Cold Facts

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Dylan Energy Takes Us Back to the Future | 8

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The complete Dylan Energy system, manufactured by EHP Manufacturing Company.
Credit: Dylan Energy Photo Gallery

In all instances, “CSA CSM” indicates a Corporate Sustaining Member of CSA.

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From the Executive Director

Each year when February rolls around, the winter blues are in full swing, but I always perk up knowing that this issue of *Cold Facts* spotlights Young Professionals. This year, in particular, has been very exciting because we received so many Young Professional submissions that we will be running a second feature in a future issue of *Cold Facts*! The submissions we received are a great representation of numerous segments of the cryogenics industry. I encourage you to read the Young Professionals feature on page 32 of this issue, and recommend any individuals you think we should spotlight next year or in a later issue this year.

A number of other exciting opportunities are coming up in the next few months, starting with our CSA awards that honor persons who have contributed to the industry and to the society in various ways. Nominations are now open for a number of these awards including the Robert W. Vance Award, the William E. Gifford Award, the CSA Technical Awards, and the CSA Fellow recognition. The awards will be presented at the upcoming CEC/ICMC'23 in Honolulu, Hawaii. The deadline to submit nominations for all the awards is May 5, 2023. To read full details, please visit the CSA website at **http://2csa.us/award**.

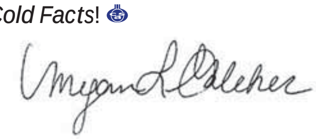
Prior to CEC/ICMC'23, CSA will be hosting a number of short courses on July 9, 2023, in Honolulu, Hawaii. This year, we will be offering one full-day course and four half-day courses. Course titles include Cryocooler Fundamentals; Aspects of Cryostat Design; The Science and Engineering of Cryogenic Hydrogen; Introduction to Dilution Refrigeration; and Practical Cryogenic Thermometry and Instrumentation. We are offering discounted early bird rates through June 9, 2023. For full details and registration, visit the CSA website at **http://2csa.us/sc23**.

The week after CEC/ICMC'23, CSA, with NASA, will be hosting the 30th Space Cryogenics Workshop on July 16-18, 2023, at the Outrigger Nona Resort and Spa in Kailua-Kona, Hawaii. The Outrigger Kona is an oceanfront resort on the Kona Coast of Hawaii. Perched above the lava cliffs of Keauhou Bay on 22 acres of Kona coastline, the resort offers spectacular sunsets, ocean breezes and breathtaking island views. We are thrilled to be hosting SCW at such a desirable venue. Please plan to join us!

Abstracts are now being solicited in all areas of cryogenics related to space applications, including missions, cryostats, components, sensors, instrumentation, cryocoolers, facilities, launch vehicles and more. Abstracts should be concise statements of no more than 500 words. The deadline for submission of abstracts is March 3, 2023. Abstracts should be emailed to SCW 2023 Co-chairs Ali Kashani and Jeffrey Feller of NASA Ames Research Center at abstracts@scw2023.com.

For full details regarding SCW, including registration and sponsorship opportunities, please visit **https://spacecryogenicsworkshop.org**.

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



Back to the Future: Combining Hydrogen Hybrid Technology and Enhancing Solar & Wind

by Brent Woodall

Martin Cain, Dylan Energy CEO, with the programming control panel of Dylan Energy System in Research and Development Facility. *Credit: Dylan Energy Photo Gallery*

Type of System	*Kg Hydrogen MW Net*
Dylan System	16 Kg
Gen Set System	58 Kg
Steam Boiler System	65 Kg
Gas Turbine System	93 Kg

Figure 1: Dylan system comparisons. *Credit: Dylan Energy*

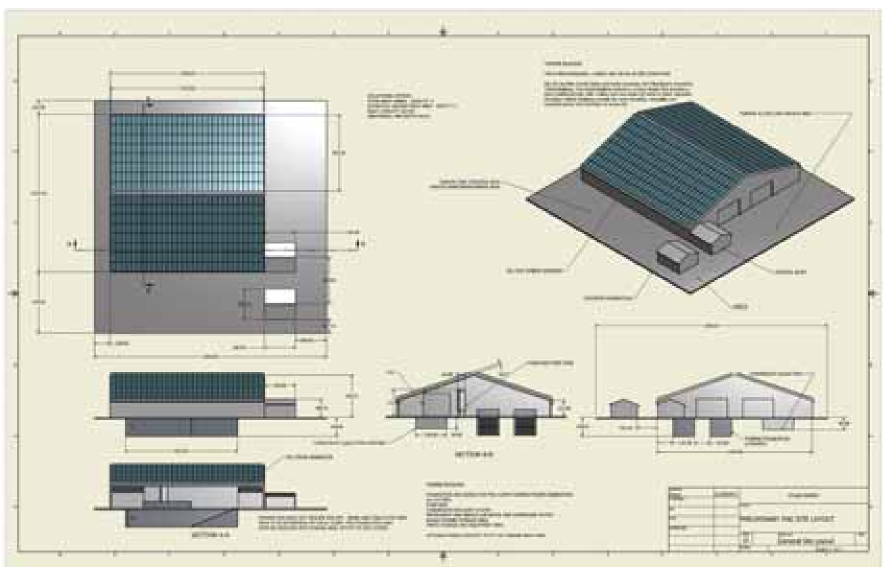


Figure 2: The Dylan Energy concept for housing. To view full size image, visit http://2csa.us/dylan. *Credit: Dylan Energy*

The first time I saw the first prototype of the Dylan Energy system, I thought of old Doc Brown and *Back to the Future*. Remember them? Doc invented something called the 'Flux Capacitor.'

With the Dylan Energy system and our partners, we are capable of consuming 400 tons daily of municipal solid waste (MSW), commonly referred to as landfills, and producing 576 mW of electricity during a 24-hour period of time. This includes medical/drugs/sharpies; municipal and urban waste; industrial, pesticides and their containers; biomass; animal housing; coal; ashes from incinerators; sewage; galvanic sludge; organic sludge from petrochemical; materials with low radioactivity; used oils; batteries; tires; waste of explosive material; hazardous industrial waste; and plastics (with no restrictions).

Dylan Energy is a hybridization solution, encompassing hydrogen, clean natural gas or other fuel sources to enhance already existing solar and wind projects. The recently passed Inflation Reduction Act (IRA) is expected to support development of new hybrid projects throughout the continental US. Hybrids can include microgrids, along with utility-scale solar and wind projects that can be retrofitted with a Dylan Energy complete energy storage package.

Dylan Energy, with the assistance of authorized inspection agencies, Bureau Veritas inspection and insurance companies, will construct steam generation systems to the ASME Boiler and Pressure Vessel Code, an American Society of Mechanical Engineers (ASME) standard that regulates the design and construction of boilers and pressure vessels. Using our ASME code certification and working with Bureau Veritas Inspection and insurance companies, we will be able to design and certify our system to any local jurisdictional code. This also enables Dylan Energy working with Bureau Veritas inspection and insurance companies to any international code, such as the European PED, Canadian CRN and others. Thus, most countries can benefit from our energy efficiency with minimal impact on the planet.

Due to the pollution produced to make battery systems, many of our existing energy solutions (excluding the Dylan Energy system) are devastating to our environment and the world's ecosystem. The current US governmental administration has recently entered into an agreement with the Democratic Republic of the Congo and Zambia to bolster the green energy supply chain, despite the Democratic Republic of Congo-documented issues with child labor. *"They dig in absolutely subhuman, gut-wrenching conditions for a dollar a day, feeding cobalt* *up the supply chain into lithium batteries, phones, tablets, and electric cars."*[1]

Seventy-five percent of all cobalt comes from African countries, whereas the Dylan Energy system is a completely domestic-based package. The Dylan system will eliminate the need for batteries and battery systems, which are costly to maintain and need to be replaced over time. Dylan Energy can be the battery source, per se, with a fraction of clean hydrogen or clean natural gas under California emission standards. The Dylan Energy system, when fully implemented, will reduce fuel consumption up to 80% in its steam generation. With burn consumption low, this will also, in effect, reduce the company's carbon footprint up to 80%.

One of the challenges with renewable energy is the intermittency of the resource. By combining existing wind or solar projects with a Dylan Energy system, we can firm up the intermittence of the renewable energy and enhance the predictability of energy each hour back to the grid. Depending on the size of the Dylan Energy system, we can also shift the renewable energy to the times of day when loads are highest and provide dependable, clean energy when the grid needs it the most. The Dylan system will also provide for off-grid energy assistance for even the most energy-strapped regions of the country.

During this past summer, Texas abandoned wind turbines due to lack of wind, and solar facilities were shut down due to the Texas heat. Even more recently, dead whales have washed up on the beaches of New Jersey and New York due to the construction of huge, offshore wind farms along the Atlantic Coast. In both instances, with the installation of a Dylan system, the need for disruption to our environment and our ecosystem can be eliminated.

The current power grid is vulnerable to food processing companies, manufacturing companies, data centers, water treatment facilities etc., the daily survival of humankind. The Dylan Energy system, however, can be made portable for disaster-stricken areas and can be electric-magnetic-pulse-proofed to thwart acts of domestic terrorism. Such savings would be passed on to utility companies. (Whether that savings is passed through to consumers is up to the companies and regulators).

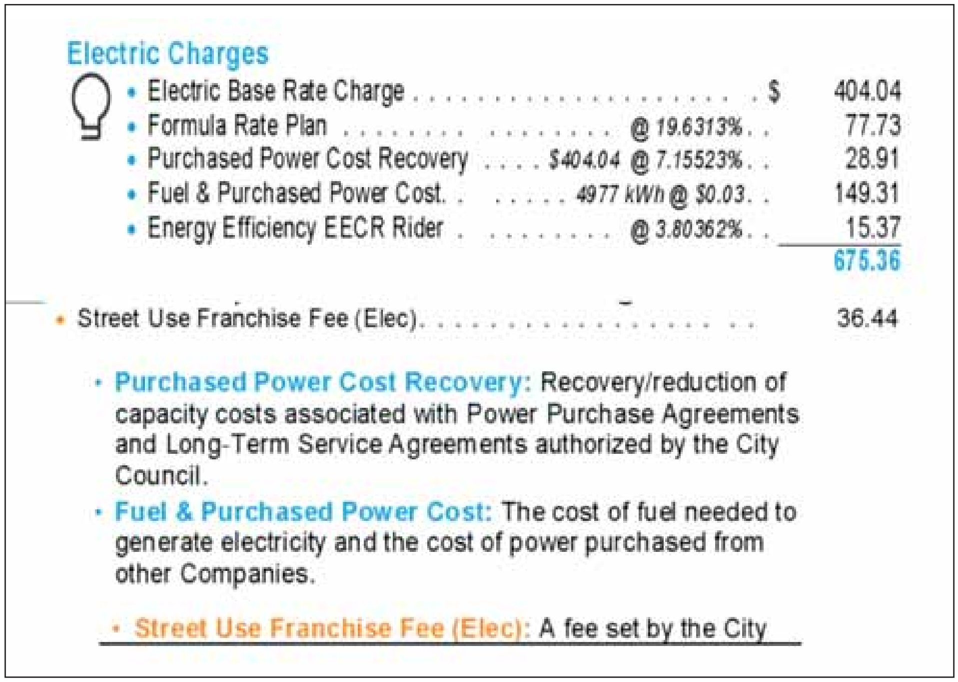


Figure 3: Typical increased costs of current energy companies found on a user's energy bill. *Credit: Dylan Energy*

The Dylan Energy concept for housing units does not draw attention to the power source (Figure 2), which reduces attacks such as what happened in Las Vegas, Nevada, January 6, 2023, when a man drove his car into a large solar plant facility.[2] Additionally, situations like that in Fresno, Calif., can be avoided. Recently, the mayor of Fresno, city council members, and other elected officials throughout Fresno County met at Fresno City Hall to call out PG&E for their "high rates, and lack of attention" to the central valley.[3]

Remember the day when most cities and towns had their own power source for their own electrical power generation? Then, large power companies came in and offered a cheaper rate than they could produce it for. Now, large power companies have added price increases every year: peak demand charge, electric base rate charge, formula rate charge, purchased-power cost recovery, fuel and purchased-power cost, energy efficiency EECR rider, transmission fees, street-use franchise fees, city taxes, etc. (Figure 3) With the Dylan Energy Power Generation System, electricity could be provided for the end user at a much lower cost.

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Liquid Helium Ballast Refrigeration

by Richard J. Warburton , Richard C. Reineman*, Eric Brinton*, and Robert L. Fagaly

The Need for Vibration-Free Cryogenics

The measurement of local gravitational fields requires continuous, high precision and extremely stable measurements. In 1968, the development of the superconducting gravity meter (SG)[1] vastly improved the state of the art. In contrast to mechanical quartz or metal springs, SGs use a superconducting sphere levitated in an ultra-stable magnetic field generated by persistent currents in a pair of superconducting coils. This cryogenic design enabled sensitivities that can exceed 10^{-10} m/sec^2 (*i.e.*, 0.01 ppb of the earth's gravitational field) and drifts less than 60 nm/sec^2/year. Many gravity measurements (hydrology, volcanology, geothermal energy and post-glacial rebound) require durations that last years, and, in many cases, decades. To fulfill this need, extremely long hold time cryostats were developed to maintain the SG at operational temperatures close to 4 K. Special techniques were also developed to prevent cryocooler-induced accelerations from contaminating the geophysical signals of interest. While most superconducting quantum interference device (SQUID) measurement systems[2] do not require multiyear measurement times, they benefit from improved cryogenic systems that minimize or eliminate the expenditure of liquid helium.

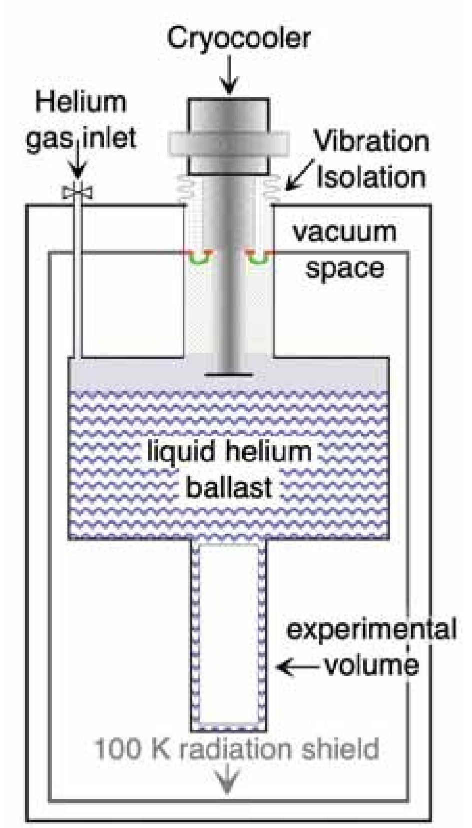
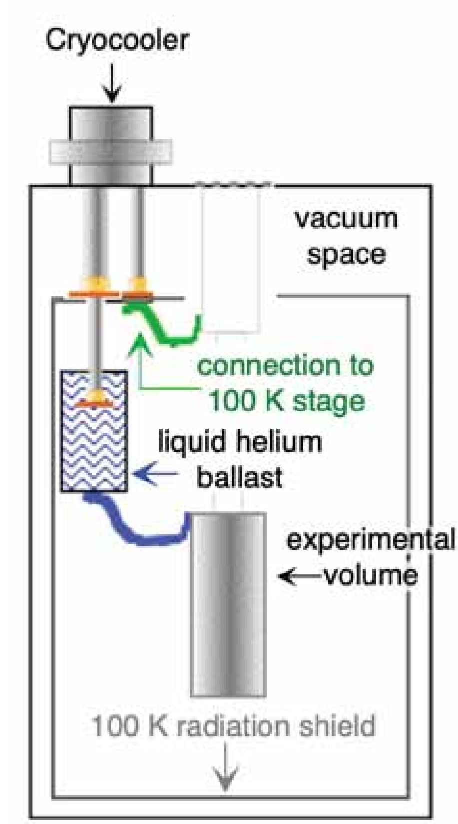


Figure 1a: Gravimeter dewar. *Credit: R. Fagaly*



1b: Alternate design to minimize liquid helium. *Credit: R. Fagaly*

Cryocooled Systems

Early SGs and SQUID systems were operated in carefully shielded and evacuated dewars with reservoirs of liquid helium that had to be replenished periodically by transferring liquid from storage dewars. Hold times between transfers varied dramatically depending on the dewar storage volume and heat loads into the helium reservoir. Early SG dewars had volumes of 200 liters and five-inch diameter necks that allowed the insertion of the sensor into the dewar. Typically, 100 liters of liquid would be transferred every 20 to 30 days to maintain the 4 K liquid helium reservoir. This process not only disturbed the gravity record but was expensive. The earliest SQUID dewars ranged from five to 25 liters and were of fiberglass construction[2] to allow measurements of external magnetic fields; these required refills ranging from twice/week to twice/month under normal operating conditions.

As an alternative to the use of liquid cryogens, closed-cycle refrigeration[3] became desirable for several reasons. These include reduction of operating costs, simplified use in remote locations, avoiding interruptions in cryogen deliveries, safety and the convenience of not having to transfer at periodic intervals. Unfortunately, directly connecting the experiment to the cryocooler introduced significant noise.

The first practical cryocooled superconducting sensor operating at 4 K (as opposed to the use of cryocoolers for MRI systems where vibration- and motion-induced noise was not significant) was the BTi CryoSQUID.[4] Based on a two-stage Gifford-McMahon (GM) refrigerator with 1 W refrigeration power at 15 K, the use of a Joule-Thompson (JT) stage allowed 4 K operation with reduced vibration. The subsequent development of pulse tube refrigeration[5] allowed operation with significantly reduced vibration. However, there remained three significant obstacles to using closed-cycle refrigeration with highly sensitive superconducting instrumentation:

- Mechanical movement of the internal components of the cryocooler,
- Short-term temperature variation of the cryocooler's coldhead, which can vary from ±0.1 K to ±0.5 K at Hz scale frequencies, and
- Long-term temperature changes of the cryocooler's coldhead as the unit ages.

Liquid Helium Ballast Systems

To minimize these obstacles, a mechanically isolated cryocooler was developed first to extend the hold time of the liquid helium reservoir, and eventually to liquefy helium gas to both fill and maintain

▶ *continues on page 12*

the liquid helium reservoir. Figure 1a and 1b show two different designs that have been implemented. Figure 1a shows the cryocooler inserted in the neck of the dewar, either partway or into the liquid ballast tank. Figure 1b shows the cryocooler located in the vacuum space with flexible connections (typically copper braid), thermally coupling the two cold stages of the coldhead to the radiation shields of the dewar. This design, suitable for a variety of SQUID magnetometer systems, minimizes the amount of liquid helium (typically 1 ~ 2 liters), while allowing interruptions of many hours for either movement of the magnetometer system or ultraprecise measurements.

In 1981, long before the development of 4 K GM cryocoolers,[3] GWR Instruments, in conjunction with S.H.E. Corporation, developed dewar systems (Model TT40, TT60 and TT70) based on the Figure 1b design that used a doubly shielded 200-liter dewar in conjunction with a two-stage (APD Cryogenics DE202) GM cryocooler capable of achieving temperatures below 10 K. The upper stage was used to cool the outer thermal shield, and the lower (cold) stage was used to cool the inner stage. The use of the cryocooler reduced the liquid helium boiloff of the dewar from 1 liter/day to 0.2 liter/day, allowing a 1,000-day hold time. Connecting the cryocooler to the shields via flexible copper braiding significantly reduced the coupling of the vibration generated by the cryocooler to the sensor. Although this dewar had an exceptional hold time, only a few more were manufactured since it was very difficult to remove the coldhead for servicing at the required one-to-two-year intervals. The next models were similar to that shown in Figure 1a, but with the sensor first inserted through the neck of the dewar, and the coldhead inserted afterward. Helium gas in contact with concentric heat exchangers transferred heat from the dewar shields to the coldhead. A separate support frame supported the coldhead without allowing contact with the neck. This design entirely isolated the coldhead vibrations from the dewar and gravity sensor and was a major advance in decreasing this source of noise on the sensor. This design simplified coldhead service and decreased noise, but the tradeoff was a decrease in hold times to less than 500 days.

In 1993, GWR produced a 125-liter compact dewar design that was much smaller and one that could be operated at many preexisting geodetic observatories. It used the same APD Cryogenics DE202 coldhead; however, the gravity meter was installed permanently into the dewar belly through removable seals in the dewar belly and vacuum chamber. This allowed the neck diameter to be reduced from 12.7 cm to the diameter of the coldhead and made it both easier to transfer heat from the coldhead stages to the dewar shields and to isolate the coldhead vibrations from the dewar and sensor. After testing at Royal Observatory in Brussels, on August 4, 1995, the first compact SG C021 was moved to a room at the end of a 100-meter-long tunnel at a seismic station in Membach, Belgium, where it is still operating today. This instrument is testament to the design of a liquid helium ballast system. At the end of 2022, this gravimeter had measured variations in gravity for 10,000 consecutive days (over 27 years), and it holds two world records: first, for measuring a continuous gravity signal at a single location for the longest time in the world, and second, for the longest circulation of electric currents in superconducting circuits.[6]

By 1997, Leybold Vacuum introduced the first practical closed cycle 4 K refrigeration system, the Leybold KelKool 4.2. Its GM coldhead cooled below the 4.2 liquefaction temperature, producing about 50 W cooling power at its upper stage at 50 K and about 0.5 W cooling power at the lower stage at 4 K. Soon afterward, GWR produced an ultralong dewar based upon the 125-liter compact design but with its neck enlarged to accommodate the much larger 4.2 GM coldhead. It is believed that this is the first design that coupled a 4 K GM coldhead with a dewar and a liquid helium storage volume in which the coldhead was used to liquefy He gas into a storage volume cryostat using only the GM cryocooler.[7] Although very reliable, the coldhead was too heavy for one person to handle and required a support crane for insertion and removal. In addition, the compressor and water chiller required 7 kW of power versus the 2-kW power for the APA DE202 202 system. Two systems were manufactured with the Leybold KelKool 4.2 and two with the Leybold 4.2 Lab coldhead, which reduced the power load to 3.5 kW. Soon after the last shipment to the Japanese Showa Station in Antarctica in March 2003, Leybold discontinued manufacturing these cryocoolers.

At about the same time, Sumitomo Heavy Industries (SHI) entered the market with a new smaller 4 K refrigeration system, the SHI RDK-101 coldhead and CAN-11 compressor. This system produces about 0.2 W of cooling power at 4 K and is about the same size as the APD 202 DE202 so that it can easily be handled by one person. This led to the development of GWR's present iGrav superconducting gravimeter (Figure 2) that uses a 16-liter dewar with the coldhead supported by a small external frame with helium gas exchanging heat between the coldhead and the dewar shield. Helium gas is sealed in the dewar using a flexible membrane, and heat is added to the dewar's neck to control the pressure close to atmospheric pressure. Since the pressure differential is very small across the sealing membrane, the temperature variations of the storage volume vary with atmospheric pressure with a dependence of about 1 mK/mBar. The development of the iGrav's dewar/refrigeration system is the result of about 25 years of development, and to date, about 50 of the iGrav systems have been shipped worldwide.

The liquid helium ballast systems minimize the obstacles to using closed-cycle refrigeration for operating highly sensitive superconducting instrumentation. The liquid ballast technique isolates the experimental volume from the coldhead vibrations, and, because of the large heat capacity of the liquid helium, reduces the Hz level ±0.1K (or greater) thermal variations of the cryocooler to mK levels. It also allows for short interruptions of electrical power without system warm-up, essentially acting as a thermal storage battery. "Battery life" depends critically on the dewar volume and design of the interface of the coldhead and dewar neck.

Figure 1: GWR iGRAV® Superconducting Gravimeter.
Credit: GWR Instruments

GWR's iGrav, with its reduced size and weight, simplifies installation and transportation while providing more than 10 days of "battery life." This allows ample time for most service requirements and allows the instrument to be moved from one location to another without warm-up.

Another major advantage of liquid helium ballast systems is that liquid helium is not needed for the initial cooldown. By injecting room temperature gas into the cryogenic insert, the cryocooler is used to condense gas directly into the reservoir. Yet another advantage of a liquid helium ballast system is that, if cryocooler vibration interferes with the experiment, it can be shut down during the measurement time. This is particularly attractive for SQUID measurements or where portability is needed.

Initially developed for GWR's superconducting gravity meters[7],[8] in conjunction with Tristan Technologies, liquid helium ballasted systems have been implemented on commercial SQUID neuromagnetometers,[8],[9] rock magnetometers and magnetic microscopes. This method to liquefy and maintain helium led directly to small-scale liquefaction systems[9] to produce and maintain liquid helium on demand for general use. These systems are ideal for helium gas recovery and reuse, which is important for this non-renewable resource. This product is currently licensed to QD-USA[10] for manufacture and distribution worldwide.

GWR recently delivered its one hundredth cryocooled system. These superconducting gravity meter systems are often operated in rugged field conditions for decades without interruption. In many cases, this "helium battery" concept provides a superior solution for bridging power interruptions compared to power backup systems using generators and batteries. For information on GWR's superconducting gravity systems or liquid helium ballast systems, contact info@gwrinstruments.com. For liquefaction systems, contact info@qdusa.com.

Acknowledgement

The late Ray Sarwinski was instrumental in the early development of cryocooled dewars, both at SHE and Tristan Technologies.

*GWR Instruments, San Diego, CA 92121
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20 Years of Cross-Cutting Technologies

by Adam Swanger, Principal Investigator, Cryogenics Test Laboratory, NASA Kennedy Space Center, Florida USA

For more than 20 years, the Cryogenics Test Laboratory at NASA Kennedy Space Center (KSC) has stood as a one-of-a-kind capability for research, development and application of cross-cutting technologies to meet both government and industry needs. Thermal insulation systems, integrated refrigeration systems, advanced propellant transfer systems, low temperature materials and applications, plus the theme "Energy Efficient Cryogenics," the Cryo Test Lab has pioneered technologies such as Integrated Refrigeration and Storage (IRAS)[1] for advanced liquid hydrogen operations; aerogel blanket insulation[2], the world's best insulation material in ambient pressure and soft vacuum; and the patent pending Cryogenic Flux Capacitor[3] for high density storage and on-demand supply of cryogenic fluids.

Practical cryogenic thermal insulation system testing is a cornerstone of the Cryo Test Lab identity. Through a suite of custom-built liquid nitrogen (LN_2) cryostats, the lab has produced high quality thermal performance data for a huge variety of insulation materials and systems, from common to exotic, and formalized the process of LN_2 boiloff calorimetry by spearheading the writing, and eventual adoption of ASTM standard C1774. The Cryostat-100 (C-100)[4], a vertical-cylindrical cryostat, is the flagship calorimeter of the lab and has been successfully used to test insulation systems with R-values as high as 9,000 Btu·in/hr·ft2·˚F and heat loads ranging from 100 mW to 130 W. Testing can be conducted over the full vacuum pressure range, from 10^{-8} torr up to ambient pressure, and has historically been limited to inert background gases such as nitrogen or helium. However, recently C-100 has been modified to test with hydrogen as a background gas and is currently characterizing the performance of bulk-fill insulation materials such as perlite and glass bubbles purged with hydrogen for potential use in future megascale (100,000+ m^3) LH_2 storage tanks. Core features of the C-100 design, along with the invaluable practical experience gained from operating the instrument for many years, is now being applied to the design and construction of an LH_2-based boiloff calorimeter deemed Cryostat-900. This new capability is planned to be operational in 2023 and will fill a crucial gap in the cryogenic insulation system data archive by providing absolute performance measurements at operational conditions for actual LH_2 storage tanks and equipment.

Filling Cryostat-100 with LN_2 in preparation for insulation testing. *Credit: NASA*

As is most likely apparent from the recent cryostat work, much of the current lab portfolio focuses on liquid hydrogen-related topics. Although this is in part a response to the rapidly growing hydrogen economy, being located at the Kennedy Space Center – site of the largest LH_2 storage and transfer systems in the world, built to support the Apollo, the space shuttle, and now Artemis-manned spaceflight programs — the Cryo Test Lab has always been well-positioned to tackle various LH_2 challenges. Through projects such as the Cost-Efficient Storage and Transfer (CESAT) of Cryogens[5] that constructed and tested a pair of 1,000-liter spherical cryostats using LH_2 and laid the groundwork for the adoption of glass bubble insulation in the new 4,700 m^3 storage tank at KSC[6], along with the Ground Operations Demonstration Unit for Liquid Hydrogen (GODU-LH_2) that pioneered large-scale IRAS, the Cryo Test Lab has safely and successfully conducted complex testing programs using LH_2 on numerous occasions. However, in many cases, using LH_2 is impractical, especially for small, lab-scale testing. In these instances, the lab has numerous cryocoolers and associated vacuum chambers capable of testing at temperatures as low as 14 K.

Consistent utilization of cryocoolers began at the Cryo Test Lab in the 2011 timeframe with the purchase of an AL230 Gifford-McMahon unit from Cryomech (CSA CSM). This machine has been a workhorse for the lab, supporting a host of unique test setups for everything from training of low temperature shape memory alloys[7] to performance characterization of deep space cryogenic thermal coatings[8]. In the years since purchasing the initial AL230, the lab has added five additional units: two AL325s and a PT30 pulse tube from Cryomech, a Stirling cycle Cryotel GT unit from Sunpower (CSA CSM), and a STC90 machine from AFCryo (now Fabrum) (CSA CSM). These cryocoolers have played a critical role in many of the Cryo Test Lab's research projects over the last decade, including CO_2 capture for Mars In-Situ Resource Utilization (ISRU), sub-20 K and extreme thermal cycling (e.g., 20 K to 373 K) component testing, and dry-charging of cryogenic flux capacitors. Beginning in 2018, the Cryo Test Lab has also been involved in the development of novel hydrogen-based cryocoolers that may aid in long duration cryogenic propellant management to support future deep space missions.

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Qubit Measurement Systems Right Out of the Box?

by Russell Lake, Director of Quantum Applications, Bluefors, russell.lake@bluefors.com

Necessity of mK-Cryogenics

During the past years, advances in both lithography and millikelvin cryogenics have supported and enabled vast improvement in the sophistication of experimental research on electrical circuits that display uniquely quantum mechanical behavior. It comes as no surprise that dilution refrigerator measurement systems have moved beyond basic physics research contraptions, and into central focus in the new era of quantum engineering. Achieving millikelvin temperatures remains a prerequisite for many of the leading hardware candidates for quantum computing with solid-state devices. For example, superconducting quantum circuits need temperatures low enough to keep microwave thermal photon populations on the chip negligible. In addition, the amplifiers that are typically required to achieve high-fidelity dispersive readouts are also based on superconductors and operate at the lowest noise temperatures allowed by physical limits.

Enabling Quantum Technology

Since 2008, Bluefors, based in Helsinki, Finland, has aimed to support sub-Kelvin measurement applications by providing well-engineered reliable systems that are easy to use. To continue technical leadership, Bluefors pursues several important developments aimed specifically at improving functionality for quantum measurement applications. These include scaled-up wiring infrastructure, coaxial infrared (IR) filtering, and advanced diagnostics for measuring noise temperatures (see Figure 1). In immediate applications, high-density wiring addresses the problem of sending control and readout tones to the largest quantum processor units currently available. The lines are thermalized at each temperature stage using matched cryogenic microwave attenuators. Signals are conditioned using high density filter banks, realized by using cryogenically compatible materials that are installed at the base temperature stage. Bluefors also developed IR filters that are designed to protect superconducting qubits devices from photons with higher energy than typical superconductor pair breaking energies. The IR filter has low insertion loss in the spectral range where signals are sent to the qubit but utilizes a microwave absorber material to dissipate high frequencies. Diagnostic tools, such as the cryogenic variable temperature noise source, also offer new ways to measure the quality of readout lines by implementing Y-factor analysis in the cryogenic environment[1], [2].

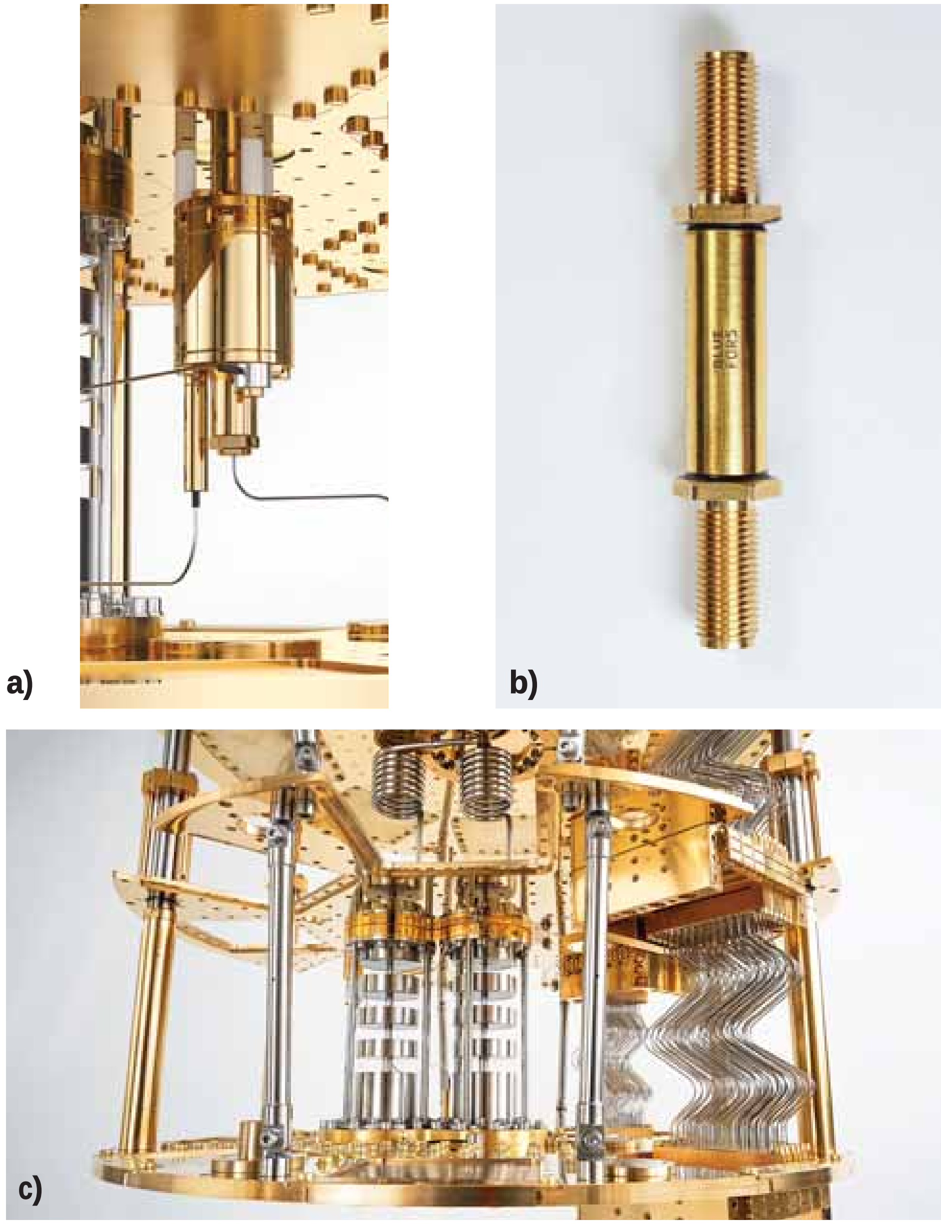

Figure 1: Recent developments enabling quantum technological applications at millikelvin temperatures, a) Cryogenic variable-temperature noise source, b) Bluefors IR filter, c) High-density wiring in an XLDsl dilution refrigerator measurement system. Credit: Bluefors

Application Examples

In spring 2021, Bluefors published two application notes to provide working examples of quantum measurements from within the manufacturing environment. The first application note (in collaboration with Keysight Technologies) was a concise guide to setting up and running a single-qubit characterization measurement including integration of the room temperature electronics with the cryogenic system. The measurement results demonstrated the signal input-output, hardware-software interface, and a qubit measurement system capable of reaching long qubit energy relaxation times of order 100 μs[3]. The second application note (in collaboration with Zurich Instruments) reported statistics spanning 100 hours of measurement time of the qubit energy-relaxation times: a crucial system parameter for qubit applications[4]. In addition, the measurements enabled a comparison between Bluefors measurement systems installed at Chalmers University (Gothenburg, Sweden) and in the Bluefors factory itself. Interlaboratory comparisons are often performed in the context of international metrology but have not been commonly applied to the field of solid-state qubits. Can the cryogenics industry demystify the factors that lead to high performance quantum devices through benchmarking data, measurement examples, and clear documentation? Building integrated quantum systems is a multidisciplinary pursuit that needs innovations in interconnects, room temperature and cryogenic electronics, and, of course, the cryogenic environment itself.

Outlook

Integrating the components required for a turnkey quantum measurement system is a major engineering effort that involves many partners around the world. Improving measurement setups and publishing the results promotes the utilization of cryogenics and will have a broad positive impact on quantum measurement science.

Customers and stakeholders benefit from reduced time to bring up new systems, and the cryogenics industry can benefit from improved knowledge of the application of dilution refrigerator systems. **www.bluefors.com**

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Cryocooler, EMI Filtering and Control Electronics Expertise Integrate in HyTI-2 Mission

by Dr. Carl Kirkconnell, Founder, West Coast Solutions

The West Coast Solutions (WCS) – Creare team was selected by the Hawaii Space Flight Laboratory to play a critical role in the development of the HyTI-2 payload as part of the upcoming Active Cooling for Multispectral Earth Sensors (ACMES) satellite mission. WCS and Creare provide the combined experience to meet the challenge of control electronics, EMI filtering, and cryocooler integration support. The ACMES mission is funded by the NASA InVEST program, which validates new technologies in space prior to use in future Earth science missions. The HyTI-2 payload will simultaneously validate two new technologies, each representing an important advance in satellite remote sensing capability for earth science.

WCS is a multidisciplinary team of experienced aerospace and defense professionals committed to solving technical problems concerning cryogenics, space electronics, and expeditionary power. Their extensive body of work includes many successful Department of Defense, space, civil research and commercial programs. The Huntington Beach, Calif.-based company is in its seventh year of operation, and recently expanded its facility to include the new WCS space hardware manufacturing lab, to be commissioned in February 2023 and used to support HyTI-2. Creare is an innovative technology and product development company of 170 people located in Hanover, N.H. For almost 60 years, Creare's engineers and staff have collaborated to solve problems and bring ideas from the drawing board to high-performance products for critical applications. Their efforts have resulted in new companies that dominate their market segment to solutions that have enabled the exploration of space and efficient manufacture of critical defense systems.

HyTi solar panel fit check. *Credit: West Coast Solutions*

The first technology is called Active Thermal Architecture (ATA), which will overcome the difficulty of maintaining a longer cryocooler duty cycle in the warm LEO orbit by using a miniature pumped fluid loop to remove waste heat via a radiator. The second new technology is the second generation Hyperspectral Thermal Imager (HyTI), which captures both high spectral and spatial longwave infrared images using a spatially modulated interferometric imaging technique. The three main areas where the HyTI imager will be useful are: studying the gases emitted during a volcanic eruption, supporting precision agriculture and better understanding evaporative transport mechanisms.

As with the original HyTI mission, WCS will serve as the lead for cryocooler systems engineering on the HyTI-2 team. In this role, they will provide critical subject matter expertise on all aspects of cryocooler integration, including exported vibration mitigation, thermal management, and electromagnetic interference mitigation. In addition, WCS will again work in partnership with Creare LLC to deliver the Creare Micro Cryocooler Control Electronics for Tactical Space (MCCE-TS) as well as the Creare/WCS Cryocooler Active Ripple Filter (CARF) electronics. The MCCE-TS product brings a lower cost and more compact controller to the space cryocooler market. The CARF electronics filter out EMI generated by the cryocooler that would otherwise impact the data signal.

"We chose West Coast Solutions again for HyTI-2 because of the amazing experience we had working with them on HyTI-1. As far as we know, WCS and Creare are the only companies that can provide this combination of control electronics, EMI filtering and cryocooler integration support. It is important to emphasize that we needed a combination of the cryocooler control system and the active ripple filter system because of the electrical sensitivity on the rest of the spacecraft bus. WCS and Creare have been great to work with, and we look forward to continuing this longstanding and successful collaboration," said Miguel Nunes, the deputy director of the Hawaii Space Flight Laboratory, as well as the co-investigator and systems engineer for the HyTI mission. **https://wecoso.com**

Launching a Groundbreaking Mobile Liquid Hydrogen System

by Melissa Perlman

GenH2, an industry leader in hydrogen infrastructure solutions, announced the launch of its groundbreaking LS20 mobile liquid hydrogen system, an end-to-end liquefaction and storage system. The innovative, mobile liquefaction unit offers a space-optimized, fully integrated liquid hydrogen solution to be used in a range of applications from transportation to energy backup, to accelerating the use of liquid hydrogen through pilot projects and testing. It will also be utilized as a lab setting for testing material, insulation, thermodynamic properties and use cases for its applications.

With a mission to provide light-scale infrastructure solutions for liquid hydrogen, $GenH_2$ designed the LS20 with the capability of producing small amounts of liquid hydrogen in order to provide access to more hydrogen researchers and hydrogen industry players. The LS20 can produce between two and 20 kg of liquid hydrogen per day, to provide liquid hydrogen at-the-ready when and where it is needed. Twenty kg of liquid hydrogen contains nearly 2,400 Megajoules of energy and can be readily stored and used within $GenH_2$'s ultralight utility tank systems.

"The development of the LS20 has been a culmination of decades of experience and engineering within and in conjunction with NASA," said Jong Baik, chief technology officer of $GenH_2$. "Providing researchers and developers of hydrogen infrastructure with a modular, efficient way of getting their hands on liquid hydrogen is a vital requirement to advance the hydrogen economy."

The smallest liquid hydrogen mobile unit currently commercially available, the LS20 is self-sustaining and can run independently with a portable generator or plug into a building's power source. This makes the LS20 ideal for dispensing fuel to multipurpose drones and providing an emergency power supply to first responders. Additionally, the LS20 units are manufacturing, ready to keep up with the increasing demand for hydrogen and enable

Chris Wallington, GenH2 vice president, with LS20 mobile unit. *Credit: GenH2*

faster infrastructure build-out and adoption. According to Baik, with its flexibility, compact size, and speed-to-market capabilities, the LS20 is a game-changer for a rapidly growing hydrogen industry.

The LS20 is designed for those areas where relatively compact systems are necessary to enable hydrogen viability. As a complete system, the LS20 can liquefy, store and dispense liquid hydrogen from any gaseous hydrogen source, such as a storage tank or an electrolyzer. This compact, flexible system offers the user the ability to provide liquid hydrogen when and where it is needed.

The key features of LS20 technology include: Convenient and safe liquid hydrogen production on demand between two and 20 kg per day; DOT-approved 400-liter capacity liquid hydrogen storage tank with zero boiloff storage feature; Fully automated liquid hydrogen pro- duction/storage level control and monitoring system; Zero loss, liquid-to-liquid transfer system with hydrogen gas recovery bag; Detachable liquid hydrogen storage tank for separate liquid hydrogen transport; Innovative quick-connect vacuum jacketed receptacles; Ultralight liquid hydrogen tanks for hydrogen mobilities such as cars, drones, UAVs, trucks, etc.; Hydrogen detection sensor, oxygen monitoring, infrared hydrogen flame detectors; and Multiple pressure relief devices and advanced emergency venting system.

The LS20 also serves as a foundation for higher capacity $GenH_2$ systems including the 100 Kg/LH_2-per day and 1,000 Kg/LH_2-per day solutions. Once deployed, these solutions will be an innovative addition to the options for advanced clean energy. The LS20 demonstrates $GenH_2$'s continuing support for the expansion of the hydrogen economy. The company is working closely with the Department of Energy, NASA, various universities and energy companies around the globe for a better tomorrow. To learn more, visit: **www.DiscoverHydrogen.com**.

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**.

Leiden Cryogenics

High-end custom-made dilution refrigerators with very low vibrations and high cooling power that meet customers' specific requirements: fully customizable with modular components and various wiring options.

MVE Biological Solutions

MVE Biological Solutions, a global leading manufacturer of vacuum-insulated products and cryogenic systems, offers a range of cryogenic freezers and aluminum dewars engineered for ultimate reliability and maximized hold times.

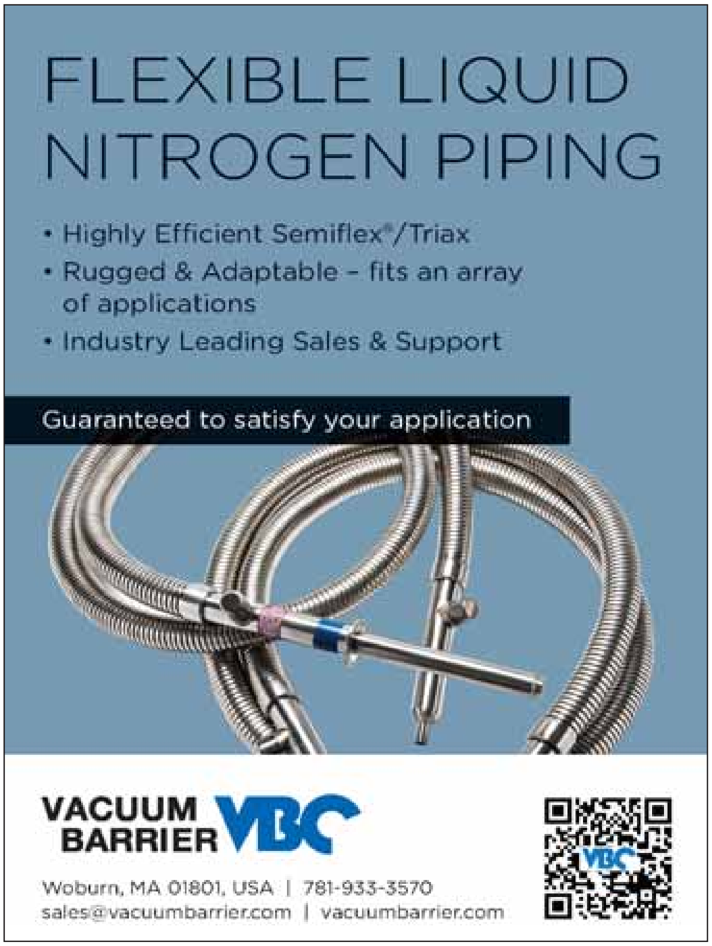
Onnes Technologies

A Dutch quantum technology startup that develops and builds cryogenic nanopositioning tools for physics research at milli-Kelvin temperatures. Onnes' technology offers the next step in cryo-positioning as alternative to the classic stick-slip technology.

ZeroAvia*

ZeroAvia is developing the world's first zero-emission liquid hydrogen electric powertrain for civil aviation. The company repowers certified fixed-wing airframes for retrofit and linefit, with its zero-emission powertrains.

***CSA CSM**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Customer Service with Expertise and a Smile Sets Vacuum Barrier Apart

by Lisa Angelli, Marketing Manager, Vacuum Barrier Corporation

For more than 60 years, Vacuum Barrier Corporation (VBC) has been an industry leader in LN_2 dosing and piping systems; designing, engineering and fabricating systems for the food and beverage industries, such as bottled water, beer, wine and coffee; for semiconductor growth and testing; for pharmaceutical and biotech; and in the cannabis industry. VBC prides itself on investigating its clients' unique applications and providing a custom solution, with a focus on being a one-stop source for complete, safe and defect-free LN_2 systems.

One of the keys to meeting their customers' needs is VBC's Field Service team. Made up of field service engineers (FSEs), the service team is responsible for providing technical support and troubleshooting assistance for both new and existing systems. While remote support is often sufficient, many new systems require on-site equipment, start-up support and detailed operator training. Traveling to customer sites on a weekly basis, the FSEs become the face of the company.

Technically minded and able to work independently and under pressure, a good field service engineer must also be personable. "We may be the only face-to-face experience a customer has with Vacuum Barrier," says Field Service Engineer Austin Henderson. "It is imperative that we develop trust quickly and build a strong relationship with customers."

"Liquid nitrogen systems are a niche subject and can differ significantly compared to traditional systems and equipment," adds Field Service Engineer Tyler Jordan. "It is essential that new customers learn these systems quickly and have a complete understanding. That task falls to us."

When a customer purchases and installs a new system, the FSEs are there to ensure a smooth start-up process. "While we're often not present to install the equipment, we are there for the final inspection and to verify that everything is installed correctly," explains VBC Field Service Engineer Robert Long, who is joined on the team by Aaron Moore. "All VBC field service engineers include customer training as one of their top responsibilities," says Moore. Maintenance procedures and troubleshooting steps are reviewed to reduce minor issues, and routine visits can be scheduled to inspect and perform maintenance, further minimizing any potential for downtime.

From left to right: Vacuum Barrier Corporation Field Service Engineers Joseph Downey, Tyler Jordan, Austin Henderson, Robert Long, and Aaron Moore. *Credit: VBC*

Minimizing downtime is a goal of any production facility, and is a top priority for VBC. When there are issues with installed equipment that cannot be easily addressed over the phone, field service engineers are ready to travel. "We are the experts in the field on our systems, and are prepared for any issue that may arise. We are able to address any questions or concerns," says VBC Field Service Engineer Joseph Downey. "There is no time to 'guess.' The problem must be identified and resolved quickly."

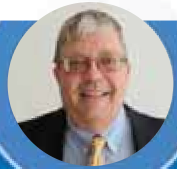
A common assumption is that field service engineers just repair equipment, but there's far more to the role. They are the key to maintaining Vacuum Barrier's high level of customer service.

VBC vacuum jacketed piping systems are available in both dynamic vacuum, which requires a vacuum pump, as well as sealed vacuum. This vacuum insulation is highly efficient and limits liquid nitrogen boiloff. Complete system design takes into account all factors of a customer's application.

Among pharmaceutical and biotech applications, VBC's SEMIFLEX®/Triax piping system delivers low pressure LN_2, critical for the cryogenic preservation of blood, reproductive cells, vaccines and other biological tissues and materials in storage freezers. Additionally, VBC offers specialized solutions for molecular beam epitaxy (MBE), an epitaxy method for thin film deposition of single molecular layer. A combination of modulating inlet phase separators and Triax piping ensures that subcooled, single-phase LN_2 circulates through a shroud.

A significant number of VBC applications utilize NITRODOSE® LN_2 injection systems to either pressurize cans and bottles for products that are not carbonated or to reduce oxygen in the container. Pressurizing the container ensures that the product can be stored, palletized and shipped due to its increased structural integrity. Oxygen inerting promotes longer shelf life and freshness, typically for snack foods, cooking oils and in the growing cannabis industry. The beer and coffee industries may use LN_2 dosing to create nitrogenated products which, when poured properly, create a foamy head and smooth mouthfeel.

For more information about Vacuum Barrier Corporation's customer service and field service engineers, or to better understand the VBC family of products, visit **www.vacuumbarrier.com**.



Cryo Bios

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

Vasilli Petrovich Peshkov

In my previous column (Vol 38, No. 5), I mentioned that William Fairbank made one of the first detections of second sound in He II. The *first* recorded detection of second sound was made by Vasilli Peshkov in Moscow a number of years earlier. Peshkov had a long and productive career making important advances in He II, ^{3}He and other cryogenic topics.

Vasilli Petrovich Peshkov was born in Blagoveshchensk, Russia, in 1913. He attended high school there and briefly worked as an electrician before entering Moscow State University in 1934, where he studied physics. Upon graduation in 1940, he moved to the Institute for Physical Problems (IPP) in Moscow for graduate studies under Professor Peter Kapitza (*Cold Facts*, Vol. 34, No. 5). There, Peshkov found himself in one of the most productive cryogenics research groups of the time, a group with a particular specialization in He II. Kapitza was, in fact, one of the co-discoverers (along with Jack Allen of Cambridge – Vol. 36, No. 4) of superfluidity in He II.

Peshkov conducted his Ph.D. research on He II, and it was during this work that he developed a technique using temperature measurements to detect second sound. This work was reported in 1946 but had been done earlier; the reporting delays were a result of World War II. In addition to earning his doctorate, the detection of second sound resulted in Peshkov being awarded the USSR State Prize. Having received his doctorate, Peshkov stayed at IPP for the rest of his career, finishing as a deputy director of the institute.

The research carried out by Peshkov and his team at IPP covered a wide range of topics in helium cryogenics, including magnetic refrigeration, dilution refrigeration, quantum turbulence, propagation of second sound, properties of ^{3}He and of ^{4}He–^{3}He mixtures. Peshkov was able to develop a two-stage magnetic refrigerator which reached a temperature of 3 mk – a first in the USSR. Peshkov continued to be interested in developing practical techniques for working at subKelvin temperatures, including precision thermometry and cryostat design. He developed a transducer for reliably producing second sound in experiments. His research work resulted in him being awarded a second USSR State Prize in 1953.

A good example of his work can be found in "Second Sound in Helium II", V.P. Peshkov, *Soviet Physics JETP*, Vol. 11, No. 3 (1960). In this publication, Peshkov describes precision measurements of the velocity and attenuation of second sound in He II down to 0.38 K. In addition, Peshkov also taught extensively during his career and at institutions including Moscow State University and Mendeleev Moscow Chemical Technology Institute where he chaired the Physics Department. Interested in international collaboration and scientific publication, Peshkov served on the Editorial Board of the *Journal of Low Temperature Physics* from its founding until his death in 1980.

Cool Cryo Guests

by Nils Tellier, PE, EPSIM Corporation

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 3: Front End Purification

This series of articles aims to provide tips for cryogenic air separation units (ASUs), particularly in considering energy costs.

Front End Purification

Pressurized process air from the compressor must be cleaned of moisture, CO_2 and as many trace hydrocarbons as possible before entering the cold box. This is accomplished by front-end purification adsorbers or, to a large extent, by reversing heat exchangers (REVEX). This article will focus on the former.

Adsorbers

Adsorbers consist of two or more pressure vessels, a reactivation heater and a switching valve skid. Compressed air enters one vessel, typically from the bottom, although other configurations exist, such as radial beds. Moisture from the air is completely adsorbed onto a bed of activated alumina (Al2O3) before the air enters a bed of molecular sieve – typically 13X – to remove CO_2 completely. While one vessel is in service cleaning the compressed air, the other vessel is being reactivated. The vessels switch every four to eight hours, depending on their design.

It is paramount that moisture is entirely adsorbed in the alumina. Molecular sieve also adsorbs moisture but cannot desorb it under normal reactivation temperature. Any moisture retained in the molecular sieve reduces the capacity to adsorb CO_2, leading to a breakthrough. The first indications of CO_2 breakthrough are vibrations in the turbo expander, higher pressure drop in the main exchangers and possibly a dangerous concentration level around the main condenser in the low pressure column, which gives nesting opportunities to hydrocarbons such as acetylene.

Figure 1: Adsorber vessels and valve skid. *Credit: Nils Tellier*

Adsorbers operate on the principle of pressure swing. However, given the large vessels and adsorbent interface areas, it takes little pressure to damage the beds during a switch between service and reactivation. Once an interface screen starts lifting due to an excessive pressure differential event, the adsorbent beads will gradually dislodge the screen until the vessel is made inoperable. For this reason, pressure differential interlocks set around 5 psi (0.35 Bar) should always be calibrated and operational. Bypassing a pressure interlock to switch beds prematurely will most likely result in shutting down the entire plant to repair the adsorber in a matter of weeks.

The proper operation of adsorbers is witnessed with the reactivation temperature profile. There should be two concave inflections in the vent's temperature curve: one when the moisture is completely removed and the second when CO_2 is fully desorbed. Excess heat beyond the second inflection provides reassurance of complete reactivation. That excess heat must be kept to a minimum to limit energy consumption and maximize the cooling step. Excess heat is controlled by the timing of the heating step, not by the temperature, which must reach a minimum threshold to desorb the molecular sieve.

A special reactivation should be considered each time the ASU is derimed, such as every 16,000 hours, to remove any moisture from the molecular sieve. Switching valves, flange gaskets, and pressure relief valves should be checked for external or internal leaks whenever the adsorbers exhibit dissymmetry in the pressure and temperature cycles.

The adsorbent should be tested and replaced every 64,000 to 80,000 hours as the beads break into dust over time. Caution must be exercised when replacing adsorbent; the vessels must be considered confined spaces because molecular sieve also adsorbs oxygen, presenting a deadly risk of asphyxiation.

Figure 2: Lifted adsorber bed. *Credit: Nils Tellier*

To Chill or Not to Chill

Chilling the compressed air reduces the moisture load before it enters the adsorbers. Moist air can only be cooled to approximately 40 ºF (4.5 ºC) before calcium carbonate (CaCO3) precipitates and acts like an ice plug. Methods for chilling the compressed air are typically accomplished by circulating chilled water in the air compressor after-cooler, or by direct contact in a packed tower. The water chilling can be done with a refrigeration unit or by evaporation in a second direct contact tower against waste nitrogen from the ASU. Air chilling can be an alternative to upgrading the adsorber beds if the surplus mole sieve capacity is sufficient.

Controls and Instrumentation

A malfunction of the front-end purification will likely result in shutting down the entire ASU. (Such a plant trip should unload but not shut down the air compressor.) For this reason, controls and instrumentation must be adaptable, reliable and simple to operate and maintain. As mentioned earlier, pressure and differential interlocks across the main valves are of paramount importance. Reliable temperature measurement is also critical. 3-wire RTDs with proper PLC input modules are preferable to thermocouples or temperature transducers; the latter two have shown reliability problems in the author's experience. Limit switches on valves, providing interlock protection, prevent the adsorbers from "running on good faith" and, thus, protect the whole plant from possible catastrophic damage if a main valve malfunctions. At the outlet of the front-end purification, a CO_2 analyzer and a dust filter with pressure differential measurement will protect the cold box. CO_2 will break through long before moisture reaches the cold box. Adsorbent beads will gradually turn to dust, which can be very difficult to remove from the cryogenic equipment.

Conclusion

Front-end air purification provides a reliable and efficient means to fully remove moisture and CO_2 for air separation plants. It benefits from ongoing technological progress in other industries such as pharmaceutical and automation. Owners of older plants should consider replacing the activated alumina and molecular sieve, as the performance of adsorbents improves significantly over each decade. Opportunities to reduce energy consumption include extending the cycle times, reducing the heating time (but not the temperature), reducing the pressure drop across the adsorbers and minimizing air chilling.

The next articles in the series will look at the ASU cold box.

Figure 3: Adsorbers and direct contact air chiller tower in the background. *Credit: Nils Tellier*

Cool Fuel

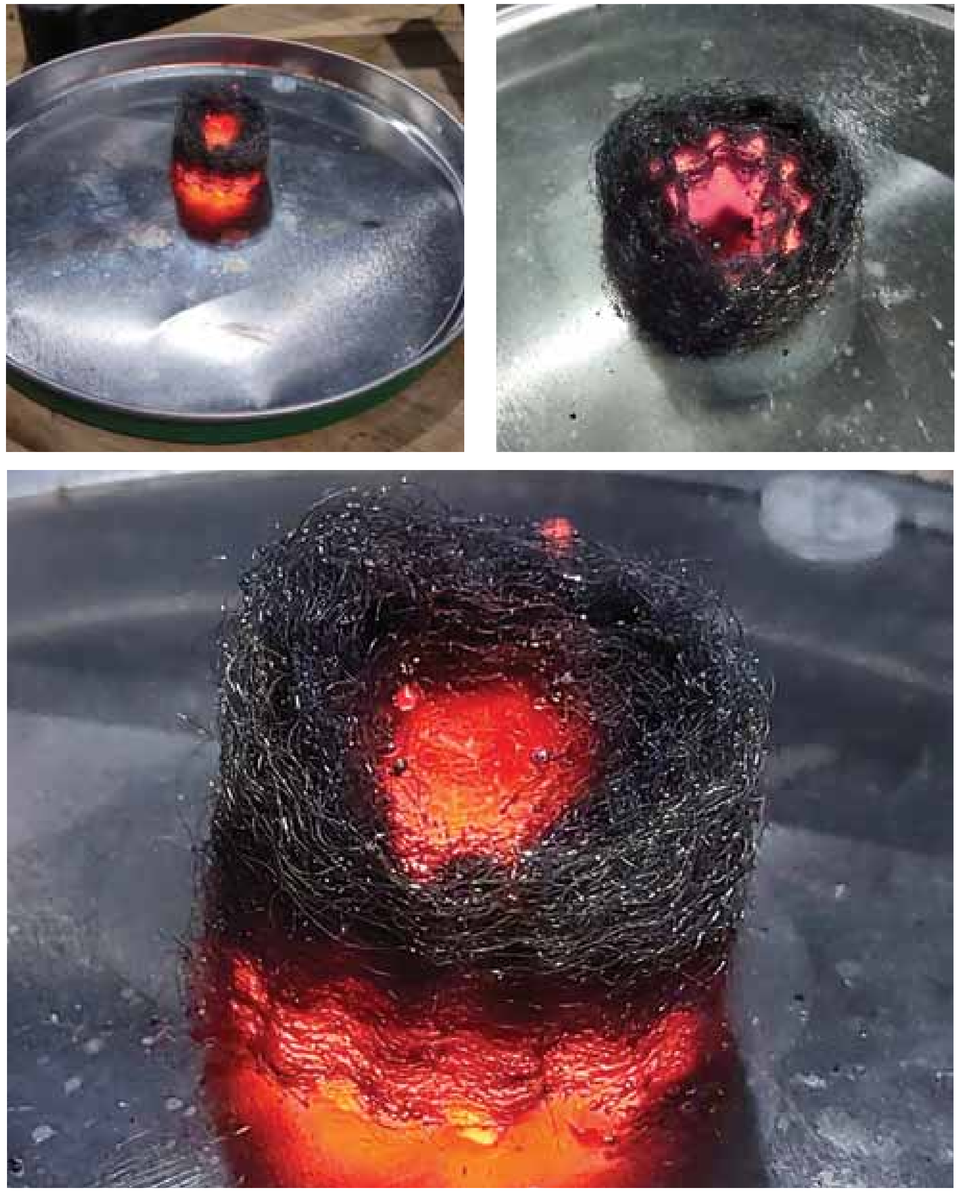
by Dr. Jacob Leachman, Associate Professor, Washington State University, jacob.leachman@wsu.edu

The Class I Needed

Flash back for a moment to that time in college when the professor had a typo on the assignment that caused you to lose a night in frustration. Anger, fatigue and disrespect come to mind as you storm to class the next day, hand in the assignment and point out the mistake, now corrected. The professor, unmoved by the display, proceeds to pull up the original research publication on which the assignment was based, where the same error appears – an error, sans erratum, that propagated like a virus through the field. Reality sets in that the lesson we thought we were being taught was not the most important lesson we needed after all. Moreover, we left with a working and corrected code to stop the chain. Confidence and a realization of ability, no, obligation to contribute come to mind.

Earlier this month I realized a dream I've had for nearly two decades: a graduate level course on cryogenic hydrogen. Why such a niche topic? The amount of money moving into liquid hydrogen is bringing people, with or without training, into this industry. North America has safely distributed 80-90% of small merchant hydrogen via liquid tanker truck for over 60 years, and I want the streak to continue indefinitely. However, the amount of merchant hydrogen we need to distribute must increase approximately three orders of magnitude to meet the International Energy Agency's 2050 clean hydrogen goals. Innovation will be all but essential for scaling to these needs, and the original pioneers of cryogenic hydrogen who really understood these systems are nearly all gone. We don't have time to piecemeal together the courses on hydrogen technologies, thermodynamics, thermophysical properties, heat transfer, and cryogenics that I had to. Moreover, there are many lessons (and errors) I've had to learn the hard way that need not be repeated.

A new textbook is in development to accompany the course "Cool Fuel: The Science and Engineering of Cryogenic Hydrogen." I partnered with my colleagues, Professor Konstantin Matveev and Professor Øivind Wilhelmsen, to draft the text over the last year. Konstantin is also from Washington State University and adds considerable experience with reduced order modeling and computational fluid dynamics in the areas of thermoacoustics and fluid-surface phenomena. Øivind is from the Norwegian University of Science and Technology (NTNU) where he developed complementary cryogenic property models as well as many optimizations of large-scale liquefaction systems and components. Between the three of us, we've drafted a compelling set of chapters:



Liquid air droplets are used to burn a hole through stainless steel wool during a workshop.
Credit: Washington State University

1. Historical and future trends in liquid hydrogen technologies
2. Thermophysical properties of hydrogen
3. Ortho-parahydrogen conversion
4. Liquefaction via recuperative and regenerative cycles
5. Heat exchanger design
6. Transfer analysis
7. Storage
8. Safety

Lectures will follow the text contents with the class concluding at the end of April. I am working with WSU's Global Campus to offer the course asynchronously to industry professionals. We are not aware of a single course or textbook that covers this breadth of topics that are necessary for designing most cryogenic hydrogen systems.

No education in cryogenics would be complete without hands-on safety training. The best feeling of confidence results from successfully applying what you've learned from the classroom in the laboratory. The HYPER laboratory is developing a series of ten hands-on cryogenic safety workshops we plan to offer to the public through our service center. Topics include basic cryogen safety; safety plan development; practical skills like leak detection of fittings and valves; and the workshop culminates in liquid hydrogen transfers. The series will be offered during our safety week that initiates every term. The goal of the workshops is for participants to maintain the superior safety record of the industry while reducing the anxiety associated with developing and implementing new cryogenic hydrogen systems.

If you are interested in taking the course or have specific topics you'd like to see incorporated in the book or workshops, please reach out: jacob.leachman@wsu.edu. I'll include you in notifications as content becomes available. With your engagement, this class, text and workshop series could become the cryogenic hydrogen experience we all needed and thankfully got.

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SPOTLIGHT ON A NEW CORPORATE SUSTAINING MEMBER (CSA CSM) : Aerospace Fabrication & Materials, LLC

New Building Expansion at Aerospace Fab

by Brent Anderson, Owner, Aerospace Fabrication and Materials, LLC

In late fall 2022, key members of the Farmington, Minn. community joined with owners and employees of Aerospace Fabrication & Materials, LLC at a groundbreaking ceremony to kick off the building of their facility's addition. This development will enable the company to continue to expand diverse product offerings in aerospace and cryogenic insulation applications and beyond.

Community members and representatives from Aerospace Fabrication & Materials, LLC break ground on the expansion of their Farmington, Minn. facility. *Credit: Aerospace Fabrication & Materials, LLC*

The Project

The new construction project is in the Farmington Industrial Park and will increase the facility size from 20,000 square feet to 33,500 square feet, allowing for more specialized production and providing space for new processing systems. In addition, it will expand stockroom space, provide a shop location and allow for extra clean room facilities. "We are excited to witness the rapid growth of the aerospace and cryogenic industries," said Rod Guenther, managing partner and general manager. "This additional manufacturing space will allow us to meet the needs of our current customers as well as more effectively pursue new markets."

Brent Anderson, business development manager, added, "We look forward to expanding our capabilities to provide high-quality passive thermal control products from MLI (multilayer insulation) blankets to highly effective superinsulation for our planet and the space environment. With the addition of key pieces of equipment, we anticipate our core capabilities to be second to none in the industry, allowing us to deliver outstanding products and services."

Aerospace Fabrication is eager for construction to move rapidly and anticipates the project to be wrapped up by spring 2023. Aerospace Fabrication & Materials, LLC is an ISO- and AS-registered manufacturer that specializes in the design, manufacture and installation of multilayer insulation blankets (MLI) and associated passive thermal control products. Since its establishment in 1999, the company has provided MLI blankets for a variety of aerospace and cryogenic environments, including big science missions, optical telescopes, cryogenic storage tanks, and the International Space Station. **www.aerospacefab.com**

Space Cryogenics

by Ben Nugent, Aerospace Engineer, NASA Glenn Research Center

Cryogenic Coupler Developments for In-Space Transfer

NASA's plans for future missions establish a desire to produce hardware that is both sustainable and reusable. With an importance being placed on refueling operations, and several different companies producing hardware, a key factor moving forward will be having standards that allow future hardware to interact seamlessly. As a ground example of this, imagine you are going to refuel your car. Instead of trying to find a specific gas station that is compatible with your model of vehicle, you are able to pull into any station and fill up.

In order to achieve sustainable space operations, a Universal Standard for Automated Couplers (USA Couplers) for a reusable, bidirectional coupler for in-space and on-ground cryogenic propellant transfer is required. The eventual goal is a standardized design that could work for both in-space mating and near T-0 conditions that will eliminate compatibility issues for future missions, including refueling opportunities between spacecraft designed by different contractors in different countries.

In the past 10 years, NASA's Space Technology Mission Directorate has funded the design and development of eight different cryogenic couplers. Included among these are Low Separation Force Quick Disconnects being developed at Kennedy Space Center (see Figure 1), Dust-Tolerant Magnetic Couplers being developed at Armstrong Flight Research Center, and a robotically operated Cryogen Coupler Adapter from Goddard Space Flight Center that flew as part of Robotic Refueling Mission 3 (RRM3). (No cryogenics were tested during the mission.)

Additionally, several of NASA's industry partners – such as Altius Space Machines (their Fluid Transfer Coupling developed through Small Business Research Innovation funding[2]) and SpaceX (their fluid couplers

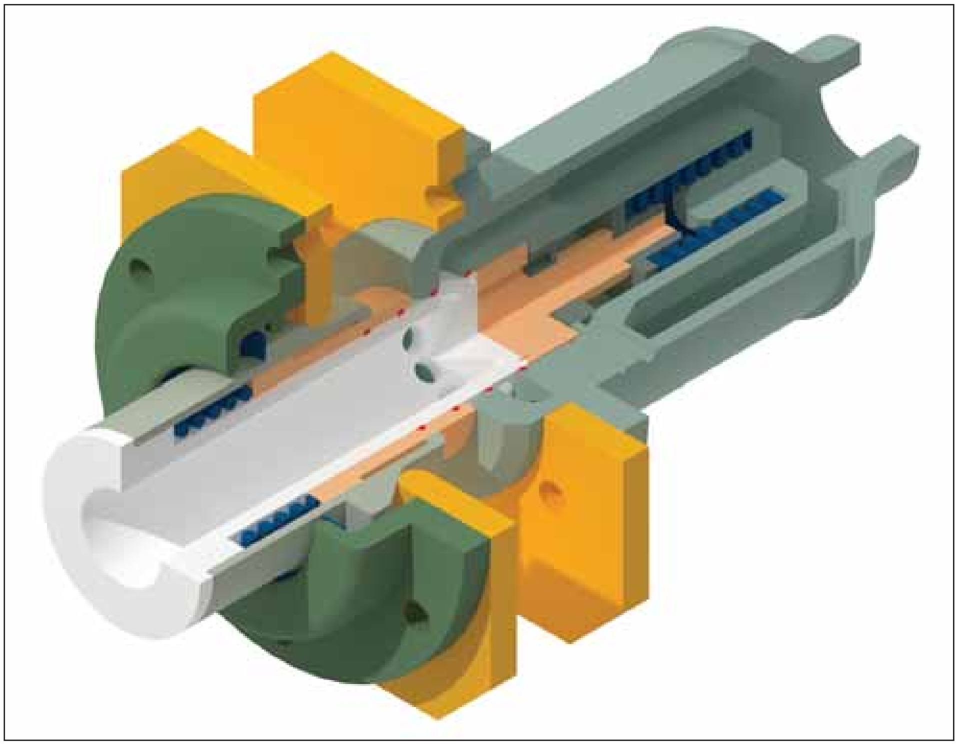

Figure 1. Low Separation Force Quick Disconnect, which reroutes fluid to flow into a connected line perpendicular to the flow path, so that disconnect pressure is independent of line pressure. *Credit: NASA*

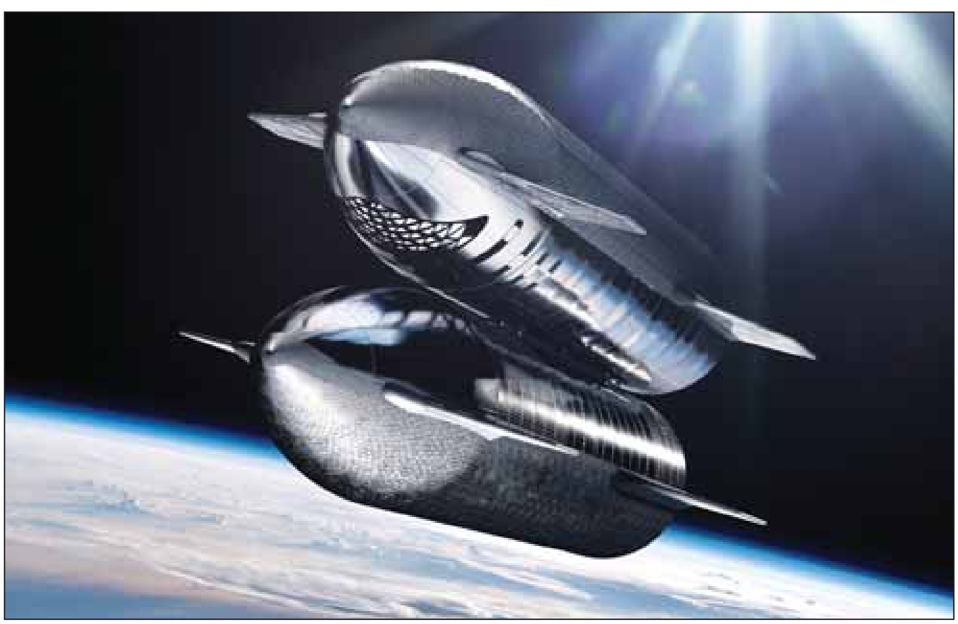

Figure 2. Starship orbital refueling method. *Credit: SpaceX Twitter [6]*

developed as part of NASA's Tipping Point activities[1]) (see Figure 2) – are developing couplers through NASA's Human Landing System study and prototype phase.[5] Each design provides unique solutions to difficult problems, and each design is different and incompatible with the others. None of the current designs have progressed past ground testing with liquid nitrogen, resulting in a Technology Readiness Level (TRL) of 4 to 5 (see Figure 3).

The key performance parameters for a standardized coupler would need to include minimizing hydraulic losses, heat loads into the coupler, and external and internal leakage. The coupler would also need to include an automated self-mating and alignment mechanism and would require a low mating/de-mating force. Other architectural trades that need to be performed include the determination of interface seal type between radial and face (and possibly other), distance to shutoff valves, and whether the coupler is plate mounted with other fluids, mechanical, and electrical connections as a part of a bigger interface versus freestanding (each connector having its own mechanisms to ensure successful connection).

NASA is currently funding multiple tipping points to address cryocoupler development as well. These have progressed to testing phases: one where SpaceX completed testing with liquid nitrogen on their coupling device as a part of the Tipping Point award[1], and another scheduled for a flight demonstration in the mid-2020s using liquid hydrogen.

Future mission integration opportunities for cryogenic fluid transfer include: The Human Landing System where SpaceX was recently awarded a second human landing demonstration[3], various industrial uses of cryogens in earth orbit, as well as future Mars transportation systems.[4]

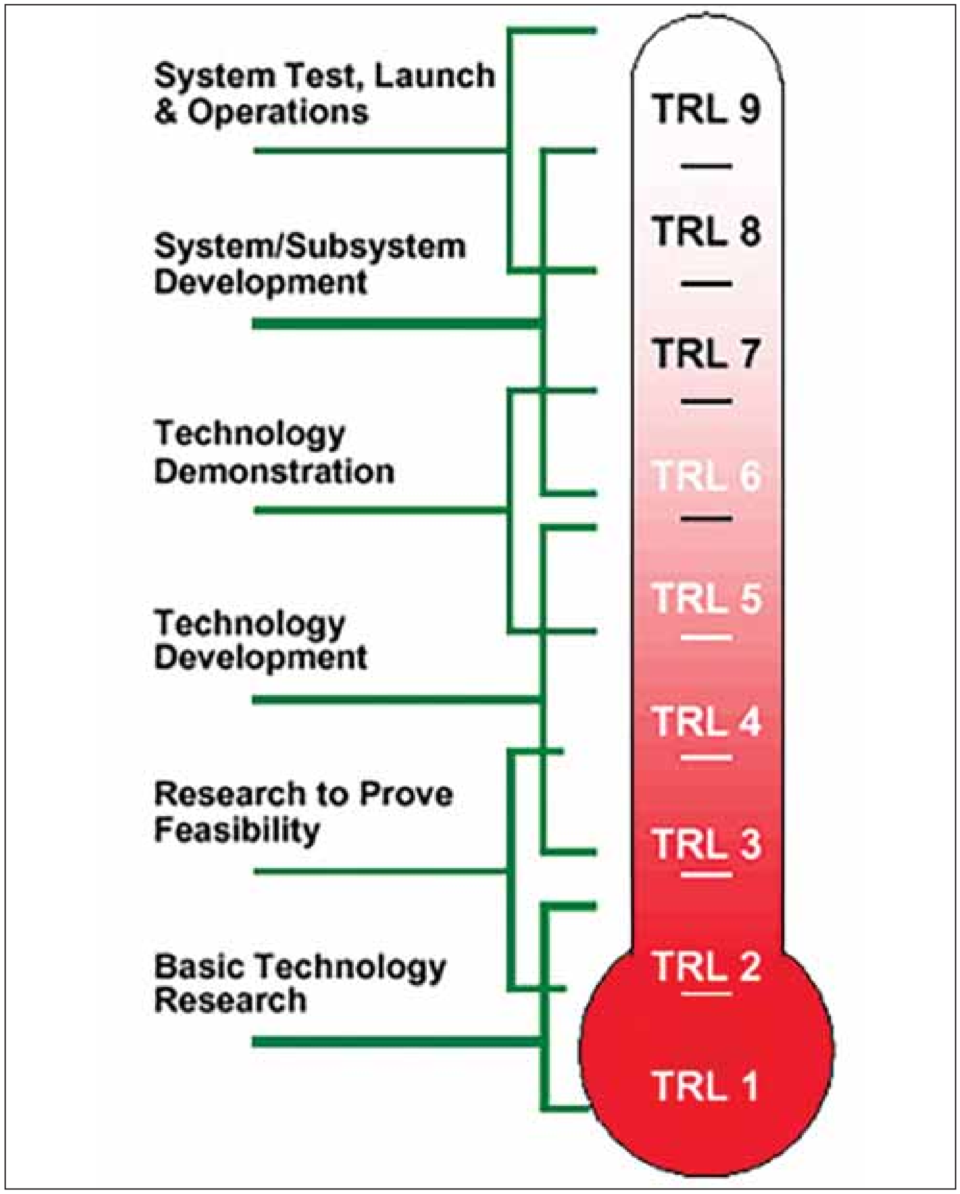

Figure 3. NASA Technology Readiness Level (TRL) Chart. *Credit: NASA*

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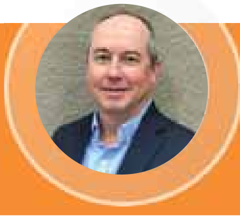

by James E. Fesmire, President, Energy Evolution LLC, james@321energy.us

Liquid Hydrogen On Board

Clockwise from top left: Demonstrations of LH_2 on board: truck with hydrogen combustion engine by Cummins[3]; ZeroAvia completes first flight of world's largest hydrogen-electric plane (Gloucestershire UK)[6]; Toyota race car with hydrogen-electric power plant[8]; and the world's largest zero-emission vehicle: a 2 MW hydrogen-electric powerplant by First Mode in this Anglo American haul truck at a platinum mine in South Africa.[9].

In the past two years we've seen, from the North American perspective, a rapid shift to news about liquid hydrogen onboard applications. This shift has happened by two parts in quick succession. The first was the shift from the host of "alternative energies" (including hydrogen gas as one of many) to the focus on gaseous hydrogen (namely, 350 bar and 700 bar) as the core of the clean energy future and a true energy carrier (bidirectional player between electricity and molecule). The second was the shift from gaseous hydrogen to liquid hydrogen (LH_2) for uses in both the industrial energy storage and onboard transportation vehicles for land, sea and air. For vehicles, the energy carrier LH_2 is being used onboard for both fully electric machines and for combustion engines.

Hydrogen storage can be combined with conventional batteries for a truly hybrid electric vehicle such as the GenH2 long-haul truck by Daimler Benz.[1] This approach can also solve the boiloff problem, as any excess boiloff vapors can be used to power a hydrogen electric cell ("fuel cell") and charge a battery bank installed on the vehicle or on the ground/facility side. Honda is introducing a new CRV model in 2024 which includes hydrogen electric for the primary power but also batteries to mitigate gaps in the hydrogen infrastructure, still in the infancy stage.[2] In another way, hydrogen storage for combustion engines can be augmented with electric batteries to make heavy-duty vehicles with the necessary power, range, duty cycle and filling profiles to meet any range of specific requirements. Cummins, for example, is developing a hydrogen combustion engine for medium-duty and heavy-duty trucks.[3] The heavy-duty truck, equipped with the new X15H engine, will require LH_2 tanks onboard to reach its objectives. We see from the demonstrations and prototypes that LH_2 onboard is already working its way into the mainstream.

Developers at H3 Dynamics are substituting electric batteries for hydrogen in long-range drones. Hydrogen electric cells provide a greatly extended range and overall lighter weight. The next step is to use an LH_2 tank to give the 25 kg unmanned drone a range of 900 km.[4]

Universal Hydrogen is preparing its converted De Havilland Dash 8-300 turboprop plane for initial flight tests this year in Moses Lake, Wash. The electric aircraft, running on hydrogen, will be equipped with modular LH_2 tanks designed to be routinely removed, refilled and replaced for flight.[5]

On January 19, 2023, ZeroAvia completed a 10-minute flight of the world's largest hydrogen-electric airplane at Cotswold Airport in Gloucestershire, UK. With a fully electric architecture, the 19-seat Dornier 228 twin-engine aircraft also incorporates the use of lithium-ion battery packs to provide peak power support during takeoff. The

600-kW powertrain will eventually rely on its hydrogen gas supply from onboard, wing-mounted LH_2 tanks.[6]

Toyota has revealed ambitions to switch to liquid hydrogen for its developmental Corolla racer after securing another finish with the car in its second outing in the Fuji 24 Hours race. This combustion engine began trial runs with LH_2 onboard in October 2022 and is planned for racing action in 2023.[7]

Meanwhile, Toyota is also working on a hydrogen-powered Corolla Cross automobile. Like the race car, the crossover is powered by a turbocharged three-cylinder engine and is equipped with two compressed gas hydrogen tanks, sited under the floor. In an attempt to improve the travel range of the Corolla, the team is hard at work attempting to install onboard LH_2 tanks.[8]

Decarbonization activity abounds in the area of heavy machinery and haul trucks for the mining industry. A fully electric, zero-emission mining truck supplied by solar-produced green hydrogen was commissioned in South Africa by Anglo American in 2022. Recently announced was First Mode's $1.5-billion merger with Anglo American's nuGen.[9] First Mode will retrofit and decarbonize roughly 400 Anglo American haul trucks over the next 15 years.

Hydrogen as the energy carrier, and onboard LH_2 tanks as the energy storage battery, make possible a clean energy future for the world in ways that just work better than burning fossil fuels. An indicator in the US is the Department of Energy's Funding Opportunity announcement DE-FOA-0002920 for work centered around heavy-duty trucks.[10] LH_2 onboard tanks and LH_2 transfer systems are among the four areas listed. There are many opportunities ahead for engineered systems development and R&D needed to put liquid hydrogen to work for billions of end users.

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YOUNG PROFESSIONALS 2023

The Next Generation in Cryogenics and Superconductivity

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

Chloe Gunderson, 28

What is your educational and professional background? I graduated from the University of Wisconsin-Madison with a bachelor's degree in mechanical engineering (ME) and a Certificate in Business in 2018. I then received a NASA Space Technology Research Fellowship (NSTRF), which allowed me to stay at the university as a graduate student and gain professional experience at various NASA centers during yearly Visiting Technologist Experiences. I earned my master's degree in ME in 2020 and will complete my doctorate in ME with a doctoral minor in physics this semester. Both my master's and doctorate have been focused primarily on the development of the Active Magnetic Regenerative Refrigeration system (AMRR), a novel sub-Kelvin cooling system for space science detectors.

How did you get into cryogenics? As an undergrad, I was approached by one of my professors, Franklin Miller, about a possible research position in his cryogenics research lab. I had no prior experience with cryogenics but became interested after learning more about his research projects – particularly his work with Pulsating Heat Pipes (PHPs) and the Superfluid Magnetic Pump (SMP). The opportunity to work on challenging research involving the combination of superfluid, superconductive and paramagnetic elements excited me. Because of this, I decided to work as an undergrad researcher with Professor Miller my senior year and remain a graduate student to further develop the AMRR.

What is your present company/position? I am currently working as a research assistant at the University of Wisconsin while I wrap up my doctorate research. I'm in the final stages of data collection for characterization of the AMRR system and expect to defend my dissertation in March 2023.

What has your experience been with industry mentors? I've been incredibly fortunate to be surrounded by many great mentors during my time as a graduate student, and I attribute much of my personal growth and scientific contribution to these advisors. Professor Miller has played a particularly significant role in my development as the one who introduced me to cryogenics, encouraged me to apply for NASA internships and fellowships, and taught me both practical lab skills and how to think like a cryogenic scientist.

What awards/honors have you received? In my senior year as an undergraduate, Professor Miller encouraged me to apply for the NSTRF, which provided two years of funding for the development of the AMRR system and supported me as I pursued my master's degree. Following my master's degree, I applied for the NASA Space Technology Graduate Research Opportunity, which provided an additional two years of support and funding while I pursued my doctorate. In the first year of my doctorate program, I presented my work on the design and construction of the AMRR system at the International Cryocooler Conference. This publication was chosen for the Best Student Paper Award. (A condensed version of this paper is published in this *Cold Facts* issue.)

What are some of your contributions to the cryogenic field? As a graduate student and NASA fellow, I have had the opportunity to work on a variety of sub-Kelvin technologies, with the common goal of improving the efficiency and reliability of cooling systems for astrophysics missions. One of these projects involved the development of an improved thermodynamic model of CCA, a paramagnetic material commonly used in the lowest temperature stages of the Continuous Adiabatic Demagnetization Refrigerator (CADR). Our findings may help better inform material selection and design of these low temperature stages to meet detector requirements. Similarly, my work developing the novel AMRR system also represents an important advancement in the sub-Kelvin space. This system is unique in that it can provide distributed and scalable sub-Kelvin cooling via the displacement of a 3He-4He mixture using the non-moving SMP.

What do you believe the most important developments in cryogenics are? Improving efficiency and reliability of the systems that provide cooling at ultralow temperatures is a primary objective for astrophysics detectors and quantum systems. For space applications, some of the most significant considerations are low mass, low vibration and scalability. The AMRR system I have been working to develop addresses these concerns as it has no moving parts and is, therefore, non-vibrating. The circulatory nature of the system also removes the need for heavier thermal links and shielding, resulting in a scalable low-mass cooling solution. Though the bulk of my research has been supporting space science applications, many of the developments could be applied to meet the cooling requirements for quantum systems as well.

What advances do you hope to see in the future? How long do you think it will take to achieve these advances? I'm particularly excited about advancements in space-flight coolers. Current work to develop CADRs that span greater temperature ranges and PHPs that span large physical distances with very low mass have promising results. I think we could see these fly in space within 10–15 years.

Where can readers find out more about your projects? For more information about my research and links to previous publications, check out my LinkedIn. I try to keep it updated with my latest work.

Theodore Golfinopoulos, 39

What is your educational and professional background? I hold a doctorate and a master's degree in electrical engineering from the Massachusetts Institute of Technology, and two bachelor's degrees: electrical and mechanical engineering, both from Rensselaer Polytechnic Institute. My doctorate was carried out at MIT's Plasma Science and Fusion Center, where I stayed for a postdoctoral position before joining the staff as a research scientist. I also worked briefly with MIT's Kavli Institute on the Transiting Exoplanet Survey Satellite. In my spare time, I participate with the Middle East Entrepreneurs of Tomorrow (meet.org), a dialog and enrichment program for excelling Palestinian and Israeli high school students.

What is your present company/position? I am a research scientist at MIT's Plasma Science and Fusion Center.

How did you get into cryogenics? My experience with cryogenics stems from my involvement in the development of high field superconducting magnets for use in fusion energy applications. In the earlier days of our project, the SPARC tokamak, the team was fairly small, and many of us found ourselves thrust into new topical areas – so it was with me.

What has your experience been with industry mentors? In the field of cryogenics, my primary mentor has been Philip Michael. Phil has an unassuming and humble manner, yet in almost any conversation about superconducting magnets, his advice is the first sought, as he has likely already done it, and if he hasn't, he has the proper literature at hand, joined with insightful and measured questions. He has amassed an extensive amount of practical and conceptual knowledge and is generous in sharing it, especially with students and early career scientists. I have been extremely fortunate to work alongside him.

I have also learned a great deal from Ernie Ihloff and Alex Zhukovsky, who both possess a wealth of experience and the treasure of good character; Brian LaBombard, one of my doctoral thesis supervisors, with whom I continue to work daily; and Rui Vieira, an old hand in magnets.

What awards/honors have you received? I have twice received MIT's Infinite Mile Award.

What are some of your contributions to the cryogenic field? In September 2021, the largest-ever high temperature superconducting magnet – the SPARC Toroidal Field Model Coil, or TFMC – reached the enormous peak field of 20 teslas, with stored energy of over 100 megajoules. This feat – the culmination of two years of frenetic effort – was accomplished by the combined contributions of many people across multiple institutions, particularly MIT, Commonwealth Fusion Systems (CFS), and numerous collaborators in industry and academia. It represents a critical milestone on the path to SPARC, a high field tokamak that aims to be the first magnetically confined fusion reactor to produce more energy than it consumes. I led the team, charged with standing up the test facility for the magnet as well as operating the test. The cryogenic aspects of this facility include a new 20-m^3 cryostat, a cryogenic helium loop with 600 W cooling capacity at 20 K from eight cryocoolers and 50 kA binary current leads, together with the ancillary components. It was a privilege to work with the many talented individuals comprising our team, who achieved a great deal in a short span of time. Similarly, our industry partners – notably, Absolut System and Anderson Dahlen, among many others – deserve our thanks, working at breakneck pace during a pandemic to help us meet our schedule.

What do you believe the most important developments in cryogenics are? The global shortage of helium, combined with the growing list of applications requiring low temperature conditions, presents a severe challenge to the cryogenics community. Our own facility is adding a helium recovery system to help us eliminate waste. Such solutions may not be sufficient for industrial applications, which may need to migrate to hydrogen-based approaches to achieve sustainability.

What advances do you hope to see in the future? How long do you think it will take to achieve these advances? My career has focused on the practical realization of fusion energy. The timespan to achieving this end is frequently the subject of jocular commentary, yet the commercial availability of high temperature superconductors may accelerate it by decades. The SPARC tokamak, under construction by our partners at CFS, aims to achieve "breakeven" in this decade; this is to be followed by a pilot plant. There are numerous other exciting projects underway, including the immense ITER partnership, telling of the resolve that exists to make fusion power a reality.

▶ *continues on page 34*

Where can readers find out more about your projects? For more about the SPARC TFMC: **https://news.mit.edu/2021/MIT-CFS-major-advance-toward-fusion-energy-0908,** MIT Plasma Science and Fusion Center: **www.psfc.mit.edu/news**

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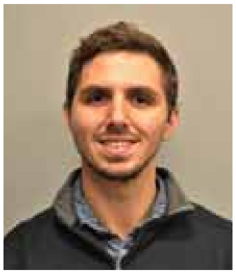

Tim Hanrahan, 30

What is your educational and professional background? I received a bachelor's degree in physics from Le Moyne College and a master's degree in mechanical engineering from Syracuse University. I've worked at Cryomech since graduating in 2016.

What is your present company/position? I am Cryomech Inc.'s special projects team supervisor.

How did you get into cryogenics? I was involved with a state program that hired graduate students to help local companies in the Syracuse, N.Y. area. As luck would have it, I was placed with Cryomech and subsequently hired after graduation.

What has your experience been with industry mentors? I've had several mentors during my career so far. Chao Wang, Brent Zerkle, and Rich Dausman have all been incredible mentors at Cryomech. Chao hired me in 2016 and taught me a lot about cryocoolers and cryogenic technology. It was inspiring to be able to work on a variety of successful new products and see the process from conceptual design to full product. Rich and Brent both taught me about leadership and inspired me to be creative and think outside the box.

What awards/honors have you received? None specific to cryogenics.

What are some of your contributions to the cryogenic field? Working at a company that's one of the leaders in cryogenics has allowed me to be a part of many contributions to the cryogenic field, serving multiple industries. For the medical industry, I've helped advance our cold helium circulation technology, which has been used to pre-cool MRI magnets by flowing helium gas through the dewar before adding liquid helium. This allows the magnet to be cooled to 20-30 K and greatly reduces liquid helium consumption. For the quantum industry, I've helped develop our 1 K cryocooler which is a high capacity, low temperature (<2 K) three-stage cooler. This has been used to cool quantum devices, including single photon detectors, and is being used in photonics-based quantum computing development. In the research market, I've worked on developing many custom cryogenic systems. We work closely with researchers with a specific application that requires a cryogenic solution that currently doesn't exist in the marketplace. Some examples include custom, low vibration cryostats and argon liquefiers used in neutrino research.

What do you believe the most important developments in cryogenics are? Cryogenics has long been an enabling technology for a wide field of research. Most recently, the invention and proliferation of the closed-cycle dilution refrigerator has enabled R&D in quantum computing and quantum technology. Using cryocoolers to replace liquid helium baths in dilution refrigerators has created a simpler and easy-to-use platform that allows researchers to focus more on their experiments and less on the cryogenics. Cryomech has been the leading supplier of cryocoolers for dilution refrigerators for several years. We continue to improve the design of our cryocoolers supporting this technology.

The biggest drawback of cryocoolers is the vibration they create, which is detrimental to some sensitive applications. I'm currently working on a project to develop a closed-cycle replacement for the cryocooler which will offer significantly lower vibration.

What advances do you hope to see in the future? How long do you think it will take to achieve these advances? There are several exciting and important technological developments happening today involving cryogenics. In the energy sector, hydrogen fuel cells and fusion energy can potentially bring clean energy to all. I think the broad utilization of hydrogen as a fuel source will require efficient storage and use of hydrogen in a liquid form. This is beginning to be adopted but will likely be several years before full utilization. Fusion energy is the holy grail of clean energy and has many technological challenges. It will likely still be several decades until it becomes a useful producer of energy.

I also hope to see the use of quantum computing in all aspects of life. Quantum computers have the potential to revolutionize the world and solve problems that classical computers cannot. This could also be several decades until we see a useful fault-tolerant quantum computer, but the large push towards developing this technology is certainly exciting.

Where can readers find out more about your projects? Readers can learn more about Cryomech and new products that we're developing at cryomech.com and can follow me on LinkedIn.

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Swapnil Rajendrakumar Shrishrimal, 31

What is your educational and professional background? I hold a master's degree in electrical engineering from the University of Texas at Arlington and a bachelor's in electronics engineering from University of Pune, India.

What is your present company/position? Presently, I'm working at SLAC, nearing my fourth year as a lead process controls engineer in the cryogenic division.

How did you get into cryogenics? After completing my master's degree, I got an opportunity to work at Thomas Jefferson National Accelerator Laboratory (JLAB) as a Cryogenic Systems Controls Engineer. There, I was introduced to the field of cryogenics. After more than two and a half years of my service at JLab, I led the operations at the Cryogenic Test Facility. I also worked on multiple projects such as LCLS-II Project at SLAC where JLab was designing the cryoplant and developing cryomodules; Cryogenic Test Facility Cold Box 3 upgrade; and Central Helium Liquefier I (CHL-I) 2K Cold Box upgrade.

What has your experience been with industry mentors? My mentors are my supervisors at both of my places of employment, Robert Norton at JLab, and Eric Fauve at SLAC. Eric and Robert are two of the most important individuals who have helped me immensely with their experience in the field of cryogenics. Robert helped me to understand cryogenics and helped in the formulation of my process controls logic. He also helped me to design the electrical / control system design. Eric's guidance has been extremely valuable to me. With my fundamentals clear, Eric mentored me to develop my expertise in process control rather than just controls. This allowed me to use my process and controls knowledge to develop a 100% automation for complex tasks like 4 K cooldown, 2 K pumpdown, and a fast cooldown of an entire LINAC.

What awards/honors have you received? In 2022, I was awarded the Department of Energy's SLAC National Accelerator Laboratory's Director's Award, the lab's highest honor. The award recognizes employees who achieve extraordinary results while modeling the lab's values of excellence, integrity, creativity, collaboration and respect.

What are some of your contributions to the cryogenic field? I have co-authored a paper about Warm Helium Compressor Commissioning at SLAC and will be authoring multiple papers in coming years with my work there. Most importantly, what I was able to develop at SLAC is the complete automation of most complex tasks in cryogenics. I have developed a simple and smart automation to completely cool down a string of 37 cryomodules from room temperature to 2 K without a need for operator intervention. This approach has been tested at SLAC and provided some outstanding results. This automation helped SLAC to commission the cryogenic system in record time without any major issues. Additionally, SLAC's tesla-style cryomodules require fast cooldown (rate exceeding 15 K/min of cooldown). This has never been performed on a string of cryomodules in an actual accelerator. At SLAC, we have developed an automation and demonstrated that achieving fast cooldown in an actual accelerator environment is possible.

What do you believe the most important developments in cryogenics are? Developing a cryogenic system to achieve a higher Carnot efficiency and a more robust system that can adapt to varying loads is essential. I'm working on addressing some of them by developing a complex automation with a fully integrated system.

What advances do you hope to see in the future? How long do you think it will take to achieve these advances? I hope that a cold compression system for small loads (<10 g/s) will be developed, and I look forward to, with active participation and funding, this being achieved within the next decade.

Where can readers find out more about your projects? www6.slac.stanford.edu/news-and-events/news-center

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Santhosh Kumar Gandla, 34

What is your educational and professional background? I hold a Master of Science in Mechanical Engineering, University at Buffalo, State University of New York.

What is your present company/position? I am a principal product engineer at Sumitomo (SHI) Cryogenics of America, Inc., where I have worked since January 2013, developing cryocoolers and cryogenic systems for healthcare, semiconductor and laboratory applications.

How did you get into cryogenics? My first real experience with cryogenics happened when I worked as an R&D intern at Praxair in the prepurification group, where I learned in detail how gases are separated in the cryogenic distillation column in air separation plants. After this, the majority of my cryogenics education and experience has been at Sumitomo (SHI) Cryogenics of America Inc., where I learned in depth about cryocoolers (4 K and 10 K), cryogenic systems, helium compressors and cryopump technologies.

What has your experience been with industry mentors? I have had many mentors at Sumitomo during the last ten years, including Dr. Ralph Longsworth, Bruce Sloan, Stephen Dunn and Dr. Mingyao Xu. Dr. Longsworth, in particular, played a significant role when I first joined the company. I was fortunate to work with him directly and learn from him for many years. Dr. Longsworth is an excellent mentor and a compassionate person. He took me under his wing during my initial years at Sumitomo, teaching and guiding me on the basics and principles of cryogenic engineering and the development of cryocoolers, compressors and various cryogenic systems.

What awards/honors have you received? In 2022, I was elected to a six-year term on the board of the International Cryocooler Conference.

What are some of your contributions to the cryogenic field? My most significant contribution is designing mobile cryogenic systems to cool MRI superconducting magnets from room temperature to 25 K, which saves more than 1,000 liters of liquid helium usage per magnet compared to traditional liquid nitrogen and liquid helium cooling. All major manufacturers currently make more than 4,000 MRIs yearly, and service and re-cool existing MRIs in the field. More than 20% of global helium is used to cool these MRI magnets, as helium reserves are very limited. Helium conservation plays a significant role so that helium can be used and available for required applications in the future. One such step toward conservation is the development of mobile cryogenic systems. Additionally, I recently led the development of the CH-160D2 high capacity single-stage cryocooler for liquid nitrogen and other 77 K applications, and CH-160D2LT for hydrogen and other 20-30 K applications. I have presented and published papers on this at the ICC, CEC, ASC and MT conferences in the last five years.

What do you believe the most important developments in cryogenics are? I believe superconductivity and the development of superconductors, created by cooling the materials to cryogenic temperatures, are among the most important developments in cryogenics. These are at the heart of MRIs and proton therapy systems, which are extensively used in healthcare and touch billions of people's lives. All my work in the last ten years and for the foreseeable future is

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dedicated to helping our healthcare customers develop cryogenic systems for their applications, positively impacting society and its people.

What advances do you hope to see in the future? How long do you think it will take to achieve these advances? I hope to see advances in superconductors and cryogenics in the transportation industry (train and aircraft), cryopreservation and quantum computing. Although there is some significant work in these fields, I think it will take another 10 to 15 years before these become cost-effective applications.

Where can readers find out more about your projects? www.shicryogenics.com, www.researchgate.net/profile/Santhosh-Kumar-Gandla/research, www.linkedin.com/in/santhosh-kumar-gandla-64164825

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Ryan Snodgrass, 31

What is your educational and professional background? My degrees are all in mechanical engineering: a bachelor's degree from The Ohio State University and a master's degree and doctorate from Cornell University. I completed multiple engineering internships and a research fellowship at the University of Freiburg in Germany. In 2019 I began a career at the National Institute of Standards and Technology (NIST) in Boulder, Colo., where I focus on thermoacoustics and cryocoolers.

What is your present company/position? I am a postdoc in the Quantum Sensors Group at NIST. I lead multiple cryogenics projects concerning pulse tube refrigerators, Gifford-McMahon cryocoolers and dilution refrigerators. My goal is to make cryogenics more accessible to the scientists at NIST and beyond who rely upon ultralow temperatures for their research.

How did you get into cryogenics? In graduate school I was very interested in refrigeration, and part of my doctorate focused on elastocaloric cooling. After my doctorate, I was looking for postdocs at national labs that were focused on refrigeration and found a great opportunity at NIST to study cryocoolers.

What has your experience been with industry mentors? I am lucky to have multiple mentors at NIST and within the thermoacoustic field. Scott Backhaus, Vincent Kotsubo, Gregory Swift, and Joel Ullom have been incredibly supportive and very influential for my research career. They are all extremely knowledgeable and push me to pursue interesting (and fun) research questions.

What awards/honors have you received? I was a National Science Foundation Graduate Research Fellow at Cornell University and a National Research Council Postdoctoral Fellow at NIST. I also was a DAAD/RISE Fellow. DAAD/RISE is a program that enables undergraduates from around the world to complete research projects in Germany.

What are some of your contributions to the cryogenic field? My recent research has focused on the real-fluid properties of helium that enable 4 kelvin cryocooler regenerators to absorb heat for "free"; this ability is utilized in commercial dilution refrigerators to precool recirculating helium 3. I have also studied miniature, cold-cycle dilution refrigerators for their use aboard astrophysics balloon flights. I will soon be publishing work demonstrating how to significantly increase the cooldown speed of commercial 4 kelvin pulse tube refrigerators.

What do you believe the most important developments in cryogenics are? Besides the development of completely new refrigeration techniques, making these techniques more accessible to scientists is my main interest. For example, miniature dilution refrigerators are enabling access to the millikelvin temperature regime with little required infrastructure – it's amazing technology!

What advances do you hope to see in the future? How long do you think it will take to achieve these advances? Terrestrial cryocoolers today are dependable and commercially available but are still not completely understood and therefore not optimized. An improved understanding of these coolers may lead to large improvements in their performance. I believe it is particularly important for us to improve the energy efficiency of cryocoolers as they become more and more ubiquitous.

Where can readers find out more about your projects? A list of publications may be found on my NIST webpage: **www.nist.gov/people/ryan-snodgrass**

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Dr. Mohammad Yazdani-Asrami, 36

What is your educational and professional background? I received a PhD in Electrical Engineering in 2018. My field of interest and expertise is cryo-electrification, i.e., electrification using cryogenics engineering and superconducting materials/technology, especially for future modern electric transportation and power system applications. One good example of such application is a cryo-electrified aircraft, which has superconducting powertrain and hydrogen as coolant or fuel.

What is your present company/position? Since early 2022, I have been a lecturer (assistant professor) in electrically powered aircraft and operations at the James Watt School of Engineering, University of Glasgow, UK. I am leading research activities on cryo-electrification in propulsion, electrification and superconductivity.

How did you get into cryogenics? I came across the word "cryogenics" right after I became familiar with superconductivity. It was at the end of my MSc program when I heard about superconductors, and how they contribute to fabricating electrical devices with fewer losses. I remember a lecturer told us that the future of electrical engineering will be shaped by advancement in battery technology and implementing superconductors. That motivated me to further research the topic and led me to discover how superconductivity and cryogenic engineering work hand in hand.

What has your experience been with industry mentors? I had the great honor of working under the supervision of Dr. Mike Staines at Robinson Research Institute on a project concerning fault-tolerant, current-limiting superconducting transformers, which holds the world record in experimentally tolerating a fault (for 1s) by a superconducting device. I found Mike a very intelligent, quite knowledgeable and enthusiastic physicist who always had questions and considered him as my role model. I learned a lot from Mike. Furthermore, I will always remember his advice: "Always ask why," words I already quote to my students. We cannot be good researchers, either scientists or engineers, if we don't have questions.

What awards/honors have you received? I was named the IOP Trusted Reviewer for consistent critical review in 2020. Additionally, I was endorsed as global talent by the UK Royal Academy of Engineering in 2021, and I was elevated to the senior member level of IEEE in 2022.

What are some of your contributions to the cryogenic field? I have been involved in various projects related to cryogenic engineering and superconducting technology, such as the design development of superconducting devices including transformer, cable and SFCLs; heat transfer measurement of bare and coated superconductors and metallic conductors at low temperatures. I have offered some solutions for fault tolerance capabilities in superconducting devices, including cable and transformers. In addition, I have researched materials characterization at low temperatures for YBCO, GdBCO, and MgB_2; advocating for superconductivity, cryogenic engineering and cryo-electrification in other communities and industries, including aviation and space sectors, implementing and advocating for artificial intelligence techniques in superconductivity. I wrote a roadmap position paper for the UK's first zero-emission aircraft project (FlyZero). I also delivered a roadmap on using artificial intelligence techniques in superconductivity for *Superconductivity Science and Technology* journal.

Additionally, I am editor at *Superconductor Science and Technology* journal (IOP publishing), *Superconductivity* journal (Elsevier), *World Journal of Engineering* (Emerald Publishing), *Aerospace Systems* journal (Springer), *International Journal of Aeronautical and Space Sciences* (Springer), and *Transformers Magazine* (TM). I also served as guest editor for several special issues of *IEEE Transactions on Applied Superconductivity* and *Superconductor Science and Technology* journals. I also chaired the special session "Artificial Intelligence for Large-Scale Power Applications," at the 2022 Applied Superconductivity Conference in Hawaii, USA. Not only that, but I will chair another special session "Artificial Intelligence Techniques for Superconductivity" at the 16th European Conference on Applied Superconductivity in Bologna, Italy in 2023.

What do you believe the most important developments in cryogenics are? What I would like to see in the near future is more advancement in cryogenic cooling systems towards higher efficiency, cost-effective, and higher power-to-mass-density cooling systems for electric aircraft and terrestrial applications. With superconductivity, I hope to see better superconductors with cheaper prices, which obviously depends on purchasing and utilizing more superconductors in industrial applications (chicken and egg problem), and more investment in developing real-scale demonstrators and proof-of-concept electric superconducting devices for power system and electric transportation applications. I wish to see these developments to make cryo-electrification a competitive technology against well-developed conventional rival/counterpart technologies.

Where can readers find out more about your projects? I actively post my research projects, findings, and research outcomes at LinkedIn: **www.linkedin.com/in/mohammad-yazdani-asrami-b91928100**

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Jad Benserhir, 27

What is your educational and professional background? I completed a joint master's degree from Grenoble-inp, Politecnico di Torino, and EPFL, focusing on various aspects of nanotechnology, including chip design and microfabrication. I am now working toward a doctorate at EPFL, with the goal of creating a high-speed and scalable readout circuit for superconducting nanowire detectors.

What is your present company/position? I am currently pursuing a doctorate in the field of cryogenic analog and mixed signal circuit design at the Advanced Quantum Architecture Lab (AQUAlab) at EPFL. My research focuses on device characterization at low temperatures and the design of scalable arrays that interface with superconducting detectors.

How did you get into cryogenics? I was amazed at the rapid development of quantum computing in recent years. Out of curiosity, I reached out to a leading expert in the field, Professor Edoardo Charbon, and soon after, I began working under his supervision.

What has your experience been with industry mentors? I am fortunate to have Professor Edoardo Charbon as both my mentor and doctorate supervisor. He brings a wealth of knowledge and experience in the field of quantum computing, making the learning journey under his guidance an exciting one.

What awards/honors have you received? Currently, I haven't received any specific awards. I am optimistic that I will be recognized in the coming months.

What are some of your contributions to the cryogenic field? A primary objective that I am focusing on is to develop an accurate photon/particle detector for the cryogenic community with a timing resolution of 3ps. This detector is based on an array of superconductive, single-photon detectors (SSPDs) known for their high speed, high detection efficiency and low-dark count rate.

What do you believe the most important developments in cryogenics are? When it comes to detecting particles, while secondary electron multiplication detectors may have high-speed and large detection capabilities, they are not efficient at detecting low-velocity impacts. As an alternative, we propose using superconducting detectors to detect neutral- or singly charged massive particles at low energies, as the energy gap

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between the superconducting and normal conducting states is small. The project is a collaboration between multiple institutions such as EPFL, University of Vienna, Basel, Single Quantum and MS Vision.

What advances do you hope to see in the future? How long do you think it will take to achieve these advances? In the future, I hope to see increased interest in the field of electronic design at low temperatures. To achieve this, it is important that electronic design is based on models provided by major foundries such as TSMC, Global Foundries and IHP. I hope that these foundries will include cryogenic models in their design kits, so that the electronic design community can produce accurate and well-designed chips for cryogenic applications.

Where can readers find out more about your projects? I am currently working on a project called superconducting mass spectroscopy and molecule analysis (SuperMaMa), which aims to use superconductive single-photon detectors (SSPDs) to detect massive particles at low energies. The project also has potential applications in dark matter experiments. For more information on SuperMaMa, you can visit the project's website at **www.supermama-project.eu**. Additionally, you can find more information about AQUAlab, the laboratory where the project is being conducted, at **www.epfl.ch/labs/aqua**

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Lakshya Gangwar, 26

What is your educational and professional background? I started my educational journey by completing my Bachelor of Technology in Mechanical Engineering from one of the top institutes in India: IIT Kanpur. Now, I am pursuing a doctorate in mechanical engineering at the University of Minnesota.

How did you get into cryogenics? My passion for thermal sciences ignited in my sophomore year after finishing coursework. I became curious to explore the physics of temperature (and heat) and ended up pursuing a research internship on flexible heat pipes for spacecraft applications. After completing my undergraduate, I started a doctorate program, applying my thermal science mind into cryogenics for cryobiology (applying cryogenic physics to biological systems). More precisely, I am working in computational and experimental heat transfer during the cryopreservation of biological systems.

What is your present company/position? I currently work as research assistant in BHMT Lab (ME) at the University of Minnesota and as a student trainee in NSF ERC-Advanced Technologies for the Preservation of Biological Systems (ATP-Bio).

What has your experience been with industry mentors? My doctorate advisor, Dr. John Bischof, is a well-known expert in cryopreservation. He is an excellent guide who inspired me to always look from a high-level view of any research problem and then think of limiting scenarios to solve at the start. His guidance has developed in me a spirit of interdisciplinary collaboration in solving a diverse problem without reinventing the wheel. He mentored me in professional skills, nurturing my overall growth as a graduate student.

What awards/honors have you received? I was a recipient of the Academic Excellence Award, IIT-Kanpur for outstanding academic performance during the 2015-16 academic year. Following that, I was awarded the German-Academic-Exchange-Service (DAAD) WISE scholarship in 2017 to pursue summer research in IKW at Leibniz University, Germany. In the fall of 2018, I received a UMN ME Departmental Fellowship, joining the doctorate program. Recently, I was privileged to receive a UMN IEM-Walter Barnes Lang fellowship in addition to a travel award from the committee for a talk in Dublin at the Cryo2022 conference.

What are some of your contributions to the cryogenic field? My contributions broadly fall in organ-cryopreservation for regenerative medicine applications (organ banking) in a team effort of BHMT-Lab & ATP-Bio. My major contribution is in demonstrating physical success in vitrification and rewarming at liter-scale (human organ-size) cryopreservation. I have also published a practical guide on vitrification and rewarming from mL-to-L scale, indicating failures to avoid for successful cryopreservation of a biomaterial (tissues, organs, organisms, etc.), which could be helpful for any cryobiologist. Currently, I am working on a cryogenic liquid convective cooling technique which could be faster than the current commercial control rate for cryogenic freezers as part of a technological development for large-scale cryopreservation. Lastly, I am contributing to a cryogenic subgroup (thermal properties) as a member of the ASME tissue property database.

What do you believe the most important developments in cryogenics are? In my opinion, cryopreservation of biological materials can serve various critical problems of our society. Starting with the human body, organ cryopreservation can save thousands of lives by enabling organ banking that could drastically reduce organ transplant waitlists. Moving to food security, by cryopreserving various aquatic embryos (fishes, shrimp, etc.), adequate supplies of seafood can be maintained away from shores and inland, unaffected by coastal natural disasters. Lastly, cryopreservation of organisms, such as coral reefs, embryos of endangered species, etc., could be a step toward saving the biodiversity of our planet.

W**hat advances do you hope to see in the future? How long do you think it will take to achieve these advances?** I would like to see advancements in transplants of cryopreserved human organs within the next two to three years. Also, the creation of organ banks would be another milestone I am eager to see in the next five to ten years. With the current rate of climate change adversaries, I also want to see cryobanks of coral reefs and endangered living species become a reality in the decade ahead.

Where can readers find out more about your projects? Any readers are welcome to check researchgate (Lakshya Gangwar), LinkedIn (**www.linkedin.com/in/lakshya-gangwar**), gangw009@umn.edu. **www.societyforcryobiology.org**

ICC21 Best Student Paper Award Recipient

The Development of an AMRR for Sub-Kelvin Cooling of Space Science Instrumentation

by C. M. Gunderson, G. F. Nellis, and F. K. Miller, University of Wisconsin-Madison

Introduction

Cryogenic detectors have higher sensitivity and better energy resolution than alternative sensors, making them an attractive option for space exploration and essential for observing low energy photons in the near- or far-IR, X-ray and submillimeter ranges.[1] Since NASA's first cryogenic missions in the early 1980s, increasingly complex space detectors have required continuous advancement in cryogenic technology.[2]

The development of a sub-Kelvin Active Magnetic Regenerative Refrigerator (AMRR) is discussed in this work. This novel AMRR addresses many of the deficiencies of current cooling solutions, as it can provide continuous and distributed sub-Kelvin cooling via circulation of a ^3He-^4He mixture using a non-moving Superfluid Magnetic Pump (SMP).[3] The resulting system eliminates the requirement for heat switches, extends the allowable distance between the detector and magnets and enables a variety of thermal integration options. It is a reliable, no-vibration, low mass and scalable sub-Kelvin cooling solution for space instrumentation.

An SMP, two regenerators, one cold heat exchanger (CHX), and two hot heat exchangers (HHXs) comprise the AMRR system shown in Figure 1.

Background

The AMRR system takes advantage of a few key characteristics of both the paramagnetic refrigerant and the helium working fluid mixture to provide distributed sub-Kelvin cooling. Paramagnetic materials have magnetic properties that are related to unfilled electron shells in some of the ions which create magnetic moments.[4] This results in a coupling between the applied magnetic field and material temperature through the entropy. Manipulation of this coupling

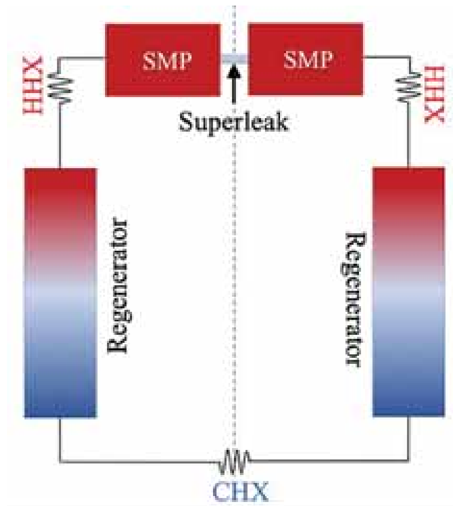

Figure 1. A diagram of the AMRR system.
Credit: University of Wisconsin-Madison

allows for the heating or cooling of paramagnetic material through the magnetization or demagnetization of an applied field, respectively, and is the primary motivation behind using these materials in refrigeration. The paramagnetic refrigerant used in this research is Gadolinium Gallium Garnet (GGG).

At near and sub-Kelvin temperatures, each of the two stable helium isotopes exhibits unique properties. There is a significant reduction in heat capacity of ^4He at 1 K, as 99% of the ^4He has transitioned into its superfluid state, which cannot carry energy.[5] In contrast, ^3He has a large magnetic spin entropy that gives rise to a large heat capacity. Therefore, ^3He is required to carry energy throughout the system, and ^4He is responsible for driving flow in the system through the thermomechanical fountain effect.[5,6] The unique combination of the GGG and ^3He-^4He mixture properties enables the AMRR refrigeration cycle using the oscillatory flow provided with the SMP.

Each magnetic regenerator consists of a canister of crushed GGG suspended inside the bore of a superconducting solenoid. As fluid is displaced out of the SMP, it moves down through the demagnetizing regenerator, which cools the mixture so that it exits the regenerator bed at the desired outlet temperature. The mixture then moves through the CHX, providing sub-Kelvin cooling to the load (e.g., one or more detectors). The mixture flows back through the opposite, magnetizing regenerator, which rejects more heat into the fluid. Finally, this heat is rejected to the precooling stage at a temperature of approximately 1.6 K. The system can then be reversed, sending flow back in the opposite direction. The fact that this AMRR system produces a flow is one of its most important advantages relative to other cryogenic refrigeration solutions.

AMRR System Design and Construction

The primary objective of this research is to provide measurable cooling

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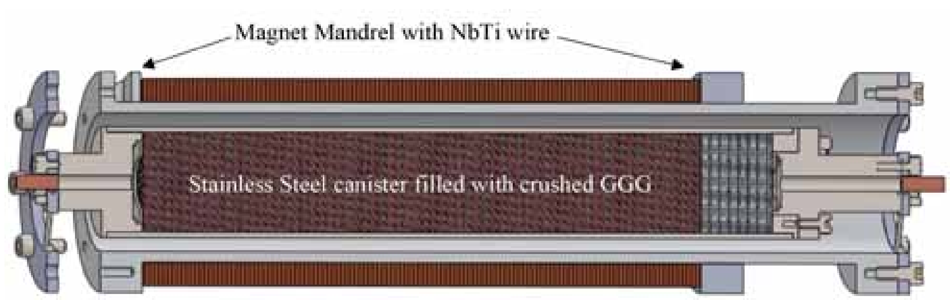


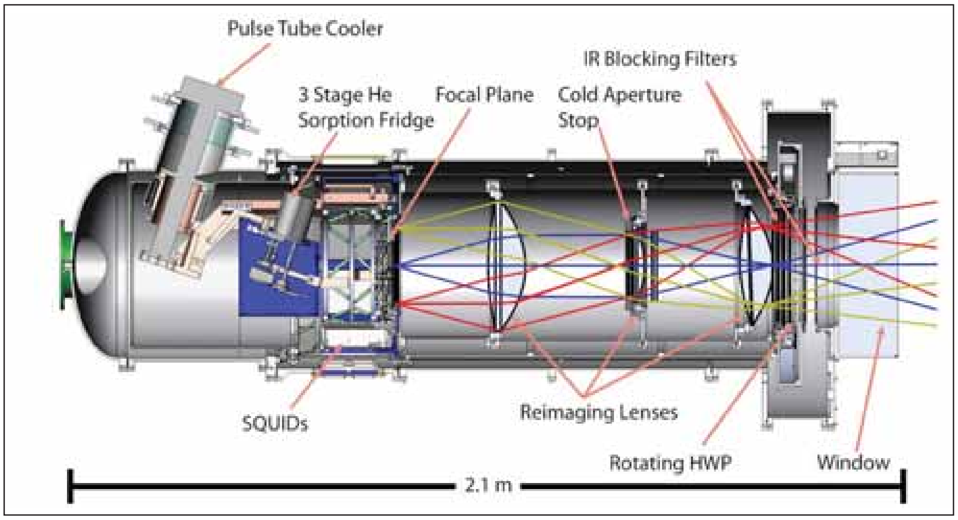
Figure 2. The final regenerator design, consisting of the GGG packed canister, the magnet mandrel and windings, and the suspension components. *Credit: University of Wisconsin-Madison*

Chase Coolers and Their Long History in CMB Science

by Charlie Danaher, Danaher Cryogenics, and Simon Chase, Chase Research Cryogenics

Making advances in science requires the proper tools. Often those tools must be developed by scientists themselves. That's the story of most science missions studying Cosmic Microwave Background radiation (CMB). Sub-Kelvin coolers developed by Chase Research Cryogenics (CSA CSM) have played a strategic role in many of these missions. Let's look at two exciting examples.

One such mission is the POLARBEAR experiment. The instrument was developed by an international collaboration – University of California, Berkeley, Lawrence Berkeley National Lab, University of Colorado, Boulder, UCSD, Imperial College, University of Paris, KEK, McGill University and Cardiff University – and installed in the Huan Tran Telescope (HTT) at the James Ax Observatory on the Chajnantor Science Reserve in the Atacama Desert in Chile, at an altitude of 17,000 feet.



A cross-section drawing of the POLARBEAR receiver. *Credit: Zigmund Kermish*

A Chase cooler was used to cool the focal plane to ~0.25 K, and to keep it there for about 24 hours. Cooling the focal plane to 0.25 Kelvin results in the thermal carrier noise being inconsequential compared to the thermal background noise of the atmosphere. The 0.25 K focal plane is the coldest stage of the receiver and is surrounded by a series of nested thermal envelopes. Upstream of the focal plane is the 4 K shield containing cooled optics, and outside of that is the 50 K envelope, which includes a series of IR thermal shields.

POLARBEAR was designed to make measurements of the CMB polarization on small angular scales to detect the B-mode polarization and put limits on inflation. A second mission objective is to reconstruct the lensing potential of the CMB with hopes of providing limits on the neutrino mass.[1] POLARBEAR was the first instrument to utilize a lenslet-coupled planar array detector architecture for CMB observations.[2] The receiver saw first light on January 10, 2012, and began its first observing season in April 2012.

The Chase cooler used in the POLARBEAR receiver was a GL10. This cooler has a sorption-pumped, He3 pot, backed by another He3 pot, which is, in turn, backed by a He4 pot. This architecture yields a cold stage temperature of 250 mK or better. The beauty of the Chase cooler is that it is a self-contained refrigerator that can be mounted to an instrument's 3 K stage plate. This architecture allows for the scientists to design the system schematically, treating the sub-K cooler as a building block, as they'd treat the cryocooler. Integration of the GL10 is simple in that, in addition to the mechanical mounting to the 3 K stage plate, it only needs electrical connection made to external power supplies and thermometer readers.

Looking forward, let's discuss an exciting astronomical mission under development called Taurus. Taurus is a NASA, ARPA-funded, balloon-borne Polarimeter for Cosmic Reionization and Galactic Dust. Taurus is a joint program involving Washington U-St. Louis, Princeton University, University of Illinois Urbana-Champaign, University of Iceland and NIST.

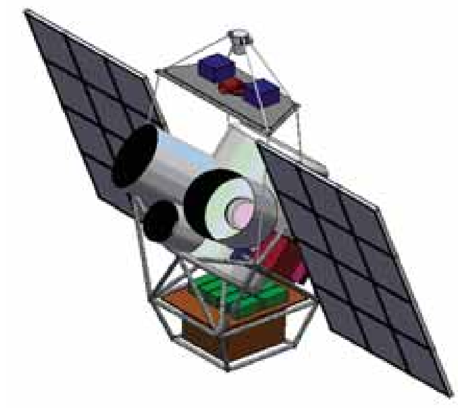
Taurus aims to measure the probability that a light ray traveling from the CMB will be scattered on its way to an instrument, whether that instrument is on Earth or in space. Knowing that probability allows scientists to understand how "blurry" that light is.[3] Current measurements tell us that tau is around 5%, but a much more precise measurement of this probability will provide new information about how quickly the first stars formed.[4]

Huan Tran Telescope (HTT) at the James Ax Observatory, Atacama Desert, Chile. *Credit: NASA*

A more precise measurement of tau will also help scientists attempting to measure the mass of neutrinos through their effect on the CMB. Massive neutrinos leave their signature through a different kind of blurring of the CMB: gravitational lensing. Light bends as it passes by massive objects in the universe on its way to Earth. This bending, or lensing, distorts the light we see from the CMB. A more precise measurement of tau will yield a better interpretation of this lensing signal, and thus to measuring the neutrino mass.[5]

Additionally, because Taurus will be largely outside of Earth's atmosphere, it will be able to measure with high sensitivity the polarized glow of dust in our galaxy, at frequencies that would be blocked by our atmosphere. The newly released Chase continuous mini dilutor (CMD) refrigerator is being evaluated for the Taurus project. This cooler can provide continuous cooling at 100 mK, which offers the possibility of continuous observation. However, what's most attractive about the CMD is its low power draw, its low mass and the simple yet robust operation.

Cryostats destined for telescope receivers will almost surely continue to be one-off, custom systems. However, scientists who are looking for a lab cryostat to host a Chase cooler, now have a commercial choice. Danaher Cryogenics (**www.DanaherCryo.com**, CSA CSM) has partnered with Chase (**www.ChaseCryogenics.com**) to offer a full line of integrated cryostats.



CAD image of Taurus Gondola. *Credit: Taurus Collaboration*

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[3] https://icasu.illinois.edu/news/Taurus

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[5] https://icasu.illinois.edu/news/Taurus

AMRR for Sub-Kelvin Cooling... Continued from page 39

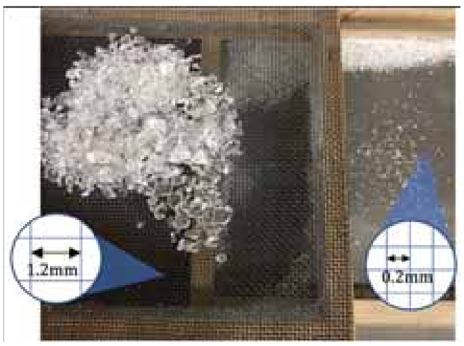

Figure 3. The two sieves used to achieve a GGG particle size of approximately ≤1 mm. *Credit: University of Wisconsin-Madison*

at the CHX with a proof-of-concept prototype of this novel AMRR. The AMRR components were designed to be compatible with an existing SMP to ensure that there is enough paramagnetic material and sufficient magnetic field to both force circulation and lift heat at the CHX. A simple 1D transient design model was developed that focused on one regenerator canister during a flow process in the AMRR system in order to assist in the design process. Using an energy balance on the regenerator canister, the canister dimensions required to maintain an outlet temperature of 750 mK during the flow process were determined. These dimensions, along with an assumed field swing, were used to constrain the regenerator magnet design. The final regenerator design, shown in Figure 2, includes the canister pieces, magnet mandrel and winding specifications and suspension design.

The regenerator canister consists of one thin-walled tube and two endcaps, all machined out of stainless steel. We packed the two canisters with crushed GGG particles to a porosity of 0.38. To achieve a target GGG particle size of roughly ≤1 mm in diameter, two sieves with 1.2 mm and 0.2 mm openings were used to create a go/no-go gage.

Thick-walled 6061 aluminum tubing was used to create the magnet mandrels, polishing the surfaces prior to winding. During the winding process, CTD-A521 magnet epoxy was continuously brushed onto the coil to improve the thermal contact between the wires and mandrel. To finish the magnets, two back-to-back 1N4001 diodes were soldered across the leads to redirect the current in the event of a quench.

Several of the regenerator components have been installed, and thus, the remaining work to finish the AMRR system assembly consists primarily of integrating the components with a circulation loop.

Conclusion and Future Work

Near-term future work includes finishing the assembly and experimental validation of the AMRR system. Once optimized, this system can be used to provide precooling to even lower temperature stages or for distributed cooling over large areas, offering an improvement over current systems and making new types of cryogenic refrigeration configurations possible.

Figure 4. One finished regenerator canister.
Credit: University of Wisconsin-Madison

Figure 5. One finished regenerator magnet.
Credit: University of Wisconsin-Madison

This article is a shortened version of a paper published at the International Cryocooler Conference, where it was the recipient of the ICC21 Best Student Paper Award.

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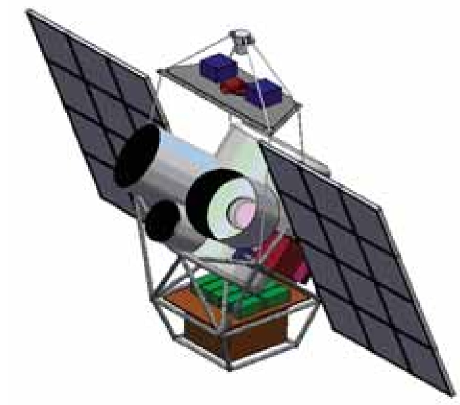
[6] Papoular, D.J., Ferrari, G., Pitaevskii, L.P. and Stringari, S., "Increasing Quantum Degeneracy by Heating a Superfluid," *Physical Review Letters*, Vol. 109, No. 8-24 (2012).

will be able to measure with high sensitivity the polarized glow of dust in our galaxy, at frequencies that would be blocked by our atmosphere. The newly released Chase continuous mini dilutor (CMD) refrigerator is being evaluated for the Taurus project. This cooler can provide continuous cooling at 100 mK, which offers the possibility of continuous observation. However, what's most attractive about the CMD is its low power draw, its low mass and the simple yet robust operation.

Cryostats destined for telescope receivers will almost surely continue to be one-off, custom systems. However, scientists who are looking for a lab cryostat to host a Chase cooler, now have a commercial choice. Danaher Cryogenics (**www.DanaherCryo.com**, CSA CSM) has partnered with Chase (**www.ChaseCryogenics.com**) to offer a full line of integrated cryostats.



CAD image of Taurus Gondola. *Credit: Taurus Collaboration*

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[1] https://lambda.gsfc.nasa.gov/product/polarbear

[2] The POLARBEAR experiment. https://arxiv.org/abs/1210.7768

[3] https://icasu.illinois.edu/news/Taurus

[4] https://icasu.illinois.edu/news/Taurus

[5] https://icasu.illinois.edu/news/Taurus

AMRR for Sub-Kelvin Cooling... Continued from page 39

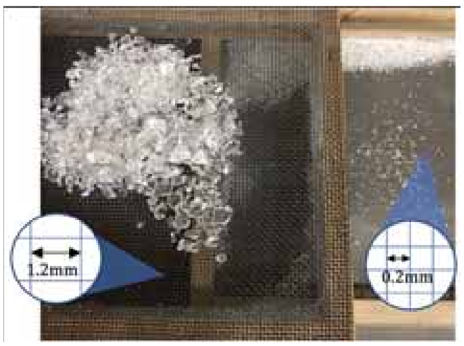

Figure 3. The two sieves used to achieve a GGG particle size of approximately ≤1 mm. *Credit: University of Wisconsin-Madison*

at the CHX with a proof-of-concept prototype of this novel AMRR. The AMRR components were designed to be compatible with an existing SMP to ensure that there is enough paramagnetic material and sufficient magnetic field to both force circulation and lift heat at the CHX. A simple 1D transient design model was developed that focused on one regenerator canister during a flow process in the AMRR system in order to assist in the design process. Using an energy balance on the regenerator canister, the canister dimensions required to maintain an outlet temperature of 750 mK during the flow process were determined. These dimensions, along with an assumed field swing, were used to constrain the regenerator magnet design. The final regenerator design, shown in Figure 2, includes the canister pieces, magnet mandrel and winding specifications and suspension design.

The regenerator canister consists of one thin-walled tube and two endcaps, all machined out of stainless steel. We packed the two canisters with crushed GGG particles to a porosity of 0.38. To achieve a target GGG particle size of roughly ≤1 mm in diameter, two sieves with 1.2 mm and 0.2 mm openings were used to create a go/no-go gage.

Thick-walled 6061 aluminum tubing was used to create the magnet mandrels, polishing the surfaces prior to winding. During the winding process, CTD-A521 magnet epoxy was continuously brushed onto the coil to improve the thermal contact between the wires and mandrel. To finish the magnets, two back-to-back 1N4001 diodes were soldered across the leads to redirect the current in the event of a quench.

Several of the regenerator components have been installed, and thus, the remaining work to finish the AMRR system assembly consists primarily of integrating the components with a circulation loop.

Conclusion and Future Work

Near-term future work includes finishing the assembly and experimental validation of the AMRR system. Once optimized, this system can be used to provide precooling to even lower temperature stages or for distributed cooling over large areas, offering an improvement over current systems and making new types of cryogenic refrigeration configurations possible.

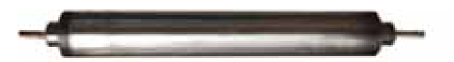

Figure 4. One finished regenerator canister. *Credit: University of Wisconsin-Madison*

Figure 5. One finished regenerator magnet. *Credit: University of Wisconsin-Madison*

This article is a shortened version of a paper published at the International Cryocooler Conference, where it was the recipient of the ICC21 Best Student Paper Award.

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[1] Rando, N., Lumb, D., Bavdaz, M., Martin, D. and Peacock, T., "Space science applications of cryogenic detectors," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, Vol. 522, No. 1-2 (2004), pp. 62-68.

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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.

Closed Loop Cryocooler

Criotec Impianti SpA

Criotec Impianti SpA has developed and manufactured a cryogenic device capable of cooling down monochromators (or other equipment), controlling the liquid nitrogen loop and keeping it free of gas, to avoid vibrations and pressure shocks. The system includes a closed loop cryocooler, flexible cryolines for the connection to customer's device and a dedicated control system based on PLC with touchscreen panel allowing to manage every parameter and record faults, alarms and historical data. The cryocirculator has an internal phase separator with their own pressure and level control system. All the cold/cryogenic components are contained inside a high vacuum insulated dewar. A large nitrogen bath provides the needed cooling power for the system and reduces liquid consumption. The large bath can be automatically refilled either from an LN_2 line or by use of a separate dewar. The supply and return path temperature are directly and constantly monitored by the PLC control system. **www.criotec.com**

Copper Thermal Straps (CuTS®)

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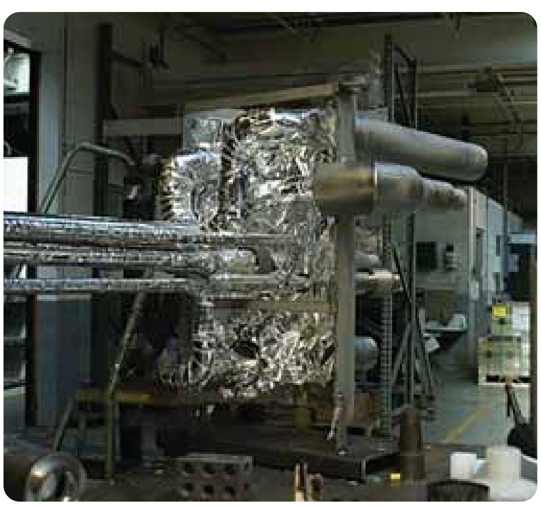
TAI designs and manufactures OFHC copper cabled thermal straps (CuTS®) for a wide range of cryogenic applications. CuTS® products are used to provide flexible, passive heat transfer for cryocoolers, cryostats, dilution refrigerators, cold boxes and other cold laboratory equipment. CuTS® are made using only OFHC copper, Technology Applications' exclusive OFHC UltraFlex I and II cabling and its cold press (swage) assembly process. CuTS® are available in more than 120 models, and customization options include gold and nickel plating and optional Aluminum 6061 end fittings. All design and consultation services are provided free of charge., TAI manufactures its own thermal straps and never outsources, and the 2023 CuTS® Catalog is available at the company's website. **www.techapps.com/thermal-straps-copper**



Multi-Layer Insulation (MLI)

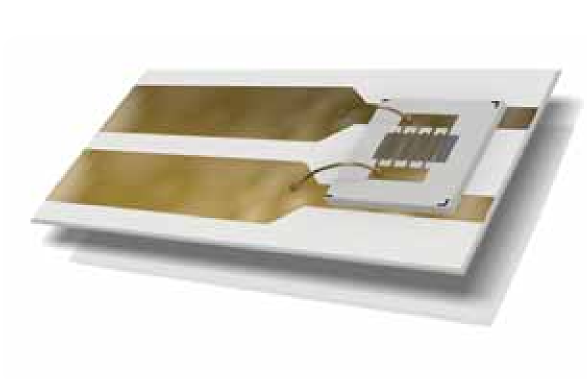
Meyer Tool & Mfg.

Meyer Tool superinsulation is made from double-aluminized mylar–.0005-inch-thick polyethylene terephthalate film, aluminized on both sides with nominal 400 angstroms coating. The vacuum-deposited aluminum has an average emissivity of 0.030. Meyer Tool's spacer is a spunbound polyester–.0004 inches thick. Its superinsulation meets Fermilab and Jefferson Lab specifications. Meyer Tool is capable of making blankets up to a maximum of 60 layers by 82 inches wide by 154 inches long (longer lengths available on special request). **www.mtm-inc.com**

Liquid Hydrogen Test Facility

Eta Space

The Liquid Hydrogen Test Facility (LHTF) features a 150-liter integrated refrigeration and storage (IRAS) system that is capable of liquefaction and zero loss storage and transfer of liquid hydrogen (LH_2). In addition to the IRAS system, the facility has all the necessary support systems needed in a modern cryogenic test laboratory such as separate indoor and outdoor test areas, each with its own purge, pressurization, vent, and vacuum systems. The indoor test cell is rated as a Class 1 Div 2 test area and includes a thermal vacuum chamber with a 30" diameter by 60" long shroud volume for component testing. Hydrogen sensors and mass spectrometers are used for leak detection and laboratory safety purposes. Customers can test their hardware and materials using LH_2 with the benefit of small batch production. Previously only available in large quantities at high costs, Eta Space has developed the LHTF to provide more affordable and responsive LH_2 testing. **https://etaspace.com**



Zirnox Cryogenic Temperature Sensor

Scientific Instruments

Scientific Instruments, the original innovators of cryogenic thermometry products, are proud to introduce the Zirnox sensor. A new thin film resistive temperature sensor that can operate over a wide temperature range (.020 K to 450 K) and exhibits negligible calibration shifts when exposed to magnetic fields and ionizing radiation environments. Comprised primarily of zirconium oxy-nitride, the material and physical properties of the sensor allow for fast thermal response, exceptional heat transfer and a range of mounting options to suit your application. Contact sales@scientificinstruments.com for more information on our competitive pricing and short lead times. **www.scientificinstruments.com**

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The Rook™ was designed to excel in bi-directional, multi-axis performance, giving users flexibility needed to optimize sample motion for their unique needs. Other benefits:

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The Rook™ is specifically designed for use in Montana Instruments' CryoAdvance™ cryostat (released in September 2021), a low vibration, cryogen-free system that allows users to access cryogenic temperatures in a 50mm (3.2K – 350K) or 100mm (3.4K-350K) sample chamber. It can also be utilized in the Cryostation® s200, Montana Instruments' largest and most versatile closed-cycle cryostat, with 200mm of sample space of configuration. **www.montanainstruments.com/the-rook**.

People & Companies in Cryogenics

Credit: Web Industries

Web Industries Inc., a global manufacturing partner in aerospace, medical, home care, and industrial markets, named **Amy Reardon Doherty** as vice president, legal. Over her career, Doherty has advised executives and business partners on a wide range of legal, financial, IP and business issues.

Web Industries also named industry veteran **John S. Madej** to serve as its next chief executive officer. He succeeds retiring CEO, Mark Pihl, who will now assume the role of chairman of the board at the employee-owned company, following a 47-year career, 34 of which was in dedicated service to Web Industries. Madej joined Web Industries as president in March 2022.

....

Credit: Cryoworks, Inc.

CryoWorks Inc. is excited to welcome **Cody Brewer** to its sales team. Brewer will champion the CryoWorks mission into green initiatives as part of the global energy transition and is dedicated to Cryoworks' program, Make It Happen, that partners with customers, thought leaders and the global energy community. Brewer brings extensive knowledge in the oil, gas, and energy sector to his role.

....

FormFactor celebrated the grand opening of its state-of-the-art demo center in San Jose, Calif. The demo center features essential test and measurement technologies for ICs used in advanced packaging, automotive devices, high-speed digital, silicon photonics and 5G/6G/millimeter-wave mobile devices.

....

France-based **Cryostar Automation** announced the completion of its renovated and extended offices in Capdenac-Gare, Southern France. The official opening ceremony on October 5, 2022, represented the culmination of two years of extension work and coincided with Cryostar Automation's celebration of its 20th anniversary. An entity of Cryostar France, Cryostar Automation specializes in automatized industrial and medical gases and cylinder filling stations.

....

The **National High Magnetic Field Laboratory** will receive $195.5 million over the next five years, a move that maintains the National MagLab, headquartered at Florida State University with partner sites at University of Florida and Los Alamos National Laboratory, as a worldwide research destination with continued support for a high magnetic field user program.

....

On January 9, 2023, **K. Alex Müller**, a Swiss physicist and innovator of ceramic superconductors, died at the age of 95. In 1987

K. Alex Müller, left, and J. George Bednorz at work at IBM Research in Zurich. Credit: IBM

at the age of 59, Müller won the Nobel Prize in Physics, sharing it with a colleague, for discovering that some ceramics can be superconductors, opening up a world of scientific and practical possibilities.

....

The Hon. Francois-Philippe Champagne, Canada's Minister of Innovation, Science and Industry, announced the launch of the National Quantum Strategy at the Perimeter Institute in Waterloo. The strategy aims to create jobs and advance quantum technologies within the country, backed by a first-of-its-kind investment of up to $360 million by the federal government and a flagship strategic procurement program, Innovative Solutions Canada to help innovative Canadian small- and medium-sized enterprises develop intellectual property, export and create jobs in the quantum sector. Innovative Solutions Canada has awarded four contracts to **Xanadu Quantum Technologies Inc., CogniFrame Inc., Photon etc. Inc., and Zero Point Cryogenics Inc.**

Meetings & Events

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

Hydrogen Technology Expo
June 28-29, 2023
Houston, Texas
www.hydrogen-expo.com

CSA Short Courses at CEC/ICMC
July 9, 2023
Honolulu, Hawaii
www.cryogenicsociety.org

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

Society for Cryobiology: CRYO2023
Minneapolis, Minnesota
July 25-27, 2023
cryo2023.com

Cryogenic Engineering and Safety Annual 5-day Course
Golden, Colorado
July 31 - August 4, 2023
www.cryocourses.com

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
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