmost at FCC to increase our energy efficiency."

SCIENTIFIC INSTRUMENTS



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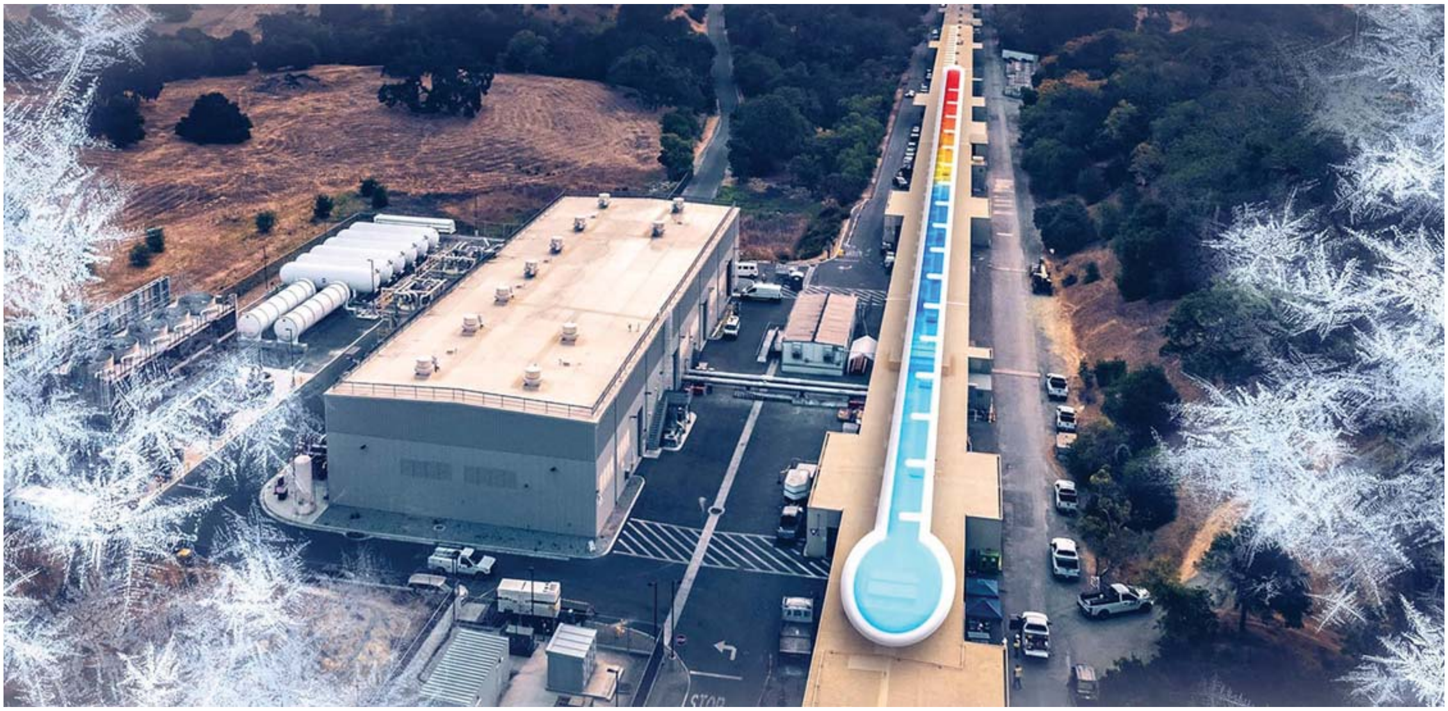

Credit: Greg Stewart/SLAC National Accelerator Laboratory

Helium's Chilling Journey to Cool a Particle Accelerator

by Chris Patrick, SLAC Communications

Today, it only takes one and a half hours to make a superconducting particle accelerator colder than outer space at the Department of Energy's SLAC National Accelerator Laboratory (CSA CSM).

"Now you click a button, and the machine gets from 4.5 kelvins down to 2 kelvins," says Eric Fauve, director of the cryogenic team at SLAC.

While the process is fully automated now, getting this accelerator, called LCLS-II, to 2 kelvins, or minus 456 degrees Fahrenheit, took six years of designing, building, installing and starting up an intricate system.

The original LCLS, or Linac Coherent Light Source, accelerates electrons to ultimately produce X-rays used in atom- and molecule-probing experiments. LCLS-II will work concurrently with LCLS. However, unlike LCLS, which uses copper parts at room temperature to accelerate electrons, the LCLS-II upgrade employs superconducting cryomodules. These cryomodules impart electrons with energy more efficiently, which will help generate more powerful X-ray pulses to expand experimental possibilities across fields.

But, whereas LCLS can operate at room temperature, LCLS-II must be cooled to 2 kelvins, just 4 degrees Fahrenheit above absolute zero, to become superconducting.

And that meant SLAC needed a team to focus on cold stuff.

Assembling a Team to Assemble a Cryoplant

Before the LCLS-II cooldown, there was no group devoted to cryogenics at SLAC.

"Our biggest challenge was that this was the first time we were doing this with a new team," Fauve says.

The LCLS-II cryogenic team, now consisting of 20 operators and engineers, formed in 2016 at SLAC to construct the facility that cools the accelerator: a cryogenic plant.

"This is a complicated system with many subsystems that work in tandem," says Viswanath Ravindranath, lead cryogenic process engineer for LCLS-II.

SLAC worked closely with engineers from DOE's Fermi National Accelerator Laboratory and Jefferson National Accelerator Facility, as well as leading cryogenic companies to design and procure materials for the cryoplant.

"This collaboration allowed the LCLS-II project to benefit from the best cryogenic resources within the DOE laboratories and elsewhere," Fauve says.

The cryoplant is filled with helium, which is cooled and then pumped to LCLS-II. While every other element freezes below 4 kelvins, helium can remain a fluid, and at 2 kelvins, helium becomes superfluid, meaning it flows without viscosity. That fact, and superfluid helium's ability to conduct heat better than any other known substance, make it the perfect refrigerant for cooling a superconducting accelerator.

Before the cooling begins, trailers piled with hotdog-shaped tanks deliver gaseous helium at ambient temperature (about 300 kelvins) to the cryoplant's outdoor storage tanks. The cryoplant requires a total of four metric tons of helium.

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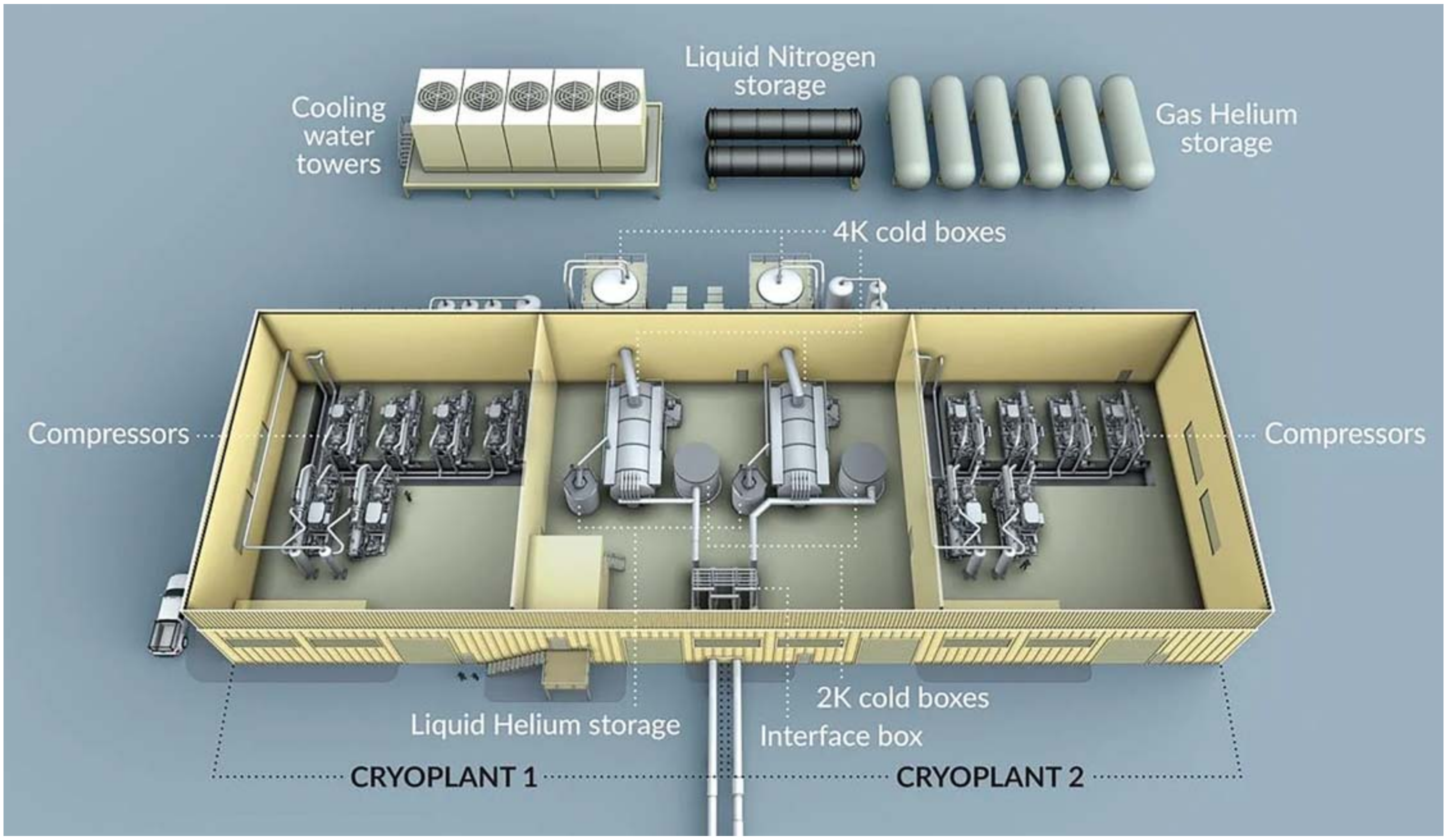

A schematic of a building with various pieces of cooling equipment and a schematic of the LCLS-II cryoplant. *Credit: Greg Stewart/SLAC National Accelerator Laboratory*

But this helium arrives impure. Any impurities will eventually freeze and clog the system, so first purifiers must trap any moisture or unwanted gases, such as nitrogen, to achieve 99.999% helium.

After purification, compressors raise the helium's pressure. The pressure and temperature of a gas are coupled: as pressure decreases, temperature also decreases. So, while helpful later, this incidentally raises helium's temperature to 370 kelvins.

Following compression, five large towers containing cooling water are used to lower helium's temperature back to 300 kelvins. The gas then enters the cryoplant's 4 K cold box, which is a giant, uber-complicated helium refrigerator.

In the cold box, liquid nitrogen running 77 kelvins knocks the helium down from 300 kelvins to 80 kelvins in a heat exchanger. In this device, the warm helium gas and colder liquid nitrogen travel in opposite directions while separated by a thin metal plate, transferring heat through the plate from the helium to the nitrogen. The plant uses 20 metric tons of liquid nitrogen every other day.

The helium then runs through a set of four turboexpanders. Now the initial gas-compressing step pays off: the turboexpanders expand the high-pressure gas, lowering its pressure enough to bring the helium all the way to 5.5 kelvins.

However, the helium has more expanding to do before it can leave the cold box. It travels through a valve that has lower pressure on the other side. This lower pressure causes the gas to expand, lowering its pressure and bringing its temperature down to 4.5 kelvins (hence the name of the 4 K cold box), where it becomes a liquid.

This liquid helium is then sent through pipes to the accelerator's cryomodules, where it cools the machine to 4.5 kelvins.

Once the 4 K cold box was up and running, it took the cryogenic team one week to cool LCLS-II from room temperature to 4.5 kelvins, which it reached for the first time on March 28, 2022. But that's not cold enough!

Colder Still

To reach 2 kelvins, the 4.5 K helium undergoes yet another (final) expansion through a valve in the accelerator's cryomodules. Again, the lower pressure on the other side of the valve causes helium's pressure to drop. This cools helium to the goal temperature of 2 kelvins.

Creating the low pressure inside the cryomodule is a feat in itself.

"The magic happens when it goes through that valve, but only because we have a train of cold compressors that maintains the pressure in the cryomodule at very low pressure," Fauve explains. This set of five compressors stationed after the valve creates the pivotal pressure difference on either side of the valve.

After months of turning on and configuring this cooling system, LCLS-II finally reached 2 kelvins on April 15.

"Everything was possible because of all the hard work over the years from so many smart

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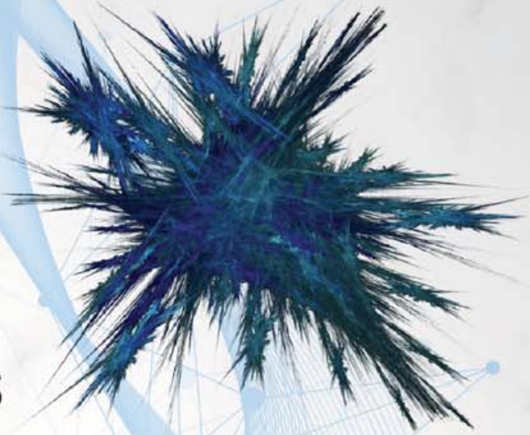
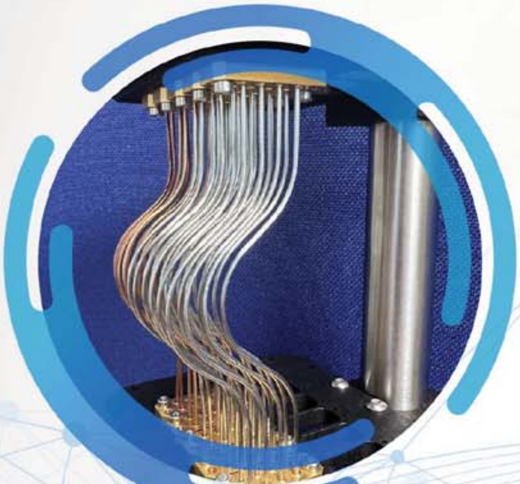
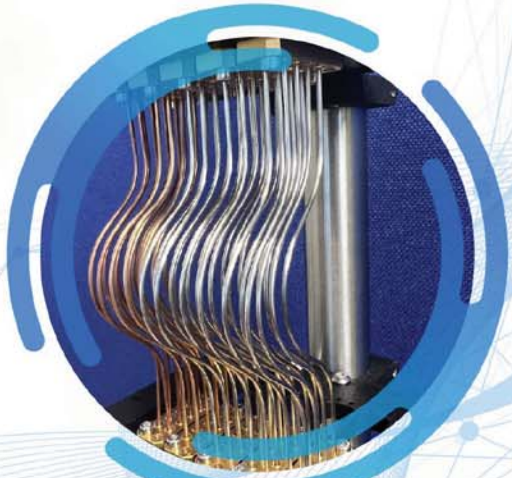
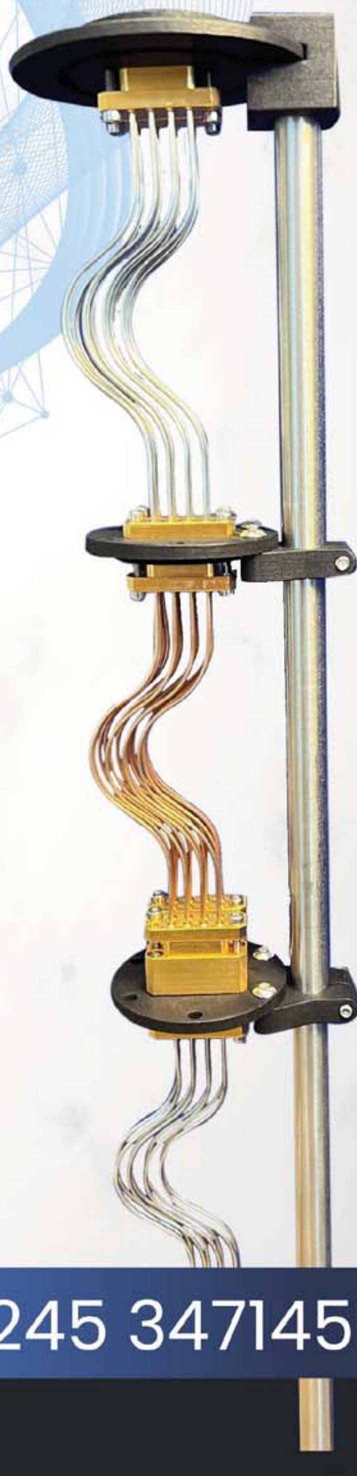
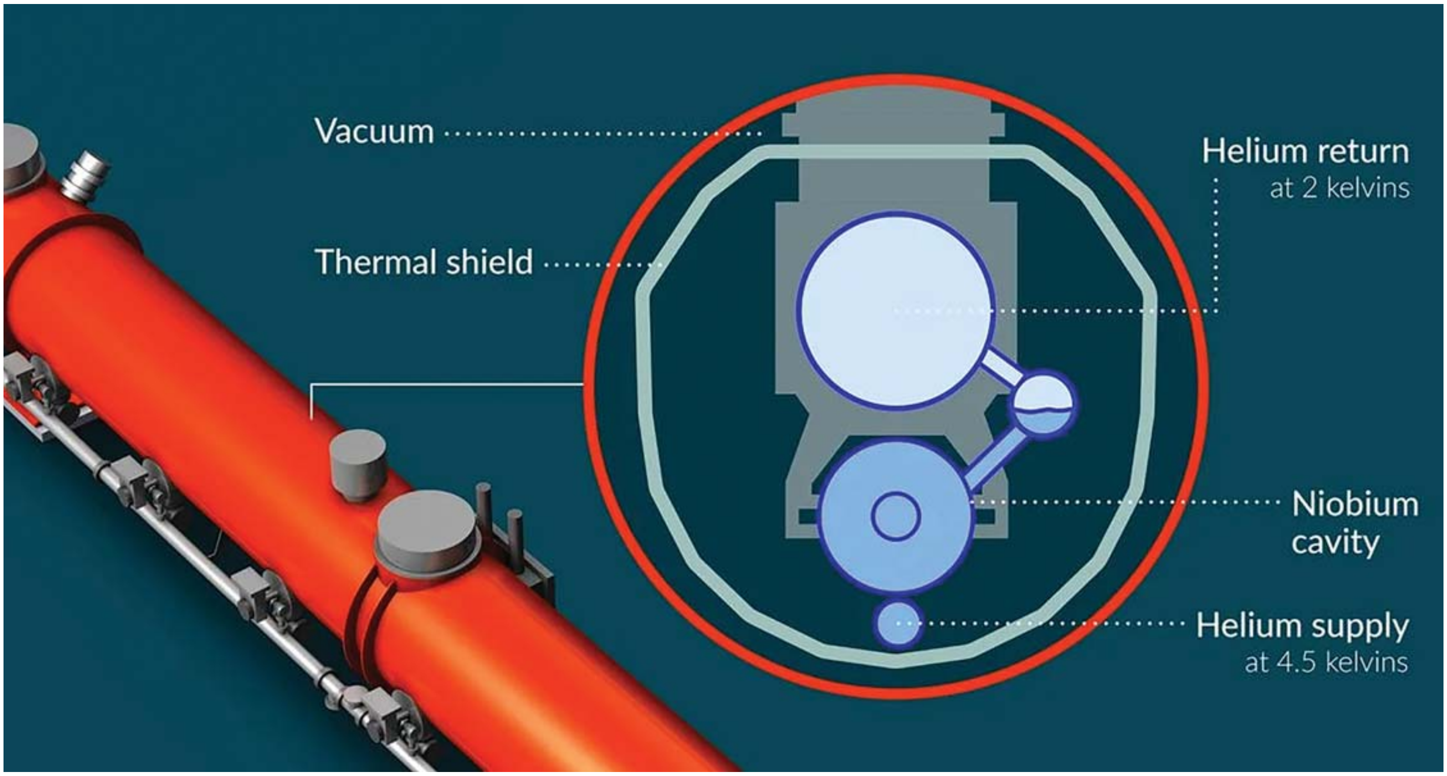








Helium's Chilling Journey to Cool a Particle Accelerator... *Continued from page 20*



A cross section of the LCLS-II accelerator showing where liquid and gaseous helium flow in and out of the system. *Credit: Greg Stewart/SLAC National Accelerator Laboratory*

and dedicated people," says Swapnil Shrishrimal, cryogenic process and controls engineer for LCLS-II. "Being a small team, as well as a young team, we are very proud of the system we commissioned."

When the electron beam is on and being accelerated by the cryomodules, the 2 kelvins helium will absorb heat from the accelerator, boil, and turn back into gas. That gas is injected back into the 4 K cold box to help cool warmer helium.

"We don't want to waste the cooling capacity, so we try to recover as much of it as possible," Ravindranath adds. The system recycles the helium, which is expensive, although essential for long-term operation.

The cryogenic team actually built two cryoplants, which share a building, but LCLS-II only uses one. The second cryoplant will support planned upgrades to LCLS-II. When both cryoplants are on, they will use approximately 10 megawatts of electrical power.

Only four other cryoplants in the US cool this much helium to two kelvins. Thomas Jefferson National Accelerator Facility and Fermi National Accelerator Laboratory, which both house cryoplants of similar magnitude and supported SLAC's design and procurement of equipment. SLAC collaborated with Oak Ridge National Laboratory, Brookhaven National Laboratory and CERN as well.

"The years of expertise and support of our partner labs allowed us to do this," Shrishrimal sums up.

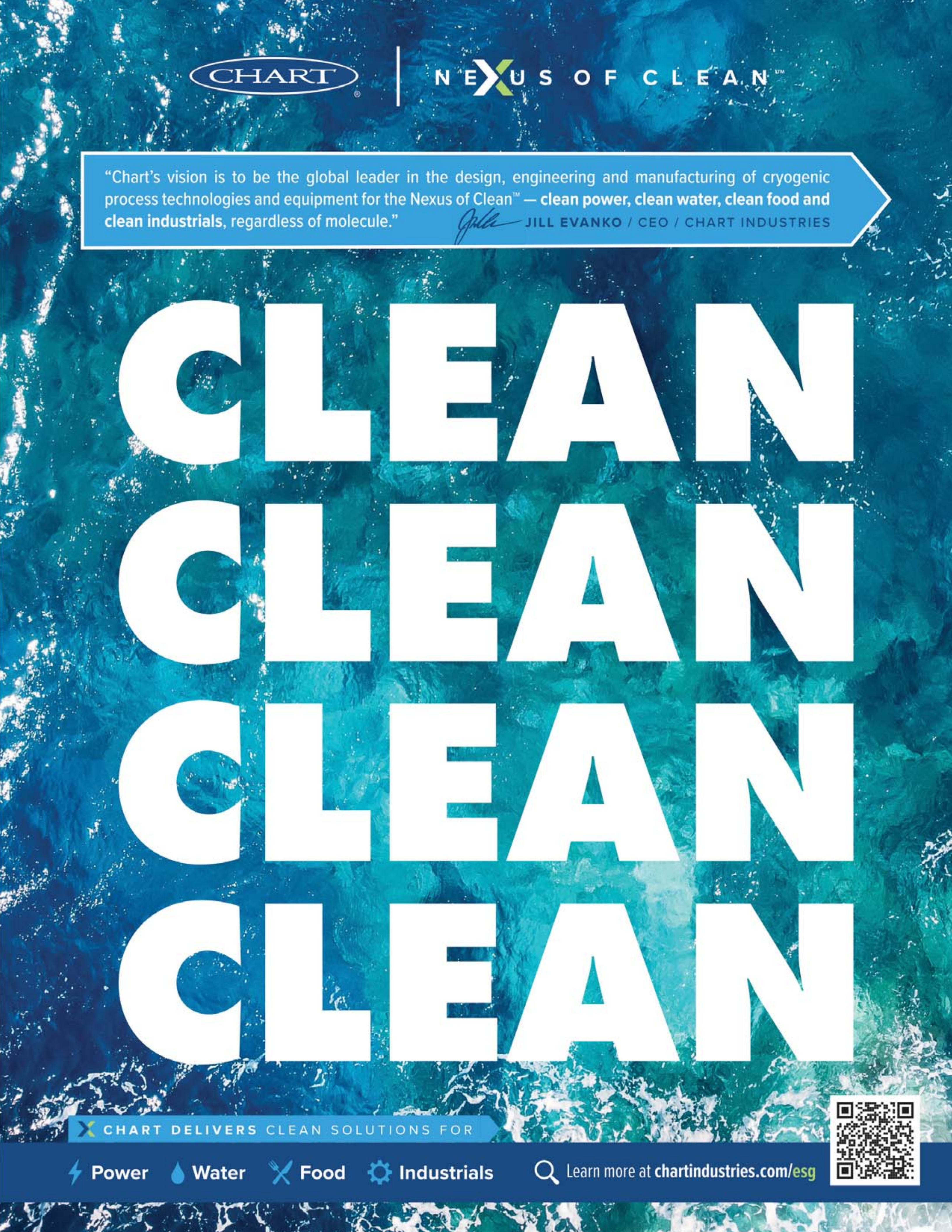
Fauve also credits the team's success to their extensive planning and dedication. The entire cryogenic team stayed on site during the pandemic to continue bringing the plant to life.

"Even when SLAC was shut down, if you were at the cryoplant you would not be able to tell the difference before and during COVID," Fauve says. "Except for the masks and social distancing, of course."

LCLS-II is expected to produce its first X-rays early next year. The cryogenic team feels confident they will continue to run their very complicated refrigerator with ease.

"It's a pretty nice and easy operation now because everything is automated," Shrishrimal says.

SLAC is operated by Stanford University for the U.S. Department of Energy's (DOE) Office of Science. The project is supported by DOE's Office of Science. LCLS is a DOE Office of Science user facility.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Cryomech Celebrates 60 Years of Cryo-Innovations

by Arifin Budihardjo, Business Development Manager, Cryomech

Cryomech celebrates 60 years of cryo-innovation at its home office in Syracuse, New York. *Credit: Cryomech Inc.*

Cryomech was founded in 1963 by William E. “Bill” Gifford. Gifford was a professor at Syracuse University from 1961 to 1978 and (in collaboration with Dr. Howard O. McMahon) invented the Gifford-McMahon (GM) cycle cryocooler in 1957. This invention made research at very low temperatures much more accessible to the scientific community. The new GM cryocooler was affordable, easy to work with and far more reliable than the “homegrown” equipment research institutions could build together at that time. In 1963 when Gifford began receiving requests from fellow scientists for GM cryocoolers for their labs, he founded Cryomech, Inc. – the era of cryocooler innovation began.

After Gifford passed in 1980, his son, Peter Gifford, led Cryomech to the next level of innovation. Cryomech continually improved GM cryocooler and pulse tube (PT) cryocooler as its key product lines. Cryomech listened to its customers and created product lines that the industries needed, powered by its cryocoolers. The helium product line, such as liquid helium plant, helium reliquefier and the comprehensive helium recovery system, is very useful to support several industries, especially during helium shortage events, such as what has occurred in 2022 and likely will continue in 2023.

Expertise in Cryo Equipment

The value Cryomech brings to its customers is expertise in cryogenics equipment. Whether in research, laboratory or industrial setting, our customers are experts in their areas of research. They do not want to be bogged down, worrying about the cryogenics equipment their experiments need. The expectation is clear: a safe, reliable high-performance cryocooler or cryostat that works every time, and at a reasonable price point. Cryomech, through the cryogenics equipment it manufactures, offers these benefits for its clients.

Industries

There are four industries in which Cryomech generally participates. The first industry is quantum information science and technology. An example of Cryomech’s role in this application is the qubits (quantum bits) in superconducting loops that require a deep cryogenics environment to function properly. Performance improvement of the qubits can be enhanced when the cryogenics environment, provided by a dilution refrigerator, powered by pulse tube cryocoolers, is reliable and consistent.

Cryomech PT425 remote motor. *Credit: Cryomech Inc.*

Second, Cryomech’s equipment is used in the healthcare and life sciences industries. From magnetic resonance imaging (MRI) to nuclear magnetic resonance (NMR), and to superconducting quantum interference device (SQUID) sensors in magnetoencephalography (MEG), high-tech life science equipment requires liquid helium to operate. This operation can be enhanced by helium management equipment, which includes cryocoolers. Cryomech also offers cold-helium circulation systems, which provide better efficiency in cooling large magnets.

Third, Cryomech participates in the clean energy industry. Applications from hydrogen, which power fuel-cell energy to the tokamak technology, lead development toward fusion energy and can be enhanced when suitable and reliable cryocoolers are involved. Finally, in the broad industry of low temperature physics, where many key research activities are being pursued from efforts in understanding our universe to investigating superconductivity behavior of a new material, Cryomech enables its customers’ objectives and uses its expertise to innovate and develop solutions that meet unique cryogenics requirements.

Today’s Innovations

Today, Cryomech occupies a brand new 76,000-square-foot manufacturing and office facility in Syracuse, New York. With more than 170 employees, Cryomech is poised to take on cryogenics projects from prototype stage to serial production mode. As its innovation legacy continues, Cryomech scientists and engineers develop larger and larger cooling capacity in pulse tube cryocoolers to meet the market’s demand for the betterment of human life. **www.cryomech.com**

SHI Cryogenics Group: Promoting Emission-Reducing Initiatives for a More Sustainable Society

by Sarah Mitchell, Marketing Communications Manager, Sumitomo (SHI) Cryogenics of America, Inc.

The Hasso-no-Mori (Forest of Ideas) within the larger Musashino Forest at Tokyo's Tanashi Works has been preserved and opened to the public. SHI's upgrades and renovations in and around manufacturing facilities have played a role in the Group's efforts to be more environmentally friendly. *Credit: Sumitomo Heavy Industries, Ltd.*

Whether designing shield coolers for life-saving MRIs, cryopumps for the latest smart device chips, or cryocoolers essential for hydrogen transportation, the SHI Cryogenics Group has been at the forefront of pioneering cryogenic technology for over 60 years.

As an integral part of the Industrial Machinery Division of Sumitomo Heavy Industries, Ltd. (SHI), the SHI Cryogenics Group's driving mission is to contribute to the development of science, technology, and healthy human life through its innovative products and services, including cryocoolers, cryopumps and helium compressors. Nowhere is this clearer than in the Group's commitment towards carbon neutrality.

SHI has long emphasized the company's positive contributions to society. The signing of the 2015 Paris Agreement, which set targets for limiting global warming to achieve a climate-neutral world by 2050, encouraged the company to examine its path toward achieving carbon neutrality by mid-century. To this end, SHI released a 2019 plan to reach net-zero greenhouse gas emissions by 2050 with the aid of two interim goals by 2030: (1) a 50% carbon dioxide decrease in the company's manufacturing processes and indirect utility emissions, and (2) a 30% emissions reduction in its supply chain and customers' use of its products.

As a result, the SHI Cryogenics Group focused on specific ways it could contribute to SHI's climate goals by examining its products, processes and customer base. Ultimately, the Group has chosen to focus on four areas of improvement: reduce its direct emissions, develop energy-saving products, provide emission-reducing solutions for customers' value chains and society, and seek out and develop carbon-reducing applications.

Curbing the SHI Cryogenics Group's Direct Emissions

Arguably, the most straightforward improvements can be achieved by curbing the Group's direct emissions as part of its manufacturing process. This includes direct emissions, such as fuel combustion and industrial processes, as well as indirect emissions from electricity, heat and other supplied utilities. In addition to regulating heating and cooling levels across facilities, SHI plans to purchase renewable energy beginning in 2023, starting with business units in Japan before expanding globally.

Upgrades and renovations in and around manufacturing facilities have already played a role in the Group's efforts to be more environmentally friendly and will continue to do so heading toward 2030. At the company's North American headquarters in Allentown, Penn., a first-of-its-kind modular helium recovery system from Linde is reducing the consumption of purchased helium by up to 70%. At the Tanashi Works factory in Tokyo, the Musashino Forest, which covers about 30% of the grounds, has been preserved, with part of it open to the public.

Energy-Saving Product Development

The SHI Cryogenics Group's entry into energy-saving product development began over 15 years ago with the release of the SICERA® Cryopump. SICERA introduced SHI's dual inverter technology into the semiconductor marketplace, allowing multiple pumps to operate on one compressor by controlling the speed of both the cryopumps and the compressors. This advancement realized an average energy savings of 20% over existing competitor products in the marketplace and laid the groundwork for similar product developments for the medical and research industries.

Over the last decade, SHI's work on Two-Stage 4K Gifford-McMahon cryocoolers has similarly targeted high efficiency and energy savings for users. Models such as the RDE-412D4 1.25 W cryocooler increased capacity by 25% over the RDK-408D2 1 W cryocooler, while maintaining the same power consumption and footprint for easy drop-in replacement. When paired with an inverter-driven compressor, speed control further increases customers' efficiency and energy savings and, in the case of MRI equipment, can reduce a magnet's cooling time and carbon dioxide emissions by about 20%.

Emission Reduction Solutions for Customers and Society

With the move of dual-inverter compressor technology into medical and research applications, SHI's customers will realize further efficiencies throughout their products' life cycles. In fact, the majority of the Group's emissions, and therefore, the focus of its reductions, are the result of the overall use of its products, from initial transportation through regular customer use.

For example, MRI manufacturers have struggled with magnet transportation from its initial production area to the larger MRI manufacturing center for decades. Magnets are typically shipped "cold" – filled with liquid helium – via air to minimize the amount of helium boiloff during transport. Using SHI's site cooling technology, which features single-stage cryocoolers, magnets can be cooled later in the manufacturing process without additional liquid helium. These magnets could be transported to the factory "warm" via ship, reducing liquid helium consumption and transport emissions.

These energy savings continue beyond the manufacturing process, thanks to dual-inverter technology. Once installed, MRIs typically operate constantly, hovering between imaging and standby mode during the day and idling at night. By utilizing an inverter-driven compressor, it's possible to toggle operation on and off during idle periods, further reducing emissions and adding to energy savings and efficiency.

Collaborating on Carbon-Reducing Applications

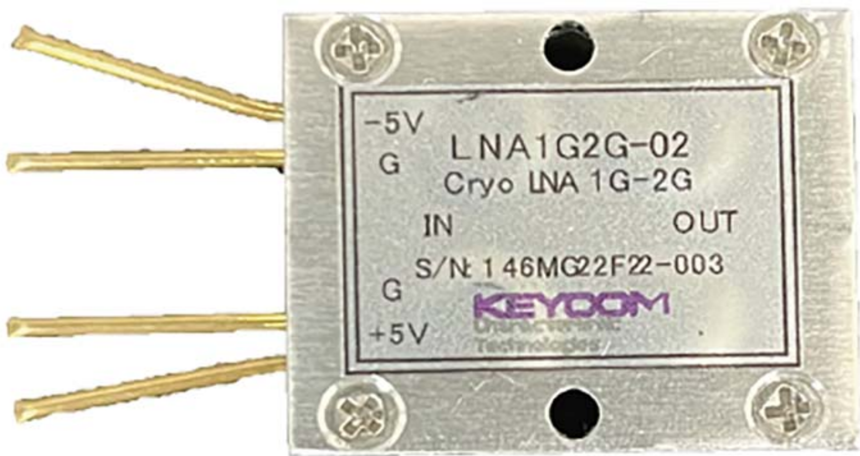
Beyond its established markets and applications, the SHI Cryogenics Group continues collaborating with new and existing partners to expand its contributions to carbon-reducing applications. Today, SHI cryocoolers are essential for storing and transporting industrial gases for fuel cell vehicles, clean energy and other applications. Single-stage cryocoolers suppress evaporation and recondense boiloff, operating intermittently thanks to inverter control that increases efficiency and saves energy. Beyond storage and transport, SHI cryocoolers are critical components in environmentally friendly applications from nuclear fusion and induction heating to wind power generation and storage.

Since its establishment nearly four centuries ago, Sumitomo's business philosophy has maintained that the company will always benefit from serving society. The SHI Cryogenics Group is determined to make steady progress toward solving social issues, particularly limiting global warming. Through constant technological innovation and collaboration with its partners, the Group is dedicated to achieving its emission-reduction goals by 2050, realizing a sustainable society for all. **www.shicryogenics.com**

KEYCOM Celebrates 30 Years of Worldwide Industry Standards

by Kenji Hanaoka, KEYCOM Sales

The computing elements of a quantum computer can only be operated properly when they are free of electronic noise. In order to achieve this state, it is necessary to realize an ultralow temperature environment in the millikelvins at a minimum. However, it is not enough to simply provide a dilution refrigerator. It is essential to install coaxial cables that can be used under cryogenic conditions to facilitate the input and output of microwaves to and from the cryocooler. KEYCOM offers a variety of coaxial cables with low thermal conductivity (made of niobium titanium, copper nickel, beryllium copper or stainless steel) for use covering cryogenic and room temperatures.



Low noise amplifier for cryogenic applications. *Credit: KEYCOM*

In the 1980s, KEYCOM's founder and president, Dr. Suzuki, focused on the water repellency and oleophilic properties of "fluororesin," and developed a cable for oil leak detection. The cable was attached parallel to a pipeline that carried jet fuel from Tokyo Metropolitan Bay to Narita Airport, about 30 miles away, and contributed greatly to the opening of Japan's leading international airport at the time.

Later in the 1990s, when the development of ultralow temperature cables started, KEYCOM once again turned its attention to fluororesin and developed niobium cables using the material. Additionally, KEYCOM had been working closely with Japan's foremost quantum computer expert, a pioneer in the development of not only niobium titanium cables but also bias tees and low-noise amplifiers for cryogenics, to establish a quality of global standard.

In 2022, KEYCOM celebrated its 30th anniversary. The company has delivered cryogenic-temperature products to more than 200 research institutes and institutions in more than 30 countries, supporting cutting-edge quantum computer research and development in the world. KEYCOM also has developed and manufactured highly accurate and reliable measurement components, devices and systems in the field of 10 µHz-300 GHz. Based on the company's accumulated experience in measurements and development of measurement devices, KEYCOM has dedicated its efforts to offering precise measurement services and devices to customers in need of fast and accurate solutions.

KEYCOM participated in the vertical laser transmission experiment for the realization of a space solar power generation system at the Japan Aerospace Exploration Agency (JAXA) and succeeded in the world's first laser transmission experiment with a transmission distance of about 200 meters. Based on these achievements, the company received a letter of appreciation from JAXA in 2016. In recognition of this achievement, KEYCOM has been selected as a member of the International Electrotechnical Commission standardization committee for permittivity measurement equipment.

Recognition for Cryo Innovations

KEYCOM received Dupont Plunkett Awards for the invention of the millimeter-wave dielectric material waveguide in 1993; a certificate of appreciation from the High Energy Accelerator Research Organization for contributions to construct B factory test facilities and long baseline neutrino oscillation test facilities in 1999; a certificate of appreciation from the National Astronomical Observatory for the development of a 100 GHz multibeam observation system installed at Nobeyama Radio Observatory Cosmic Radio Facilities in 2000; a certificate of appreciation from the High Energy Accelerator Research Organization for its contribution to achieve the world's best performance by maintaining B factory test facilities and by improving its performance in 2003; and finally, KEYCOM's Magnetic Property Characteristics Measurement System (from 100kHz to 14GHz) was awarded the ICF11 New Product and Novel Technology Award at the 11th International Conference on Ferrites in 2013.

In its 30-year history, KEYCOM's technology has become the standard in Japan and throughout the world for measuring dielectric properties in the millimeter-wave band (JIS R 1660-2) and the IEC standard for return-loss measurement methods for radio-wave absorbers (IEC62431 and JIS R 1679). KEYCOM will continue to develop excellent technologies in the ultralow frequency, VHF/UHF, microwave, millimeter-wave and ultrahigh frequency fields. **www.keycom.co.jp**

Cool Cryo Guests

by Nils Tellier, PE, EPSIM Corporation (www.epsim.us)

Our Cool Cryo Guest feature highlights articles submitted by industry experts. We encourage you to send in your work for possible inclusion in a future issue. For consideration, please contact Anne DiPaola at editor@cryogenicsociety.org.

Tips for Cryogenic Air Separation Units
Air Compression Tips Part 2-Common Mechanical and Control Issues

Mechanical Issues

Common compressor mechanical issues include stage rotor fouling and misalignment of the inlet guide vanes. These issues can be monitored from each stage temperature trend as a function of the discharge pressure and adiabatic efficiency of that stage. Efficiency losses result in an increased stage temperature difference (Tout – Tin) for a given discharge pressure.

Some air compressors have a butterfly valve in lieu of inlet guide vanes. This setup is not optimal for an air separation unit (ASU) because the mass flow of air to the cold box is controlled at the air compressor suction. Butterfly valves induce significant pressure drop when they are not fully open. Inlet guide vanes are far more effective for flow control.

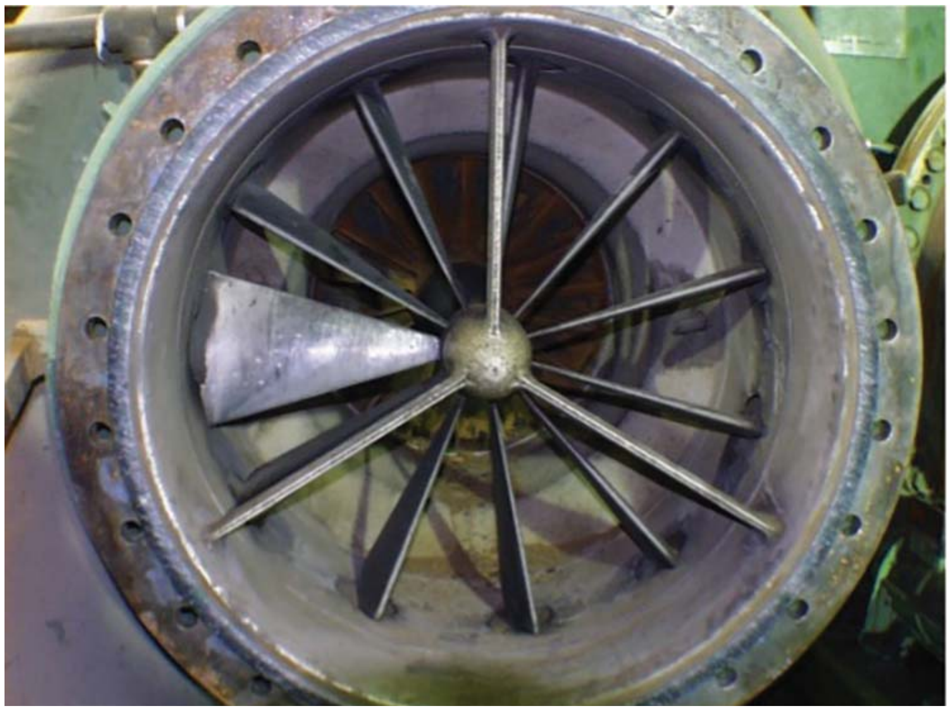


Figure 1: Inlet guide vane damage on an 8,000 HP air compressor. *Credit: Nils Tellier*

Control Issues

Excessive starts and stops on centrifugal compressors are very common. Each motor start stresses the compressor's structure, which absorbs the power of the motor internally until the motor power gets transferred to the process air or gas. To avoid unnecessary starts, most ASU protective controls should unload the air compressor rather than shut it down. This control strategy will reduce the costs associated with peak demand charges, damage, tear and wear. Exceptions to the recommendation above are compressor protections, high water level alarm in the chiller tower where entrained water could damage the adsorbers, and high rich-liquid level alarm in the lower distillation column where a liquid plug flow could damage the trays.

Centrifugal compressors require surge protection. At any given pressure, there is a minimum mass flow below which the compressor will surge, as shown by the red area in Figure 2. The relationship between the minimum mass flow and the pressure is the surge line.

Surge protection entails a recycle valve and a controller. The recycle, or vent valve in the case of an air compressor, is a fail-open analog valve that should open fully in under two seconds when the compressor unloads. This can be achieved by bleeding the instrument air from the actuator through an oversized solenoid valve.

In Figure 2, when the compressor is in the safe operation area (point 1), the recycle valve should be closed. If the mass flow of process gas is reduced to the point where it meets the surge line (point 3), the controller should de-energize the solenoid valves that supply instrument air to the recycle valve and inlet guide vanes. This results in a fast opening of the recycle valve (under 2 seconds) and slow closing of the inlet guide vanes (over 20 seconds).

It helps plant operations to determine a "surge control area" between the red area and the dotted line in Figure 2. The surge control area is set arbitrarily at flows 8 to 10 percent above the surge line, where the controller modulates the recycle valve (point 2). This analog control makes the ASU operation more forgiving during startup.

The surge controller continuously calculates the mass flow by compensating a pressure

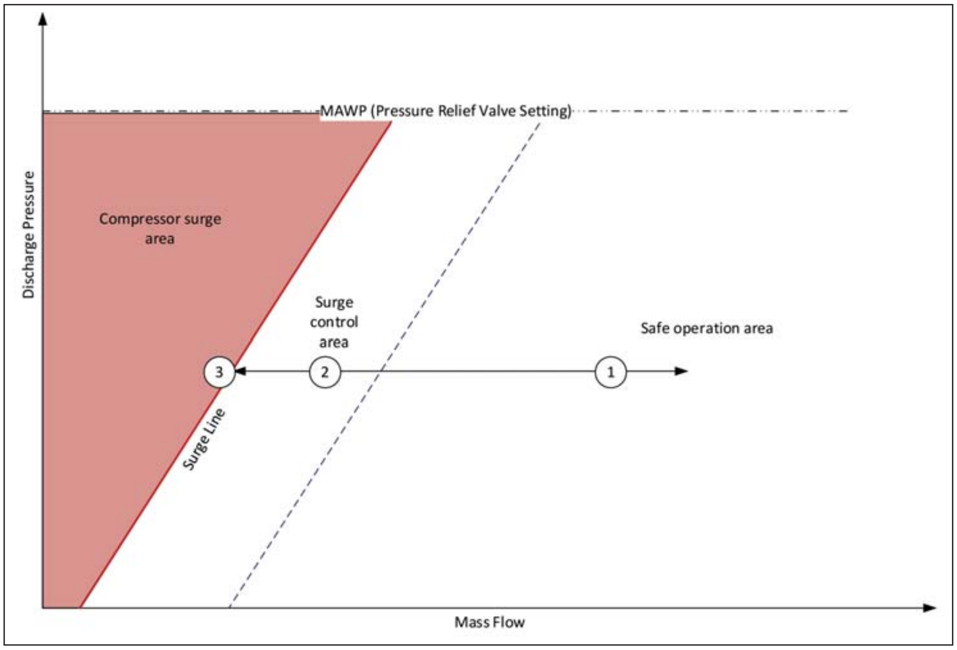


Figure 2: Centrifugal compressor control areas. *Credit: EPSIM Corporation*

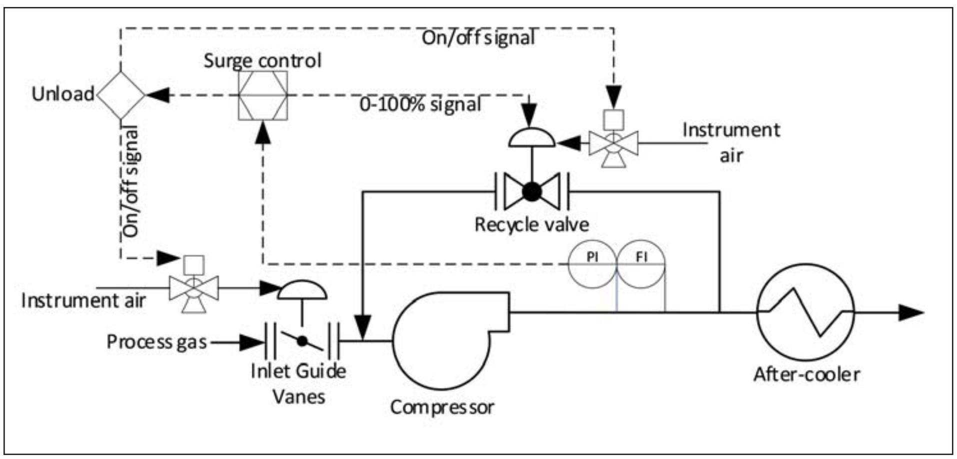


Figure 3: Compressor surge control diagram. *Credit: EPSIM Corporation*

differential measure with temperature and pressure. Next, it compares the mass flow to the surge flow at the operating pressure. The compressor unloads when the mass flow crosses the surge line. In the surge control area, the analog command to the recycle valve follows two separate PID controls: a fast one to open the valve and a slow one to close the valve. Surge protection can be programmed in the plant supervisory controls, particularly if a dedicated high-speed PLC is located next to the compressor. Alternatively, surge protection can be procured as a separate control module.

Conclusion

Given the current cost of electricity, it becomes increasingly important to seek higher operation efficiencies in contrast to limiting capital expenses. Savings can be substantiated by real-time performance monitoring.

Our next next article will look at the warm-end equipment between the air compressor and the ASU cold box.

Jobs in Cryogenics

Associate Professor in Advanced Cryogenic Technologies
University of Twente -
Enschede, NB
Full-time

Full Professor in High-Current Superconductivity
University of Twente -
Enschede, NB

Applications Sales Engineer
CPC-Cryolab -
Tampa, FL
Full-time

LEGEND-1000 Systems Engineer and Integration Lead
Oak Ridge National Laboratory -
Oak Ridge, Tennessee
Full-time

Cryogenic Engineer
Technifab Products, -
Brazil, IN
Full-time

Job openings from CSA Sustaining Members and others in the cryogenic community are included online, with recent submissions listed above.

Visit http://2csa.us/jobs to browse all current openings or learn how to submit your company's cryogenic job to our list of open positions.

Listings are free for CSA members.

What's the Matter? STAR Cryoelectronics Builds Superconducting Quantum Sensors for X-ray Analysis and Dark Matter Searches

by Robin Cantor, Ph. D., President, STAR Cryoelectronics

STAR Cryoelectronics, founded in 1999, is a leading worldwide supplier of advanced ultrasensitive quantum sensors and X-ray detectors based on superconductors and related control and readout electronics. The company also offers custom thin-film foundry services for superconductor electronics applications, cryogen-free, adiabatic demagnetization refrigerator (ADR) cryostats, and high-resolution spectrometers based on superconducting detectors for X-ray microanalysis. The company is based in Santa Fe, N.M.

One of STAR Cryoelectronics' technologies that is currently receiving significant attention is superconducting tunnel junction (STJ) quantum sensors. STJ consists of two superconducting thin films separated by a thin tunnel barrier. Energy deposition in such an STJ sensor generates excess-free charges and produces a current pulse with an amplitude that provides a measure of the energy of the absorbed particle. This detection principle is similar to conventional radiation detectors made from silicon or germanium, but the small superconducting energy gap and low-temperature operation allow STJs to have ~30x higher energy resolution than semiconductor detectors for high-accuracy measurements.

STAR Cryoelectronics initially developed STJ X-ray detectors for material analysis and biomedical applications at synchrotron light sources where the high energy resolution of STJ detectors enables the chemical analysis of dilute elements in complex samples by X-ray absorption spectroscopy, especially of light elements and first-row transition metals. STJs have been used to understand the role of dopants in novel semiconductor and scintillator materials and to help elucidate reaction mechanisms of metalloproteins.

But STJs also turn out to be very well suited to search for hypothetical elementary particles called sterile neutrinos. These particles have been postulated to account for so-called dark matter (i.e., 85% of the mass of the universe that is known to exist because of astronomical observations, but its nature is currently unknown, aside from the fact that it is not one of the known elements or particles).

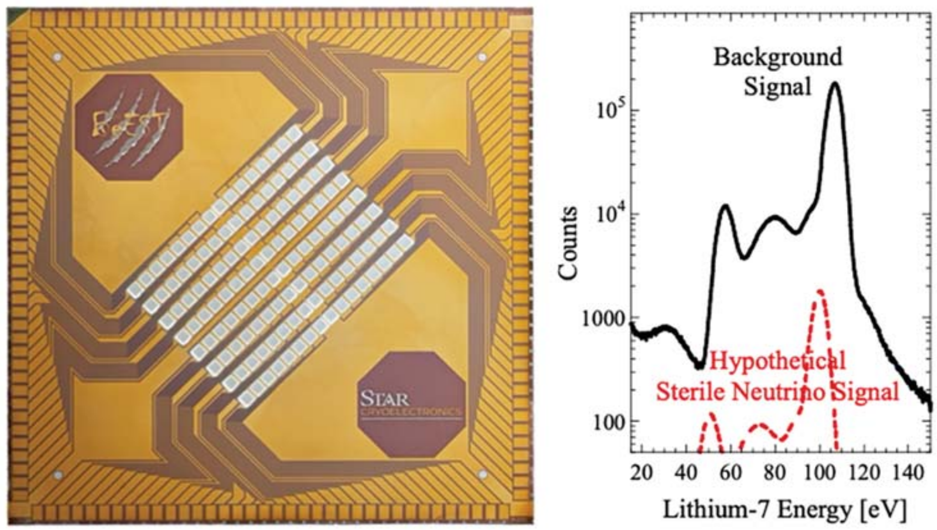


Figure: The Beryllium-7 Electron Capture in Superconducting Tunnel Junctions ("BeEST") experiment at LLNL uses quantum sensor arrays from STAR Cryoelectronics (left) to search for hypothetical sterile neutrino dark matter. The detection signature would be a small, shifted spectrum (red) added to the large background spectrum, due to known neutrinos (black). See Phys. Rev. Lett. 126, 021803 (2021) for details. *Credit: STAR Cryoelectronics*

Recent experiments with neutrinos have made it plausible to postulate the existence of additional types of neutrinos that interact with matter only through their gravitational force. These so-called sterile neutrinos could not only account for dark matter, but also help explain the matter-antimatter asymmetry in the universe (i.e., the fact that the universe does not contain any of the antimatter that should have been created during the Big Bang in roughly the same amount as the matter that we and our world consisted of).

This sterile neutrino search is conducted by the Lawrence Livermore National Laboratory, the Colorado School of Mines and several international collaborators. For the experiment, radioactive beryllium-7 is implanted directly into STJ quantum sensors. When it decays into lithium-7 and a neutrino, the neutrino escapes from the detector, but the STJ can measure the recoil energy of the lithium-7 with very high accuracy. The vast majority of decays will produce one of the three known low-mass neutrinos. But if sterile neutrinos exist, a tiny fraction of the beryllium-7 decays could produce a heavy sterile neutrino with a rest mass mc2 in the keV range. In this case, the recoil energy of the lithium-7 would be reduced by an amount dependent on the sterile neutrino mass, and a spectrum would show tiny additional peaks at lower energy (see figure). So far, no evidence for sterile neutrinos has been found [***Phys. Rev. Lett.*** 126, 021803 (2021)].

The next generation of STJ detectors that STAR Cryoelectronics is developing, however, will be several orders of magnitude more sensitive. And this sensitivity is achievable with an instrument that is a fraction of the cost of typical particle physics experiments. **www.starcryo.com**.

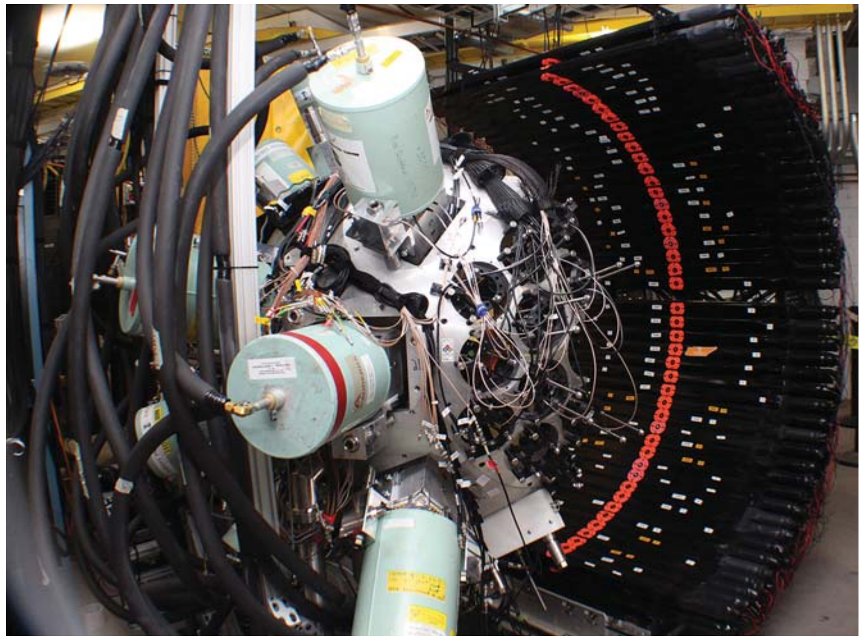
Multi-Institutional Team Publishes Paper on First Scientific Experiment at FRIB

by Lauren Biron, Lawrence Berkeley National Laboratory

A multi-institutional team of scientific users has measured how long it takes for several kinds of exotic nuclei to decay. Their paper, published in *Physical Review Letters*, marks the first experimental result from FRIB, a US Department of Energy (DOE) Office of Science user facility operated by Michigan State University.

Scientists used the one-of-a-kind facility to better understand nuclei, the collection of protons and neutrons found at the heart of atoms. Understanding these basic building blocks allows scientists to refine their best models and has applications in medicine, national security and industry.

"The breadth of the facility and the programs that are being pursued are really exciting to watch," says Heather Crawford, a physicist at Lawrence Berkeley National Laboratory (Berkeley Lab) and lead spokesperson for the first FRIB experiment. "Research is going to be coming out in different areas that will impact things we haven't even thought of yet. There's so much discovery potential."



A multi-institutional team of scientific users have published the results of the first scientific experiment at the Facility for Rare Isotope Beams in the journal Physical Review Letters. The experiment studied the decay of isotopes so unstable that they only exist for fractions of a second. To perform the study, the rare isotopes were implanted into the center of a sensitive detector known as the FRIB Decay Station initiator, shown here. *Credit: Facility for Rare Isotope Beams*

The first experiment is just a small taste of what's to come at the facility, which will become 400 times more powerful over the coming years. "It's going to be really exciting – mind-blowing, honestly," Crawford adds.

More than 50 participants from ten universities and national laboratories were involved in the first experiment. The study looked at isotopes of several elements. Isotopes are variations of a particular element; they have the same number of protons but can have different numbers of neutrons. Researchers focused on unstable isotopes near the "drip-line," the spot where neutrons can no longer bind to a nucleus. Instead, any additional neutrons drip off, like water from a saturated kitchen sponge.

Researchers smashed a beam of stable calcium-48 nuclei, traveling at about 60% of the speed of light, into a beryllium target. The calcium fragmented, producing a slew of isotopes that were separated, individually identified and delivered to a sensitive detector that measured how long they took to decay. The result? The first reported measurements of half-lives for five exotic, neutron-laden isotopes of phosphorus, silicon, aluminum and magnesium. Half-life measurements (perhaps best known from applications in carbon dating) are one of the first things researchers can observe about these short-lived particles. The fundamental information about nuclei at the limits of their existence provides a useful test for different models of the atomic world.

"This is a basic science question, but it links to the bigger picture for the field," Crawford says. "Our aim is to describe not only these nuclei, but also all kinds of nuclei. These models help us fill in the gaps, which helps us more reliably predict things we haven't been able to measure yet."

More complete theories help advance research in areas such as astrophysics and nuclear physics – for example, understanding how elements form in exploding stars or how processes unfold in nuclear reactors. Crawford and the team plan to repeat the half-life experiment again next year, taking advantage of additional beam intensity that will increase the number of isotopes produced, including rare isotopes near the neutron drip-line. In the meantime, other groups will take advantage of the facility's many beamlines and instruments.

"Bringing the facility online was a big effort by a lot of people and something the community has been looking forward to for a long time," Crawford says. "I'm excited I am young enough to keep taking advantage of it for the next several decades."

Multiple institutions collaborated on the first experiment, with researchers from Argonne National Laboratory (ANL), Berkeley Lab, Brookhaven National Laboratory, Florida State University, FRIB, Lawrence Livermore National Laboratory, Louisiana State University, Los Alamos National Laboratory, Mississippi State University, Oak Ridge National Laboratory (ORNL), and the University of Tennessee Knoxville (UTK). Scientists from ORNL, UTK, ANL, and FRIB led the collaboration to provide the instruments used in the FRIB Decay Station initiator, the sensitive detector system that measured the isotopes. **https://frib.msu.edu**

Applied Superconductivity Conference 2022: Catching Up on the Latest Research

by Sam Benz, NIST, ASC'22 Program Chair

The Applied Superconductivity Conference (**www.appliedsuperconductivity.org/asc2022**) is a biennial conference highlighting research in electronics, materials and large-scale applications of applied superconductivity. This year it was held at the Honolulu Convention Center from October 23 – 28, 2022. For the attendees, the ASC'22 conference program was an opportunity to catch up on the latest world-wide research on applied superconductivity. Many attendees personally told me how thrilled they were to be meeting friends and colleagues in person to discuss the latest results in superconductivity.

Conference Chair Art Lichtenberger opens ASC'22. *Credit: ASC'22*

The program committee of dedicated volunteers created a broad technical program covering the areas of electronics, materials and large-scale superconductivity. We accepted more than 1,700 presentations, dividing them into oral and poster sessions over the five-day conference. On the Sunday before the technical program, there were also well-attended short courses and a workshop. The committee intentionally broadened the quantum engineering and materials areas of the program to include applications of superconductors in quantum systems, in order to address this expanding superconductive research in quantum computing, information and communication. Special sessions and plenaries were specifically chosen to highlight research in materials, devices and systems that are essential for advancing the high performance superconducting technologies that are enabling applications in quantum and advanced computing and that are improving our understanding of the universe through particle accelerators and sensors.

Other highlights of the conference included five plenary talks on topics such as nanocomposite materials for high current density magnets, superconducting magnet manufacturing, research opportunities for the high energy particle accelerator community, technology developments and results from Google's superconducting, quantum computing program, and applications of superconducting sensors. There were also special invited sessions on superconducting quantum components and systems, control and readout electronics, electronic design automation (EDA) tools, transition edge sensors, artificial intelligence for large-scale power applications, REBCO coated conductors and superconducting materials for quantum science.

The ASC'22 conference is now part of the Applied Superconductivity Educational Foundation ASEF at (**www.appliedsuperconductivity.org**), which was created recently to promote exploration, learning, outreach and the exchange of scientific and technical ideas, breakthroughs and accomplishments, and to provide an array of educational and interactive experiences and events. To fulfill this broader mission, the ASEF sponsored the ELEVATE Program to promote educational opportunities, professional and leadership development, and outreach between our scientific community and society. This included Early Career and DEI Plenary Sessions and Student Career and Best Paper Competitions within the technical program, as well as a pre-conference week of educational outreach to schools in Honolulu and a post-conference ASEF Science Friday open to the public. The ASEF and the ASC'22 received significant support from the IEEE Council on Superconductivity, especially targeting ELEVATE and growing the quantum information contributions to the technical program. We are looking forward to ASC'24, to be held in Salt Lake City, Utah, September 1-6, 2024.

ASEF Board Member Anna Leese de Escobar meets with students. *Credit: ASC'22*

The Hawaii Convention Center offered indoor/outdoor networking areas. *Credit: ASC'22*

CSA Board Member Chris Rey announces the Roger W. Boom award recipient, Dr. Nusair Hasan of the Facility for Rare Isotope Beams. *Credit: CSA*

At left: Cold Facts Editor Anne DiPaola represented CSA with Executive Director Megan Galeher. Left: Art Lichtenberger welcomes attendees to ASC'22. *Credit: CSA*

HTS Superconducting Levitator at the vendor show. *Credit: ASC'22*

CSA and IEEE award recipients and council members at the IEEE Council on Superconductivity luncheon. *Credit: ASC'22*

Report on the 28th National Symposium on Cryogenics and Superconductivity (NSCS28)

by J. G. Weisend II, ESS

NSCS28
OCT 18-21, 2022 IIT Kharagpur

The cryogenics community in India is very broad and produces cutting-edge science and engineering in a wide range of cryogenic topics. This was illustrated at the recent National Symposium on Cryogenics and Superconductivity, held October 18-21, at The Indian Institute of Technology in Kharagpur, India. The symposium, organized by the Indian Cryogenics Council, was attended by 300 scientists and engineers, including some invited international attendees.

A set of short courses were held right before the start of the symposium and included: Helium Liquefaction (M. Chorowski, Wroclaw University of Science and Technology); Air Separation (S.K. Sarangi, C V Raman Global University); Superconducting Magnets (R. G. Sharma, Inter-University Accelerator Centre); and High Temperature Superconductors (T. Kiss, Kyushu University). Plenary speakers included: Dr. S. Somanath, chairman, Indian Space Research Organisation; Dr. Shashank Chaturvedi, director, Institute of Plasma Research; Prof. J. Weisend II, European Spallation Source; Prof. T. Kiss, Kyushu University; and Mr. Rajesh Harsh, Society for Applied Microwave Electronics Engineering & Research (SAMEER).

A total of 167 posters and talks were presented during the symposium on topics including cryocoolers, space cryogenics, cryogenic refrigeration, superconductivity, heat transfer, cryogenics and superconductivity for particle accelerators and tokamaks, cryogenic materials, liquid hydrogen, MRI and liquefied natural gas. During the symposium, the Indian Cryogenics Council presented Lifetime Achievement Awards to Prof. T.S. Datta (IIT. Kharagpur) and Prof. S. Kasthurirengan (Ex- IISc. Bangalore). An industrial exhibition, along with a dedicated industrial session, was also held as part of the symposium.

The cryogenics community in India, in addition to having a very strong domestic

Credit: Courtesy of NSCS '28

Credit: Courtesy of NSCS '28

program, contributes significantly to international projects such as ITER, CERN and PIP-II. The program and attendance of this year's symposium illustrates the strength of the Indian cryogenics community. In recognition of this expanding community, the designation of future meetings has been changed from symposium to conference. The next National Conference on Superconductivity and Cryogenics will be held in New Delhi in 2024. Additional information on this year's symposium can be found at **www.nscs28.com**. Details on the Indian Cryogenics Council may be found at **www.indian-cryogenics.com**.

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.

Danaher Cryogenics

Model DC6 Charger and Chase Mini Dilutor

Danaher Cryogenics developed the Charger dilution refrigerator in partnership with Chase Research Cryogenics. The Charger model is one of six systems on which Danaher Cryogenics is working with Chase to develop. The Charger can deliver continuous 100 mK cooling without all the hassles typically associated with dilution refrigerators. The Chase Mini Dilutor (CMD) is a small, self-contained unit, requiring only a few liters of He-3 gas. The DC6 Charger cryostat is incorporating the CMD into a complete cryostat. Many researchers need millikelvin temperatures to perform their work, but they don't need the large power offered by other manufacturers. In astronomy, detectors are commonly operated at 80 or 100 mK and require only a few microWatts of cooling. The infrastructure required for a typical dilution refrigerator would be a hassle on a mountain top and a non-starter for a balloon-based mission. The CMD, on the other hand, could offer the required performance without all the usual undesirable overhead and complexity associated with DRs. **www.danahercryo.com**

The Phoenix Company of Chicago

HDQ™

The Phoenix Company of Chicago introduces the HDQ™, a new high density quantum chip connection solution. Connecting quantum dilution refrigerator and cryostat cables to the processor board, the system advances RF density beyond standard installation sets. Non-magnetic blindmate PkZ® technology enables mass termination while ensuring constant impedance and consistent signal transfer for a comprehensive approach to RF transmission. The HDQ-18 connection system, the first release in this new product line, is the complete solution for dense board-level quantum computing requirements to 18 GHz. A system comprises an HDQ18 cable harness with PkZ cable assemblies and an HDQ-18 board-level housing assembly with quantum processor board-mount PkZ contacts. The cable harness breaks out to SMA connectors for connection-to-standard interconnect sets. Once the processor board has been configured with PkZ contacts installed, the mating HDQ-18 system cable harness enables a single plug-in operation of up to 47 cables. **www.phoenixofchicago.com**

ULVAC Cryogenics Inc.

LN2 Generator

ULVAC Cryogenics Inc. manufactures a lab-scaled integrated system that produces liquid nitrogen from room air at site. With easy operation, users can press a button for the machine to automatically produce liquid nitrogen whenever needed. Additionally, the automatic supply function (optional) is available to supply liquid nitrogen to a dewar or equipment, etc. The standard system is separated as two units, a liquefied machine (seen in the photo) and a nitrogen gas machine with lockable casters. Nitrogen supply from a facility's gas line instead of from a nitrogen gas machine is also available. These can produce 8 L, 14 L, 20 L, and 40 L of liquid nitrogen per day and store the produced liquid nitrogen in an internal tank. These contribute to the hassle and problem-solving of dewar deliveries every month and are extensively used in analytical or test equipment, cell or sample preservation, cryotherapy, dermatology, research purpose and any other application that requires liquid nitrogen. **www.ulvac-cryo.com/products-en/refrigerator-en/ln2_server-en/?lang=en**

Nikkiso

P2K Vertical Pump

The Nikkiso P2K model is a vertical pump design that eliminates gravitational loading on the cold end piston, extending sealing ring life and providing smooth suction valve operation for ideal NPSPR characteristics. The vertical installation offers less vibration, reduced noise and a compact system footprint. The vertical cold end is submerged inside a vacuum-jacketed sump, minimizing heat leak and increasing system efficiency (particularly in poor suction conditions). The sump is secured to the intermediate with a v-band clamp, allowing quick and easy access to the cold-end assembly for maintenance. **www.nikkiso.com/products**

Cryospain

Design, Engineering and Ongoing Resource Services for Cryo Equipment

Cryospain, a company with more than 20 years of experience in the field of industrial cryogenics, offers its clients in more than 20 countries comprehensive, turnkey solutions covering the design, manufacture, assembly, technical assistance and maintenance of equipment and installations related to cryogenics and high-pressure gases. The company's experienced team handles the design of the systems needed for every type of cryogenic gas and liquid, from gasification and supply plants to bottling systems, tank loading and unloading and liquid supply systems. Leveraging the latest design software (AutoPipe, SolidWorks Premium, AutoCAD and Autodesk Inventor among others), the company's experience means a keen understanding of recognized codes, such as API 620, API 650, API 2000, API 520, ASME PVBC, EN13445, and it can adapt to meet regulatory requirements regardless of where a project is located. **www.cryospain.com**

SHI Cryogenics Group

CH-160D2 77K Single-Stage Cryocooler

SHI has added a new model to its line of Gifford-McMahon (GM) cryocoolers with the introduction of the CH-160D2, its highest-capacity 77K cryocooler to date, with a first-stage capacity of 525/630 W at 77 K (50/60 Hz). The CH-160D2 introduces a unique design that combines the best features of SHI's CH and RDK cryocooler series. It utilizes Whisper® technology for quieter operation, as well as Displex® pneumatic drive technology, limiting the number of wear parts in the refrigerator. Its new gas-balanced valve design decreases torque and, along with its patent-pending gas-energized seal, reduces overall wear and tear. Additionally, the CH-160D2 showcases both a new stem drive and a novel heat exchanger designed to increase efficiency. Like all SHI cryocoolers, the CH-160D2 is competitively priced and offers users high quality and proven reliability. SHI has the most extensive installed base of cryocoolers worldwide and supports its customers with a global service and support network of 12 offices and numerous representatives. **www.shicryogenics.com**

People & Companies in Cryogenics

Credit: Quantum Computing Report

The UK's **National Quantum Computing Centre (NQCC)** has appointed Professor **Elham Kashefi** as its chief scientist. Professor Kashefi is a professor of quantum computing at the School of Informatics, University of Edinburgh, and directeur de recherche au CNRS at LIP6 Sorbonne Universite. Professor Kashefi has been active in quantum technology research for more than 20 years and will share her time between her activities at the NQCC and her role as the leader of the quantum informatics research group at Edinburgh.

....

Secop GmbH and **B Medical Systems** have entered into a joint development agreement to collaboratively build a new generation of medical transport boxes. These boxes will safely store and transport vaccines, biospecimens and other temperature-sensitive specimens at ultralow temperatures, even in tropical environments.

....

Following months of delays, **NASA**'s new moon rocket successfully lifted off from the Kennedy Space Center in Florida, November 17, 2022. The Space Launch System (SLS), which is now the most powerful rocket ever, launched an uncrewed Orion spacecraft into orbit. Orion is expected to fly by the moon, performing a close approach of the lunar surface on its way to a distant "retrograde orbit," a highly stable orbit that will see it travel approximately 64,000 kilometers beyond the moon. The Artemis I mission is seen as a crucial test for NASA before the agency sends astronauts to the moon on Artemis II, which is expected in 2024. Artemis III, currently earmarked for launch in 2025, will be the first crewed lunar landing since the Apollo missions in the 1960s and 1970s.

Credit: NASA/Bill Ingals

....

Zero Point Cryogenics (ZPC) received the Early Adopter of Alberta Technology with Distinction Award from Alberta Science and Technology (ASTech), which recognizes and celebrates the brightest minds and greatest achievements of outstanding individuals and organizations in the Alberta science and technology innovation community. Zero Point Cryogenics manufactures dilution refrigerators, which are the primary low temperature platform for quantum computers. The company is focused on designing robust and reliable dilution refrigerators to enable quantum technology research and innovation. ZPC is committed to supporting Canada's National Quantum Strategy.

Credit: Zero Point Cryogenics

....

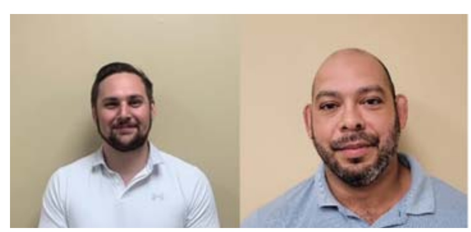
IBM announced the newest addition to the IBM quantum family in the 433-qubit Osprey processor, which features more than three times the qubits of the 127-qubit Eagle processor announced last year. In addition, IBM announced a new partnership with **Bosch** and **Vodafone**. The Bosch partnership involves an effort "to use quantum computing simulation of materials to find surrogates for the precious metals and rare earth elements in carbon-neutral powertrains – in the electric motor and the fuel cell – in the next ten years," according to a Bosch statement. Vodafone has aligned with IBM for a collaboration under which the international telecom player will work with IBM on quantum-safe cybersecurity, as well as explore quantum computing use cases for telcos.

....

ICEoxford has recently expanded into a new building in addition to its existing facility in Witney, Oxfordshire. In the past three years, ICEoxford has both increased its number of employees by 40% and doubled its positive turnover rate. Within the past year, the company has launched its DYAD system and introduced its high coax probe to its existing VTI systems.

....

Gas Equipment Co., Inc. (**GEC, CSA CSM**) is excited to welcome two new members to its cryogenic team. **Jerrod Ousley** (left) has joined as Cryogenic Sales Coordinator, and **Eric Mota** (right) is GEC's newest Industrial/Cryogenics Customer Service Representative. Ousley and Mota bring to their roles extensive knowledge of the industrial gas and cryogenic industry.



Credit: GEC

Meetings & Events

European Cryogenic Days 2023
March 28-29, 2023
Darmstadt, Germany
indico.gsi.de/event/15856/overview

Cryogenic Engineering Conference/ International Cryogenic Materials Conference (CEC/ICMC)
July 9-13, 2023
Honolulu, Hawaii
www.cec-icmc.org/2023

Space Cryogenics Workshop
Kailua-Kona, Hawaii
July 16-18, 2023
spacecryogenicsworkshop.org

EUCAS 2023: 16th European Conference on Applied Superconductivity
September 3-7, 2023
Bologna, Italy
eucas2023.esas.org

MT-28: International Conference on Magnet Technology
September 10-15, 2023
Aix-en-Provence, France
mt28.aoscongres.com/home!en

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Cryogenics Applications

- Nitrogen
- Hydrogen
- Oxygen
- Carbon Dioxide
- Helium
- Argon
- Other Natural Gases

Omegaflex welders and Omegaflex welding procedures are qualified to Section IX of the ASME Boiler and Pressure Vessel Code. Omegaflex hose assemblies are qualified to ISO-10380:2012.

Cryogenic and Vacuum Jacketed Assemblies are oven dried and purged with Argon to a moisture content of 2 PPM and verified with a moisture analyzer. Hose assemblies can be charged with Helium to maintain dryness during shipping and storage.

Cryogenics and Vacuum Jacketed Assemblies are Helium Leak checked to 1 x 10-9 std. cc/sec.

Contact OmegaFlex with your specification and we will engineer a custom jacketed hose assembly for you.

omegaflex.com

OmegaFlex®

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ISO 9001 Registered Company
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