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The Magazine of the Cryogenic Society of America, Inc.

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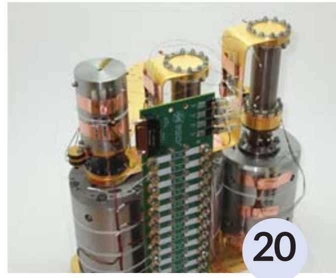

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ON OUR COVER

Ground crew members begin inflating a scientific balloon in preparation for launching NASA's Payload for Ultrahigh Energy Observations (PUEO) mission.
Credit: NASA/Scott Battaion

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Cold Facts (ISSN 1085-5262) is published six times per year by the Cryogenic Society of America, Inc.

From the Executive Director

As I write this, I've just returned from a wonderful week in Syracuse, New York, where many members of the cryogenics community gathered for the International Cryocooler Conference (ICC). Events like ICC are a reminder of the innovation, collaboration, and dedication that continue to drive our industry forward.

Prior to the conference, the Cryogenic Society of America (CSA) hosted the Foundations of Cryocoolers Short Course—an educational program founded by Dr. Ray Radebaugh that has introduced countless engineers, scientists, and students to cryocooler technology over the years.

This year's course was particularly meaningful, as it was the first time the program was offered since Ray's passing earlier this year. While his absence was deeply felt, we were honored to continue this important educational tradition in his memory. Ray was passionate about sharing knowledge and mentoring the next generation of cryogenic professionals, and we believe there is no better way to honor his legacy than by ensuring this course continues for years to come.

I would like to extend my sincere thanks to our instructors (Peter Bradley, Xihuan Hao, Franklin Miller, and Mark Zagarola) for generously sharing their expertise and stepping forward to help carry the course into its next chapter. Their commitment made this year's program a success. I would also like to thank our course sponsor, Sumitomo (SHI) Cryogenics of America, whose support helped make the event possible.

As we look ahead, I encourage all CSA members to consider another important opportunity to support our community: leadership service. CSA is currently seeking nominations for its Board of Directors, including candidates for President-Elect and three Director positions.

Our Board is composed of cryogenics innovators who are passionate about advancing the field and strengthening the Society. Serving on the Board provides a unique opportunity to help shape CSA's future while contributing to a long-standing legacy of education, collaboration, and technical excellence.

If you would like to nominate someone, please email me (megan@cryogenicsociety.org). If you are interested in nominating yourself, we encourage you to complete the candidate information form (**https://2csa.org/board**). The deadline for nominations is August 28.

Thank you for your continued support of CSA and for all you do to advance cryogenics. I look forward to seeing many of you at the Applied Superconductivity Conference (ASC) in September!

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Living as a Ray of Light, Returning as a Boulder in the Rockies—

In Memory of Dr. Ray Radebaugh

by Limin Qiu, Zhejiang University, China

Ours is an era in which true masters are exceedingly rare. To be fortunate enough to cross paths with one is a radiant serendipity, an encounter profound enough to illuminate the long years that follow.

Over the years, I have read many biographies of distinguished figures (past and present), and have been fortunate enough to become close with a few who I regard as genuine masters. As an educator, I find myself constantly observing, reflecting, and asking: what shapes these individuals? Is it an inborn gift, the quiet persistence of daily effort, or the elusive hand of chance? I have come to understand that while the making of a master is undeniably rooted in unique personal endowments, it also includes certain universal codes of growth that ordinary people can study, practice, and ultimately internalize as our own enduring strength.

Among these rare masters was Dr. Ray Radebaugh (1939–2026). Ray was an internationally renowned cryogenic scientist and former head of the Cryogenics Division at the National Institute of Standards and Technology (NIST) and was precisely such a master—one worthy of our deepest admiration. The word “Ray” means a beam of light, and his life truly lived up to that name. Like a luminous ray, he pierced the mists of the cryogenic world, illuminating the path for countless explorers who followed.

My own connection with Ray began in my graduate years, through the quiet companionship of his papers. I compiled his publications on cryocoolers into a collection, poring over them time and again. The insight that glimmered between the lines dispelled much of my confusion in those uncertain days and awakened in me a deep longing. I thought what a rare privilege it would be to one day seek his guidance in person.

That quiet longing was finally fulfilled in 2001, at the Cryogenic Engineering Conference in Madison, Wisconsin. During our first meeting, his profound warmth and amiability shattered my preconceived notions of a towering master. Throughout the venue, nearly everyone was eager to speak with him, yet he always listened with infinite patience and greeted each person with a gracious smile.

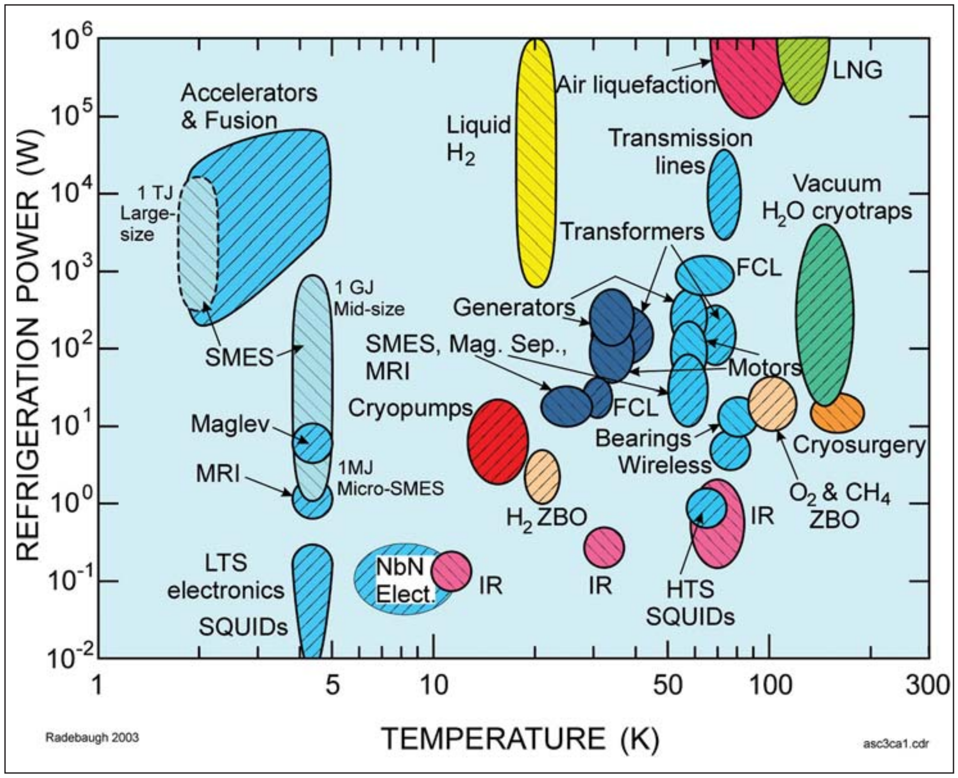

Figure 1. Dr. Radebaugh’s synthesis of cryogenic application fields and requirements (2003 Edition). Credit: Radebaugh

From that moment on, whether in chance encounters at international conferences, during his lectures at Zhejiang University, or in the lively exchanges within each other’s laboratories, I cherished every opportunity to converse with Ray and seek his counsel. Each time, his insights arrived like a clear breeze, bringing sudden clarity and quiet illumination.

In the years of knowing Ray, I gradually deciphered those codes of growth that forge a master, holding them as a guiding lodestar and sharing them with the students and colleagues around me. These codes are perhaps less a set of methodologies than a profound attitude toward life—an unwavering dedication of pursuing the ordinary to the absolute pinnacle of perfection.

Upon reflection, I see that at least five precious core strengths converged in Ray: each a blend of skill and spirit, each worthy of our careful study and wholehearted practice.

1. The Power of Insight: Bringing the Essence to Light

There is an ancient Chinese saying that “the greatest form is formless,” and it is the true master who can grant shape to this formlessness. When confronted with a phenomenon, an ordinary mind sees only a tangled web of endless threads, whereas a master can instantly grasp the core strand. When pondering a problem, the ordinary mind is often engulfed by a myriad of details, yet a master can elegantly distill the critical principles. This is not mere reduction; it is a profound insight that pierces through the superficial to capture the very essence.

Ray's own mastery of this power was most evident in how he traced the development of cryogenics. Through clear visualizations, he mapped the history and future trajectory of the field, refining these representations for decades until they achieved absolute clarity. Inspired by him, I often tell those around me: "Mastery begins with the art of synthesis." This ability to simplify complexity never arises spontaneously; it springs from long, deep reflection, repeated refinement, and the courage to discard what is irrelevant.

2. The Power of Foresight: Keeping the Future in Sight

Beyond understanding the present, a true master never views the world by standing still; rather, they stand at the crest of the era's tide, gazing out toward the horizons of the future.

In 2003, the Cryogenic Engineering Conference was held in Keystone, near Boulder, Colorado where Ray was based. After the conference, we were invited to visit his laboratory at NIST, and dinner was specially arranged at a scenic restaurant in the Rockies. The afterglow of the setting sun cascaded across the mountain ridges, painting a scene of profound tranquility and vastness. Seizing this rare opportunity, I posed a question that had been weighing on my mind: "What do you believe will be the most crucial development in the field of cryogenics over the next decade?"

He paused thoughtfully, then answered: the application of computational fluid dynamics (CFD) in cryogenics. He went on to paint a vivid picture of how this trajectory would unfold. I was thinking of studying the emerging CFD research at that time. Upon returning to China, we immediately assembled a team and recruited postdoctoral researchers, taking the initiative to pioneer research in this field. Over the next 20 years,

Figure 2. Ray attending the Zhejiang University Cryoboat Expo, an event he participated in multiple times. (Ray is pictured in the center of the second row; taken at Zhejiang University, April 2015). Credit: Zhejiang University

CFD has become a familiar and indispensable tool for our research, and we have benefited immensely from being among the earliest to champion its application.

In the following years, whether at Zhejiang University or at international conferences, I would always ask Ray similar future-oriented questions. To my profound delight, our answers grew increasingly aligned. A master's foresight is never baseless conjecture; rather, it is anchored in a deep cultivation of their field and an acute, penetrating insight into unfolding trends. This capacity can spare those who follow much trial and error, and it can guide an entire discipline to navigate the waves of its era with steady progress.

3. The Power of Focus: Marshalling Unyielding Might

To sustain such vision, a true master often carries a kind of pure devotion. Once they commit to a pursuit, they immerse themselves fully, day after day, decade after decade, with complete focus. It is not that they are averse to experiencing new things, but rather they harbor a profound understanding of the finite nature of human time and energy. Only through concentrated effort can one break through barriers and see vistas invisible to others. Some might deem such intense focus as too narrow, yet it is precisely this narrowness that propels them to the absolute pinnacle of their chosen field.

I once asked Ray out of curiosity that as a titan of the field, undoubtedly besieged by a demanding daily schedule, was he constantly interrupted by phone calls? He told me that his office phone was set solely to voicemail. He never answered calls in the moment. He would wait until his immediate work was completed, returning the messages one by one according to their urgency and importance.

This small detail captures the very essence of focus. True concentration is never a blanket rejection of the world, but rather the wisdom to know what can be left undone, and the discipline to draw distinct boundaries around one's energy. This seemingly simple resolve to leave the phone unanswered is, in truth, an indispensable foundational discipline of a master. Genuine efficiency is not measured by the sheer volume of tasks completed, but by the profound depth to which the most important work is pursued.

4. The Power of Legacy: Keeping the Flame Alight

A true master never confines their achievements to a bookshelf. What matters most is ensuring that their knowledge and

▶ *continues on page 10*

spirit continue to grow and flourish in the hands of those who follow.

Ray was not only a leading scientist, but also an extraordinary educator. He possessed a profound love for teaching and earned international renown for his short courses on cryogenics. He left his pedagogical footprints across many regions, including China, Japan, and Europe. He visited Zhejiang University multiple times to lecture, sharing his knowledge generously and patiently by answering every question from both students and colleagues. For many students, their fascination with cryogenic research was ignited by his lectures; Ray's dedication and pure passion for scientific inquiry profoundly touched and inspired everyone he met.

I have always believed that a person's true achievement is never measured merely by the volume of work they leave behind, but by whether those achievements and that very spirit continue to live on long after they are gone. A master's most profound virtue is forged not merely through creation but is ultimately fulfilled through transmission. For the younger generation, to be granted the privilege of beginning their own journey from the shoulders of a master is one of life's greatest fortunes.

5. The Power of Synthesis: Taking a Boundless Flight

For all their intense focus, true masters are never confined by the borders of a single discipline. While they cultivate their own domain with profound depth, they forever sustain a vibrant curiosity about the world; their gaze perpetually sweeping beyond the limits of their field. They understand intimately that the most spectacular breakthroughs in science often unfold at the peripheries and intersections of distinct disciplines.

This transboundary vision requires two bedrock foundations. First, a profound immersion in one's own field to establish a formidable professional grounding. And second, an inexhaustible curiosity about the world, perpetually extending the mind's exploratory reach outward.

Figure 3. A retirement gift meticulously prepared for Ray by the faculty and students of Cryoboat, containing precious records of his many visits and lectures at Zhejiang University (March 2009). *Credit: Zhejiang University*

Ray once graciously invited me to his home in Louisville, Kentucky, and that visit revealed another dimension of his life beyond research. He was an avid rock gardener, having created an expansive alpine rock garden that nearly covered his entire yard, complete with a pond and stream modeled after the Rockies. His passion for stones and dedication to gardening mirrored the focus he brought to his scientific work. This cross-disciplinary love, in turn, broadened his perspective and inspired fresh ideas in his research.

Perhaps this is the hallmark of a true master. They live life as art, infusing every corner of existence with their passion.

In February 2026, Dr. Ray Radebaugh departed this world forever, leaving behind the field of cryogenics to which he had devoted his life's work, and bidding farewell to his beloved family, his friends, and his cherished rock garden.

Yet, he has never truly left us. His academic legacy continues to radiate warmth and light within the cryogenic realm. Ray's spirit as an educator continues to nourish countless successors. And his profound love for life, paired with his unyielding dedication to research, continues to inspire us to forge bravely ahead.

I would much rather believe that he has simply transformed into a great boulder within the Rocky Mountains, standing tall upon the land he so deeply loved. From there, he silently guards the path of exploration in cryogenics, quietly watching the countless followers who chase the light he once ignited.

The codes of growth Ray left us will serve as our compass. Guiding us along the paths of science and life, and helping us remain true to our beginnings by holding fast to our passions and striving to become a light of our own. Perhaps this is the most profound and fitting memorial to Ray.

Vibration-Free Cryogenic Cooling for the Einstein Telescope: Part I

A Sorption-Based Joule-Thomson Approach

by Michiel van Limbeek, Cris Vermeer, and Marcel ter Brake, University of Twente. Romaine Kunst, Adrie Visser, Pieter Lerou, and Erik-Jan de Hoon, Demcon kryoz. Johannes Burger, Martijn Al, and Hassan Firouzbakht, Cooll.

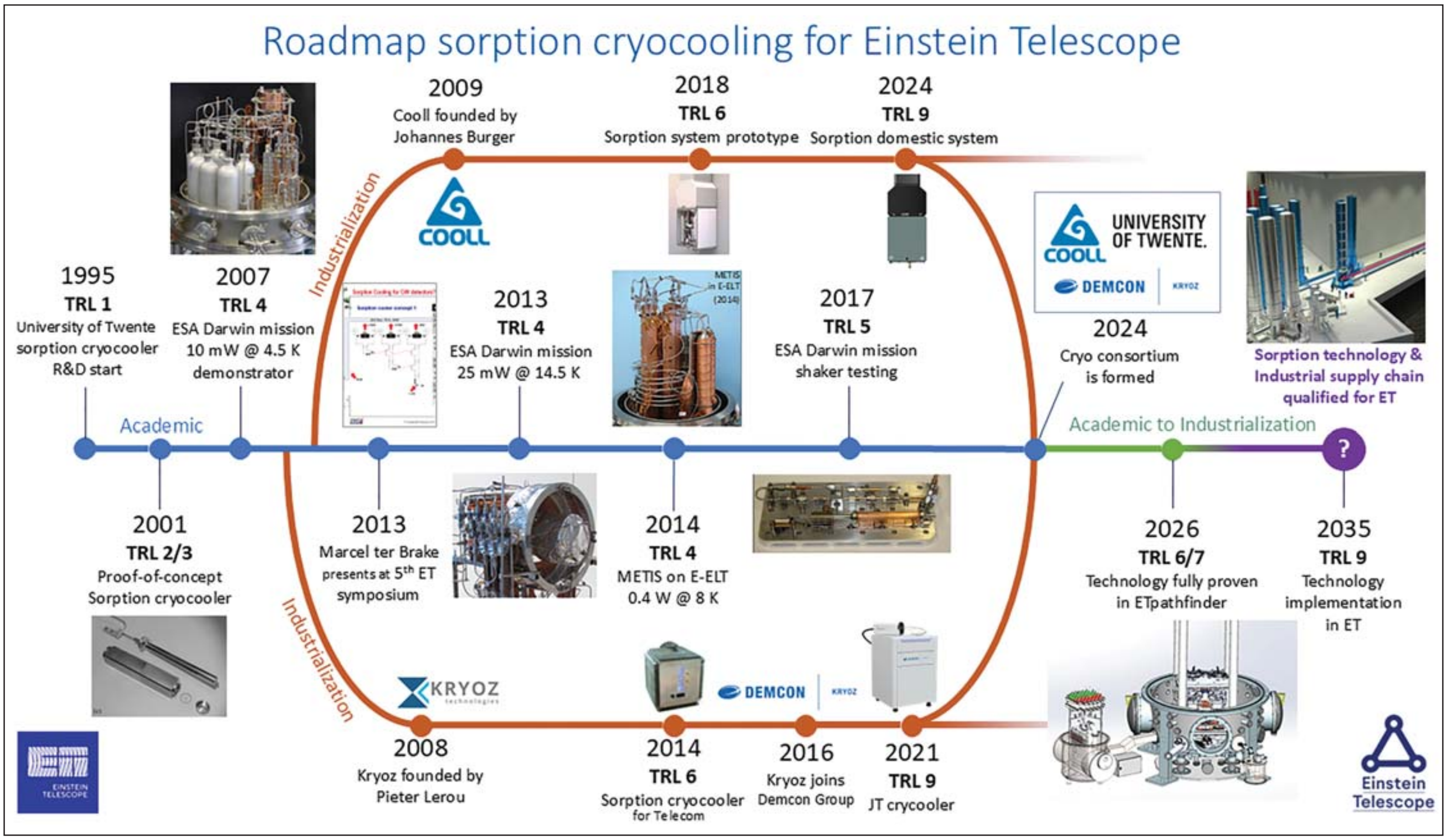

Figure 1. Roadmap for the sorption cryocooling technology for the Einstein Telescope, showing the heritage of the technology.[2-9] *Credit: ETPF Project*

The Einstein Telescope (ET) will be the first third-generation gravitational wave detector, marking a new era in gravitational wave science. To detect relative length changes smaller than 10^{-22}, one of the most revolutionary technologies in ET is the cryogenic system which will cool the main optics to approximately 10 K. Considering the extreme sensitivity targeted by third-generation laser interferometers, it is essential that this cryogenic cooling operates continuously with ultralow vibration levels in order to minimize thermal noise.

To address these stringent vibration requirements, a new sorption-compressor-driven Joule-Thomson cryocooler has been developed by a consortium of University of Twente, Demcon kryoz, and Cooll Sustainable Energy Solutions. The system features a vibration-free, three-stage cooling architecture using sorption compressors and Joule–Thomson expansion to reach a temperature down to 8 K, without any active mechanically moving parts.

The sorption-compressor-driven Joule-Thomson cryocooler has been developed for the ETpathfinder (ETPF) project. The ETPF facility is a scaled testbed for the development and demonstration of key enabling technologies for ET. Construction started in 2025 at the University of Twente and Demcon kryoz, with validation taking place at the University of Twente in the summer of 2026. The first integration steps into the ETpathfinder setup are expected by late 2026, marking a significant realization step towards meeting the requirement for ET. The vibration requirement at the cold finger is exceptionally demanding: seismic excitation has been measured at the ETpathfinder site with an amplitude spectral density of 4 nm /√Hz in the frequency range of 2-10 Hz.[1] The amplitude spectral density indicates not only how much an object is vibrating, but also helps to understand which frequencies are contributing to that vibration. The measured amplitude spectral density corresponds to a peak-to-peak displacement of 32 nm. This vibration level cannot be exceeded by the sorption-based cryocooler. To put that into perspective, a human hair has a thickness

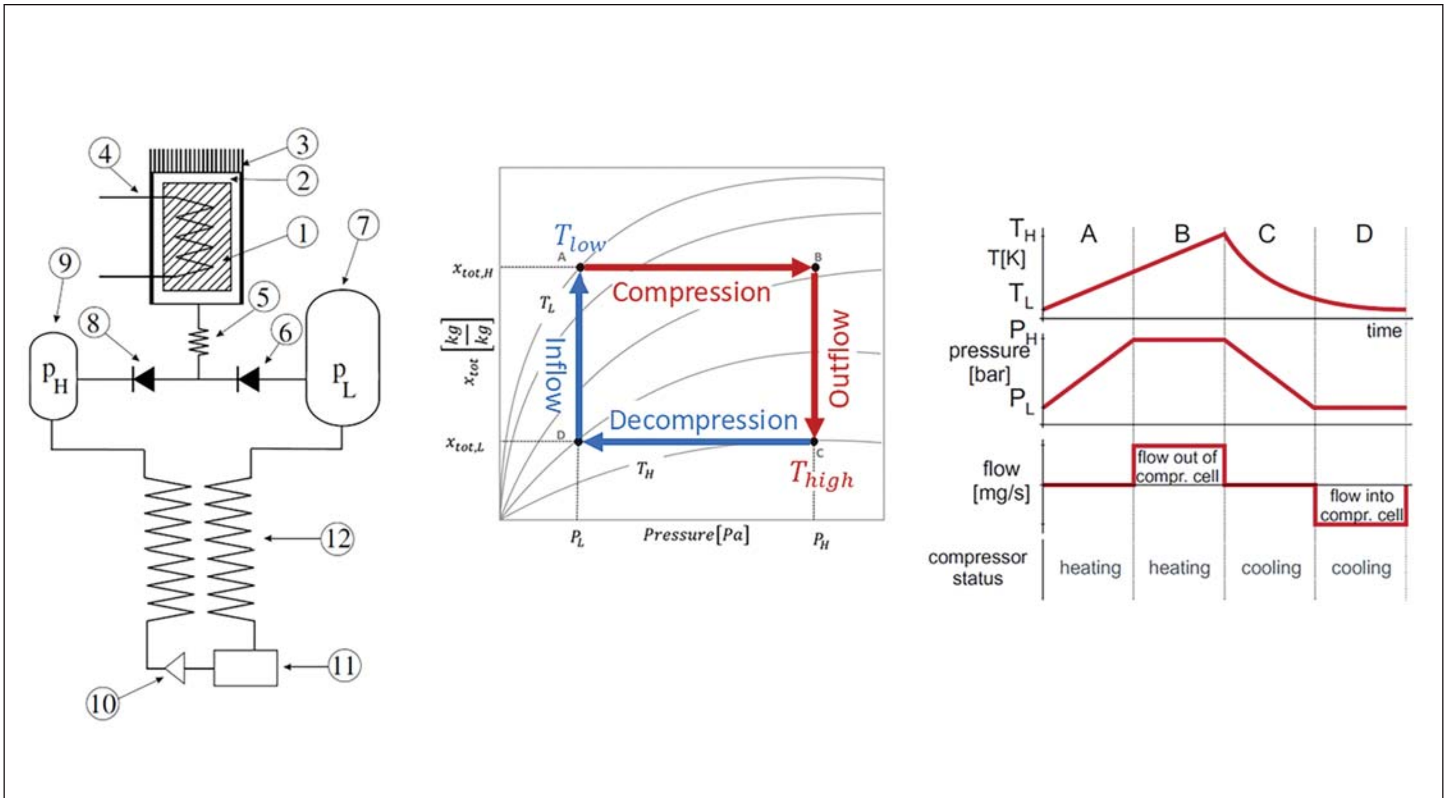

Figure 2. Simplified schematic representation of a typical JT-sorption cooler (left):1: sorber container; 2: container wall; 3: heat sink; 4: heater; 5: after cooler; 6: low pressure valve; 7: low pressure buffer; 8: high pressure valve; 9: high pressure buffer; 10: Joule-Thomson restriction; 11: evaporator; 12: counter-flow heat exchanger, along with an idealized sorption cycle (middle and right). In the initial state (T_{low}, p_{low}) the sorption compressor is heated. Once the high pressure p_{high} is reached in the cell, the high pressure check valve opens, allowing gas to flow out of the cell. The heating continues until high temperature T_{high} is reached in the cell. Then, heating is stopped and the temperature and pressure in the cell start to drop. As a result, the high pressure check valve closes. Because of the thermal contact with the heat sink the cell further cools and the pressure in the cell reduces until the low pressure is reached (P_{low}). At this point the low pressure check valve opens and working gas starts flowing into the compressor to get adsorbed while cooling in the cell continues. Once the low temperature (T_{low}) is reached, the sorption cycle restarts in the initial state.[2-4] Credit: ETPF Project

of 50 µm. Although challenging, the strong heritage in sorption-based cryocooling in Twente (The Netherlands) provides a solid foundation for the development of this innovative cryocooler, and the consortium's combined expertise ensures confidence in reaching the required technology readiness level (TRL 6–7) within the given timeframe of three years from the Dutch National Growth Fund. The roadmap of this technology is displayed in Figure 1. Previous achievements demonstrate the feasibility of this technology. For example, vibration levels below the required displacement level of 0.28 µm peak-to-peak were achieved for a 4.5 K helium sorption cryocooler for the ESA Darwin mission in 2007.[2] Furthermore, Demcon kryoz has developed the CryoEM cooler, an OEM product to cool samples to cryogenic temperatures in an Electron Microscope (EM), with specifications of approximately 1 nm peak-to-peak vibration levels, demonstrating the consortium's capability to deliver breakthrough cryogenic technologies.

The resulting system is a three-stage sorption-based Joule-Thomson (JT) cryocooler using neon, hydrogen, and helium stages to achieve an available cooling power of 50 mW at a temperature of 8 K at the cold tip of the cryocooler. The helium stage functions as a heat sink to cool the mirrors, the main optics in the interferometer. The hydrogen and neon stages provide intermediate cooling to reduce radiative heat loads and provide cooling power to the helium stage. Based on its design, the system is expected to remain well below the specified vibration levels.

This article first explains the architecture of the cryogenic cooling system, including the rationale behind key design choices. It then describes the systems engineering approach and modeling activities used to verify compliance with the requirements for cooling power, temperature and cooldown time. Finally, part two of this article will address the fundamental research and mitigation strategies implemented to achieve the most stringent requirement: extremely low-vibration levels.

System Overview

For every new gravitational wave detector, the aim is to improve sensitivity. To achieve that, various noise levels have to be reduced overall. The reduction of thermal noise was first addressed in the latest gravitational wave detector, KAGRA. Thermal noise reduction allows for a higher sensitivity in the low-frequency domain. Cryogenic temperatures of 20 K are achieved in KAGRA in a high-vacuum environment by using multi-stage pulse tube cryocoolers. However, for the Einstein Telescope, the aim is to further increase sensitivity. For example, an increased sensitivity of three orders of magnitude at 5 Hz compared to KAGRA is foreseen. Achieving cryogenic temperatures while meeting the stringent vibration requirements at the cold tip demands a cooling solution that introduces

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virtually no vibrations at the cold finger. Conventional mechanical cryogenic coolers — such as Stirling, "pulse tube," mechanical Joule-Thomson (JT), and Gifford-McMahon (GM) coolers — rely on moving mechanical components, which inevitably generate and transmit vibrational noise to the payload. To achieve a higher sensitivity than the latest detector, there is a need for a new cooling solution.

Working Principle of Sorption-based Joule-Thomson Cold Stages

A fundamentally different approach is needed, which the Twente sorption-based JT-cryocooler offers. In this concept, JT-cold stages based on the Linde-Hampson cooling cycle are driven by sorption compressors. Figure 2 illustrates the basic architecture of a sorption-based JT cryocooler. The system comprises a sorption compressor cell, two buffer volumes, and two passive valves.

The sorption compressors consist of multiple cells filled with adsorbent material, such as activated carbon. These compressors operate thermally rather than mechanically. During operation, the sorption cell is alternately heated and cooled. When heated, the adsorbed gas is desorbed, increasing pressure until the high-pressure check valve opens, allowing gas to flow into the high pressure buffer. By cyclically heating and cooling the sorption cells and directing gas flow through passive check valves, allowing gas to flow into the high pressure buffer. Hence, creating a continuous gas stream through the JT-cold stage. The cooling cycle is a Linde-Hampson cycle incorporating Joule-Thomson expansion. During the Joule-Thomson expansion, the gas expands isenthalpically across the JT-restriction into the low pressure side, where it cools significantly and may partially liquefy. This is for the reason that expansion is achieved below the inversion point. This cold gas absorbs heat from the environment via a heat exchanger — referred to as evaporator when liquefaction occurs — before returning through the counterflow heat exchanger (CFHX) to recover heat from the incoming high-pressure stream. The highly efficient counterflow heat exchangers function as recuperators; establishing an efficient cooling cycle. Once the cell is cooled and the pressure drops below the low-pressure level in the low-pressure buffer, the low-pressure check valve will open, and the cycle repeats.

System Design around Sorption-based Joule-Thomson Cold Stages

To maintain the cold tip at approximately 8 K with minimal vibration, the design avoids any phase change at the cold tip, which dictates the use of helium as the working fluid for the final stage. Helium will be operated in single gaseous phase, which is not an option for the hydrogen stage, since hydrogen is in the solid phase at 8 K. Achieving this requires multiple subfunctions within the cooling cycle:

- Pressure Management: High and low pressures must remain stable to ensure sufficient cooling power and mass flow. This is achieved first by operating the heating time of multiple cells out of phase. This stabilizes the outflow of the compressor. Final pressure regulation is achieved by the high and low pressure buffer that further dampen these flow fluctuations.
- Thermal Management: To cool the mirrors of the interferometer, flexible heat links will transfer the heat from the mirror towards the helium cold tip. Because helium alone cannot provide the required cooling power of 50 mW at 8 K, additional stages are required. The system therefore employs a three-stage architecture in which all stages are thermally linked via intercoolers:
    - Stage 1 (Neon): The neon stage cools the intermediate radiation shield and precools the helium and hydrogen cold stages at 35 K. Provides initial cooling and cools an outer radiation shield.
    - Stage 2 (Hydrogen): The hydrogen stage cools the innermost radiation shield and precools the helium cold stage at 18 K. The intercooler of the hydrogen stage determines the precooling temperature of the helium stage.
    - Stage 3 (Helium): Achieves the final 8 K at the cold tip.

  The heat will be transported through this cascade configuration through the hydrogen and neon stage towards the liquid nitrogen bath, the backend cooling source of this cooler. The ultrahigh vacuum (UHV) environment inside the mirror tower will eliminate convective losses.
- Shielding Strategy: A liquid nitrogen bath cools the the 77 K shield and the floating shield, which intercepts radiative heat load from the 300 K external environment. Inside this area are two additional actively cooled shields, one cooled by the neon stage and one cooled by the hydrogen stage. These shields will reduce the radiation heat load onto the helium cold tip. This configuration minimizes heat loads on the optics while maintaining mechanical isolation.

The helium cold stage has a cooling power of 50 mW, however; to cool the system down from room temperature to cryogenic temperatures will take weeks because of this low cooling power. Therefore, for the initial cooling down process of the system, an additional kickstarter system is introduced. This auxiliary system is a Gifford-McMahon cryocooler that provides high cooling power of 250 W during the initial phase, rapidly removing heat from the large thermal masses. Once the system reaches cryogenic conditions, the kickstarter is fully disconnected and the sorption cryocooler takes over ensuring vibration-free operation for the remainder of the process. This staged approach results in a total cooldown time of less than seven days.

Look for Part 2 of this feature in the next issue of ***Cold Facts***.

References:

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Cryotreatment

by Jack Cahn, Chief Technologist, DCI, jack@deepcryogenics.com

Mechanisms Behind Deep Cryogenic Treatment in Ground Engagement Tools

Deep cryogenic treatment (DCT) has become an important enhancement process for ground engaging tools (GETs). These components operate in some of the harshest service environments where abrasive wear, repeated impact loading, and cyclic fatigue combine to cause premature failure. Unlike conventional heat treatment alone, DCT modifies the internal microstructure of alloys at temperatures approaching -300°F (-184°C), creating improvements that directly address the dominant failure modes seen in mining GET applications.

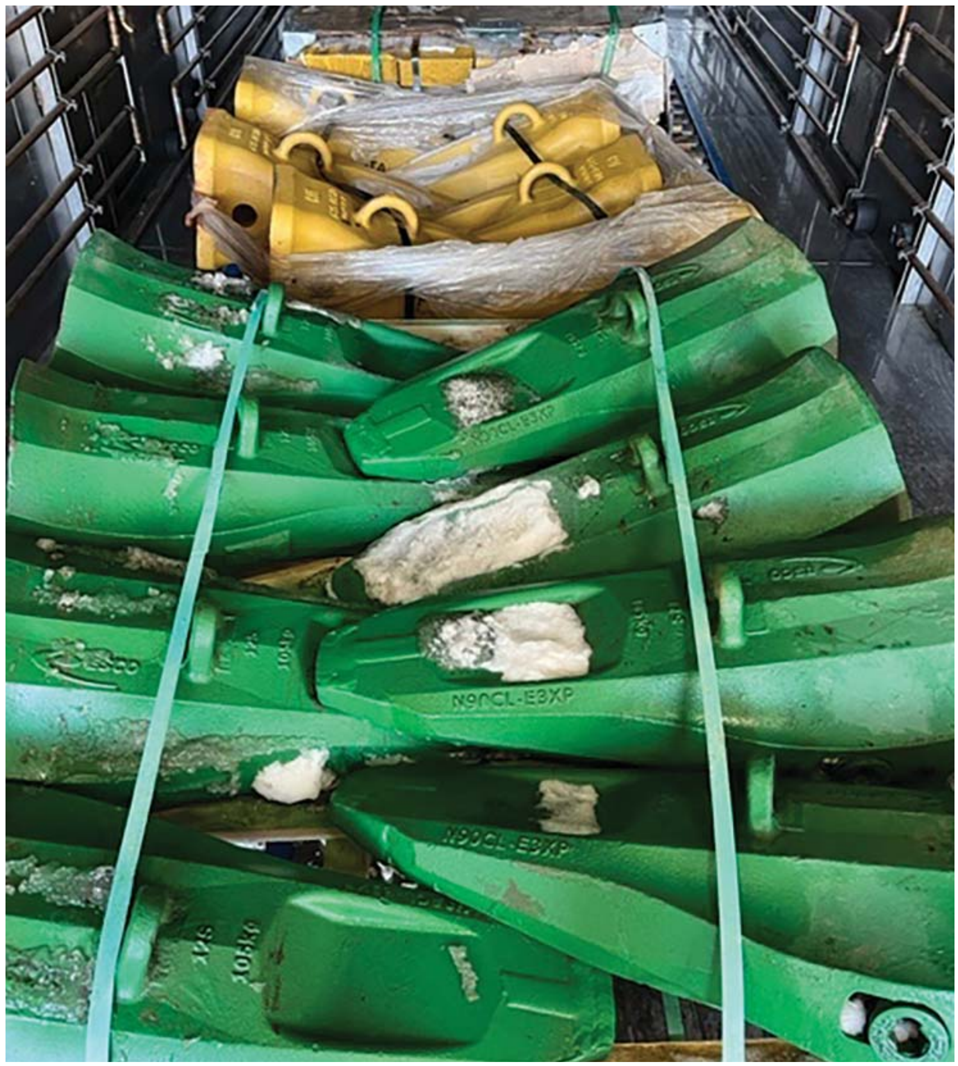


Figure 1. ***Deep cryogenic treatment of shovel teeth.*** *Credit: J. Cahn*

Primary Failure Modes in Mining Ground-Engaging Tools

In mining applications, GETs fail primarily through two mechanisms: progressive fatigue cracking and catastrophic impact fracture. A shovel tooth repeatedly striking blasted rock experiences extremely high cyclic compressive and tensile stresses. Even when the surface appears intact, microscopic fatigue cracks initiate at carbide interfaces, inclusions, or residual tensile stress regions. Over thousands of loading cycles these cracks propagate until the tooth fractures. DCT improves resistance to this process by altering residual stress distributions, refining carbide precipitation and stabilizing the alloy matrix structure. (Figure 1)

DCT Mechanisms in High Chrome White Iron

For high chrome white iron GETs, the mechanism is especially important because these alloys derive their wear resistance from large chromium carbides embedded within a martensitic matrix. Under heavy impact loading, retained austenite (left over from the casting process) can transform unpredictably, generating localized stresses that accelerate crack formation. During DCT, much of this retained austenite transforms into fine martensite, increasing matrix uniformity and dimensional stability. This reduces carbide pullout and suppresses microcrack nucleation at carbide boundaries—both common initiation points for fatigue failure in white iron mining components.

DCT Benefits in 13% Manganese Alloy Steel

In 13% manganese alloy steels (commonly used where high-impact toughness is required) the benefits of DCT are somewhat different. Hadfield manganese steel is valued because it work-hardens during service while retaining a tough austenitic core. Bucket teeth and crusher components made from manganese steel survive severe impact because the alloy absorbs energy without brittle fracture. DCT enhances this behavior by refining dislocation structures and promoting more uniform strain hardening under impact conditions. Research on high-manganese TWIP/TRIP steels shows that cryogenic processing and related surface treatments can increase compressive residual stresses and improve cyclic performance.

Role of Residual Stress in Fatigue Resistance

The importance of compressive residual stress for mining GETs cannot be overstated. Fatigue cracks grow most readily under tensile stress. DCT-induced compressive stresses counteract service-induced tensile loads, making it mechanically more difficult for cracks to open and propagate. This results in fewer tooth breakages and reduced risk of losing fragments into crushers. (Figure 2)

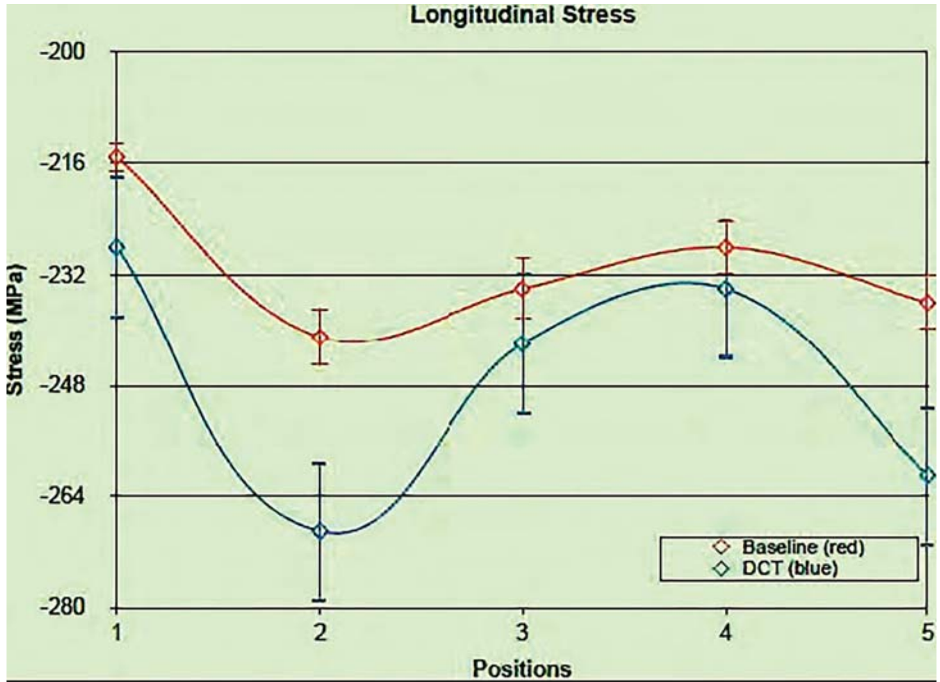


Figure 2. Residual Stress. *Credit: J. Cahn*

Impact Resistance and Structural Durability

Mining shovel teeth frequently encounter shock loads from large boulders. Conventional hardening processes often increase hardness at the expense of toughness, making the component more brittle. DCT differs because it refines the microstructure without producing the coarse brittle phases associated with over-hardening. The fine carbide distribution generated during cryogenic soaking helps disperse impact energy more evenly through the alloy matrix. This reduces localized stress concentrations that normally trigger brittle fracture.

Difference Between DCT in Cutting Tools and Mining GETs

The performance improvements seen in heavy equipment GETs differ significantly from those observed in carbon steel cutting tools used in edge-retention applications. In knives, dies, and machining tools, DCT primarily improves edge sharpness retention and abrasive wear resistance. The mechanism centers on converting retained austenite to martensite and precipitating extremely fine eta carbides that strengthen the cutting edge. The primary benefit is reduced edge rounding and slower abrasive wear during sliding contact.

Mining GETs operate under entirely different loading conditions. Bucket teeth are not precision cutting tools; they are large structural wear components exposed to high-impact gouging abrasion and repeated shock loading. Consequently, the value of DCT in GETs is less about maintaining a sharp edge and more about extending structural integrity under cyclic stress. The dominant improvements are enhanced fatigue resistance, reduced crack propagation, improved impact toughness and more stable work-hardening behavior. While abrasive wear resistance still improves, the greatest economic benefit often comes from preventing catastrophic tooth breakage and increasing service reliability in severe mining environments. (Figure 3)

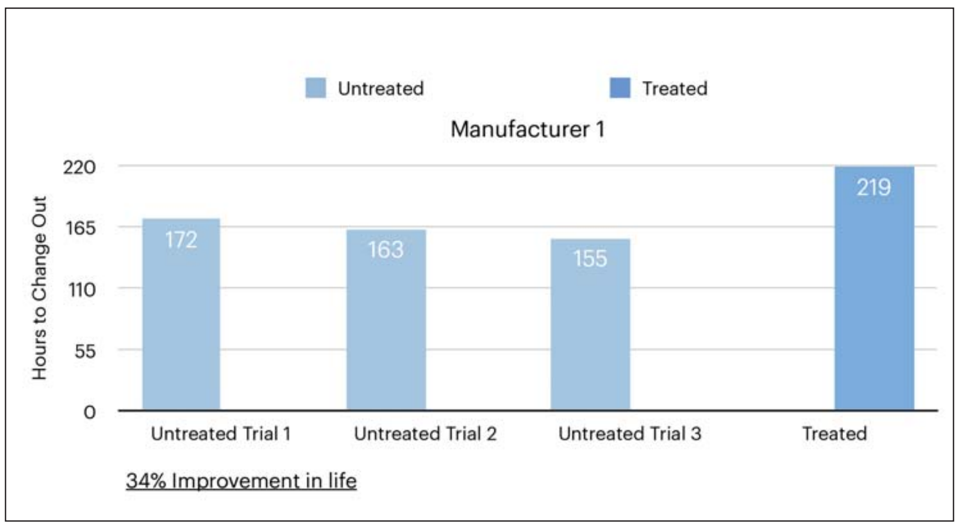
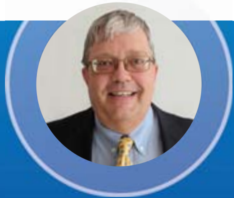


Figure 3. DCT wear life improvement. *Credit: J. Cahn*

Conclusion

Ultimately, DCT functions as a microstructural optimization process that enhances both wear and mechanical durability. For high chrome white iron and 13% manganese alloy GETs, the treatment creates a more stable, refined, and fatigue-resistant structure capable of surviving the extreme combination of abrasion and impact encountered in mining operations. By addressing crack initiation and propagation at the microscopic level, DCT provides measurable improvements in operational life, maintenance reduction, and equipment reliability.



Cryo Bios

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

Guy Gistau-Baguer *(1940 – 2024)*

Guy Gistau-Baguer made significant advances in the development of medium- and large-scale helium refrigerators and was at the forefront of moving large practical systems into scientific facilities throughout the world. Gistau-Baguer taught extensively, wrote an important text on cryogenic refrigeration, and provided years of service to the cryogenics community.

Guy was born in Génos, France and graduated from the École Nationale Supérieure des Arts et Métiers in 1963. In 1965, he joined Air Liquide where he spent the bulk of his career, retiring in 2000.

During his time at Air Liquide, Guy performed tasks including operation of an air separation plant, technical gas sales, and most extensively, the design, installation, and commissioning of helium refrigeration and liquefaction plants. Guy helped develop the first automatic helium refrigerator/liquefier (HELIAL) as well as the Tore Supra refrigerator, the CEBAF refrigerator and three plants at CERN: a 6 kW at 4.5 K refrigerator, the LEP 12/18 kW at 4.5 K refrigerator, and the LHC 18 kW at 4.5 K and 2.4 kW at 1.8 K refrigerator.

The Tore Supra refrigerator was the first to use cold compressors to reach 1.8 K (Figure 1). Today this technique is used for all large plants wishing to achieve temperatures below 4.2 K. The plants at CEBAF and CERN are large-scale helium refrigerators that are efficient, reliable, and automated. Guy was awarded nine patents in the field of helium refrigeration during his career.

After his retirement from Air Liquide, Guy worked as a consultant and educator. He taught more than 80 classes on cryogenic fundamentals and helium. He was a

Figure 1. The Tore Supra helium refrigerator showing the centrifugal cryogenic compressor (or cold compressor). *Credit: Guy Gistau*

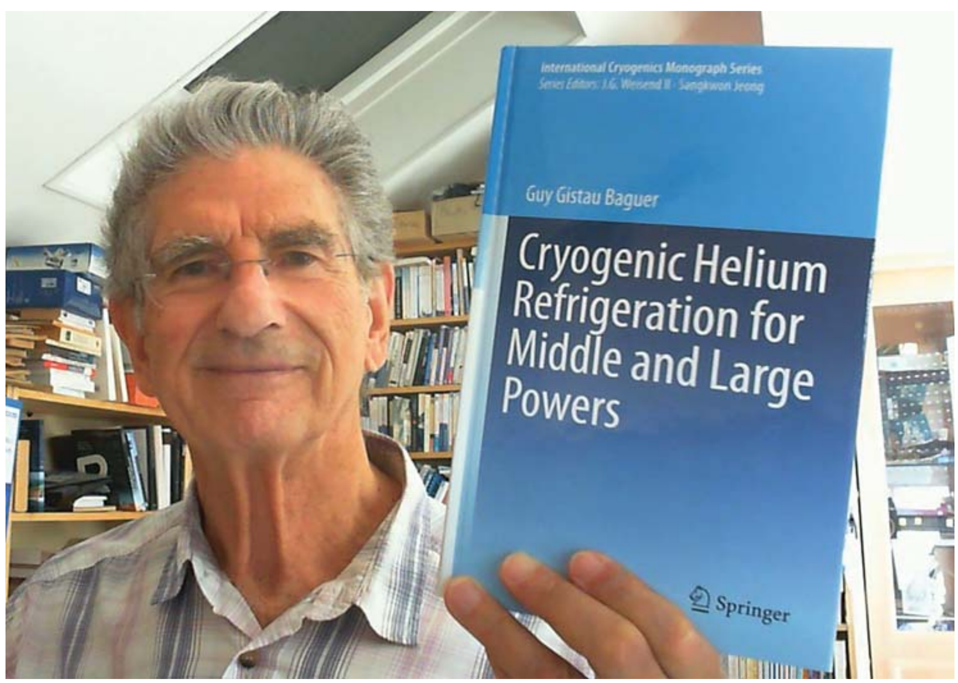


Figure 2. Guy Gistau-Baguer with his book, Cryogenic Helium Refrigeration for Middle and Large Powers. *Credit: Cryoguy.com*

consultant on many cryogenic projects including the ITER fusion experiment and the European Spallation Source (ESS).

Guy published more than 50 papers on various aspects of cryogenics including: “Design of the Cryogenic System for the Tore Supra Tokamak,” Cryogenics, Vol. 26 (1986) and “Two Large 18 kW (Equivalent Power at 4.5 K) Helium Refrigerators for CERN's LHC Project, Supplied by Air Liquide,” Advances in Cryogenic Engineering (1999).

Toward the end of his career, Guy captured his experience in the book *Cryogenic Helium Refrigeration for Medium and High Powers*, Springer (2020). This text (Figure 2) provided both theoretical and practical information on the design and operation of these refrigerators. The book was extensively equipped with figures, tables, and equations. One notable aspect of the book was a “Cryogenic Tool Box” that explains how to perform typical thermodynamic calculations with REFPROP® and Excel® for heat exchangers, expansion turbines, and other cryogenic components.

Guy was deeply involved in service to the cryogenic community. He served on the International Cryogenic Engineering Conference (ICEC) board from 1984 to 2008, chairing the board from 1998–2008. He also served on the A1/2 commission of the International Institute of Refrigeration (IIR) and the board of the Association Française du Froid, Commission Cryogénie et Supraconductivité. He also served as an advisory editor for the journal ***Cryogenics***. He was always willing to review papers, chair conference sessions, or speak to students.

For his accomplishments in cryogenics, Guy was presented the Mendelssohn Award by the ICEC board and the Charles Tellier Medal from the Association Française du Froid.

Guy Gistau-Baguer’s contributions helped bridge the gap between laboratory and industry. His efforts are part of the reason that large-scale helium cryogenic systems are ubiquitous in modern science laboratories.

Space Cryogenics

Mark Kimball, PhD, Cryogenics and Fluids Branch, NASA Goddard Space Flight Center

Goddard Goings: An Insight into Past, Present, and Future Cryogenic Missions

Hubble, James Webb, Roman; these are space telescopes most readers of this magazine probably recognize. The space observatories XRISM, Herschel, and Planck may be less recognizable. If you don't know GUSTO, TOPHAT, ARCADE, PIPER, SPIDER, and POEMM you are not alone. These are experiments that have flown or will fly at high altitudes, brought there by enormous balloons filled with helium.

NASA's scientific helium balloons in action. *Credit: NASA*

NASA's Scientific Balloon Program

Welcome to the NASA Scientific Balloon Program. This program began more than 30 years ago, and the current mission statement reads as follows.

"The primary objective of the NASA Balloon Program is to provide high altitude scientific balloon platforms for scientific and technological investigations. These investigations include fundamental scientific discoveries that contribute to our understanding of the Earth, the solar system, and the universe. Scientific balloons also provide a platform for the demonstration of promising new instrument and spacecraft technologies that enable or enhance the objectives for the Science Mission Directorate Strategic Plan."

Let's unpack this mission statement. In this case, high altitude means somewhere between 30 km (~18 miles) above the Earth's surface to more than 42 km (~25 miles). This altitude is firmly within the stratosphere—the second lowest layer of Earth's atmosphere. In this layer, there is less absorption of high-energy photons and cosmic particles than at the Earth's surface. Also, with 1/1000 the gas pressure found at sea level, there is much less turbulent disruption of an image. Missions that are part of the balloon program are a great way to make fundamental discoveries at a fraction of the cost of the development and deployment of a satellite. Balloons are also an economical (by spaceflight standards) means to demonstrate new detector technology for later incorporation into a more sophisticated (and costly) satellite program.

These last statements are reinforced by Karwan Rostem (NASA GSFC), Instrument Principal Investigator of the POEMM mission. "Scientific ballooning provides a critical, cost-effective platform for the astrophysics community, allowing researchers to test cutting-edge technologies for capturing astronomical signals above the Earth's atmosphere." Rostem said. "The Planetary Origins and Evolution Multispectral Monochrometer (POEMM) Astrophysics Pioneers mission exemplifies this advantage by utilizing a NASA long-duration balloon, floating at an altitude of 36 km, to observe protoplanetary disks, the precursors that evolve to form Solar systems like our own." We will discuss POEMM again later in this article.

This is ***Cold Facts***, Kimball! Where is the cryogenics tie-in? I'm getting there. But before I do, let's talk more about the balloons. Two classes exist: zero-pressure and super-pressure. Zero-pressure balloons are not sealed at the bottom facing the gondola and have vents on the sides to allow a zero-pressure differential to the surrounding atmosphere. This class of balloon is typically used for "conventional" flights, lasting up to 36 hours, or "long-duration" flights that may last from 4-60 days. These balloons can carry a scientific payload as massive as 3,000 kg. Super-pressure balloons, as the name implies, have the helium sealed inside the thin polyethylene film that forms the balloon. This allows them to support ultralong-duration missions up to 100 days. However, the current record stands at about 57 days. The maximum mass of the payload on these balloons is just north of 900 kg.

PIPER Logo. Credit: NASA

EXCLAIM Logo. Credit: NASA

POEMM Logo. Credit: NASA

The Scientific Balloon Program is managed by the NASA Wallops Flight Facility located on the Eastern Shore of Virginia. Until very recently, Wallops was part of NASA Goddard Space Flight Center. Now, Wallops is affiliated with the Kennedy Space Center.

Cryogenic Balloon Missions Supported by Goddard

Three recent balloon missions with sub-Kelvin detector packages have been, or currently are supported by Goddard: PIPER, EXCLAIM, and POEMM.

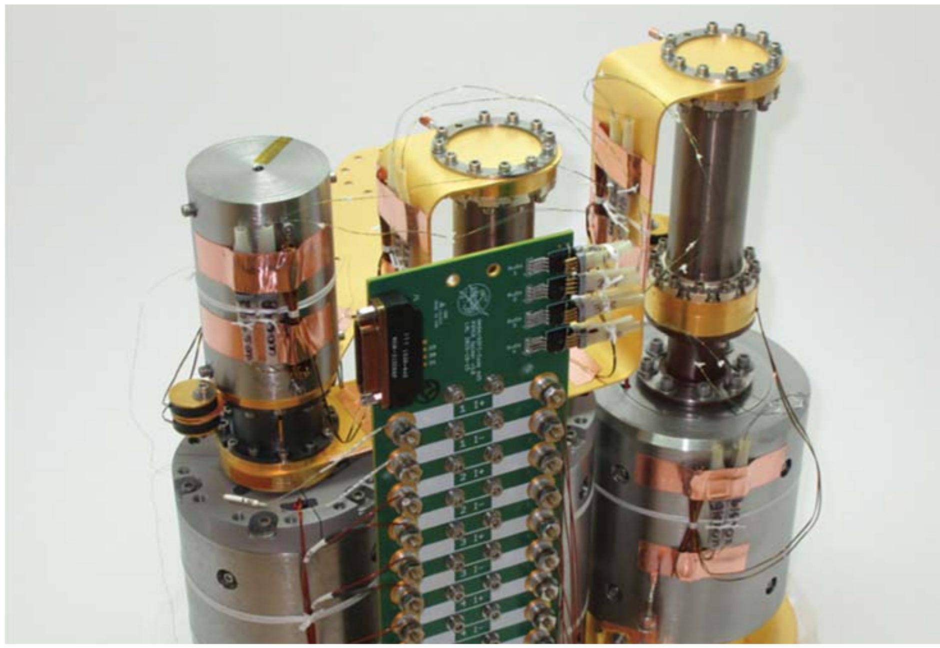


Figure 1. PIPER 4-Stage CADR. *Credit: NASA*

PIPER, the Primordial Inflation Polarization Explorer, was developed to study large-angular scale B-mode polarization in the cosmic microwave background radiation of the universe. To achieve this, two telescopes focus incoming radiation on four 32x40 arrays of superconducting transition-edge sensors developed at Goddard. These are located behind a grid of tightly spaced copper-coated tungsten wires. This grid separates polarized and non-polarized radiation and is key to the instrument. To achieve the sensitivity necessary to see the incredibly weak remnant from the Big Bang, the sensor arrays are cooled to 70 mK by a compact four-stage continuous adiabatic demagnetization refrigerator (CADR) shown in Figure 1. Heat lifted by the CADR is rejected to a helium bath contained in a very large bucket Dewar. Upon launch, there was roughly 3,000 liters of helium in the Dewar. PIPER launched on October 14, 2019, from NASA's Scientific Balloon Flight Facility in Ft. Sumner, New Mexico, and flew for 13 hours. The cryogenic system was operated successfully upon float, but, unfortunately, no scientific observations were made since the observation hatch that protected the instrument during ascent failed to open. The goal is to re-fly PIPER when the time is right.

EXCLAIM, the EXperiment for Cryogenic Large-Aperture Intensity Mapping, is another balloon-borne mission that examines the universe in the far-infrared portion of the electromagnetic spectrum. Eric Switzer, astrophysics cosmologist at GSFC and the Principal Investigator for EXCLAIM, describes the mission. "EXCLAIM is a balloon-borne far-infrared mission investigating why cosmic star formation declined sharply up to the present, despite continued efficient clustering of dark matter," Switzer said. "EXCLAIM performs line intensity mapping of carbon monoxide and singly-ionized carbon with six MKID-based spectrometers. Its cryogenic design is central to the measurement: the telescope is cooled to 1.7 K to suppress self-emission, and the detectors operate at 100 mK, cooled by a three-stage CADR coupled to a 4-He sorption fridge at 900 mK."

Switzer goes on to highlight the importance of the balloon program to NASA science in general. "Scientific ballooning provides affordable, near-space access for large payloads and plays a unique role in the space science ecosystem. It enables flight demonstrations of technology a decade or more ahead of what is baselined for space missions, advancing TRL (technology readiness level) at the system level and bridges the gap between detector lab tests and full instruments. This is especially

▶ ***continues on page 22***

valuable for complex, cryogenic payloads, where balloons buy down risk well before the rigid schedules of a space mission take hold. Ballooning also supports targeted science not well-served by the major observatories and provides early- and mid-career staff with major responsibilities and system-level ownership rarely possible on flagship missions." EXCLAIM is ready to fly now and is presently awaiting funding for their launch.

POEMM, the Planetary Origins and Evolution Multispectral Monochromator, is a Pioneers-class balloon mission currently in development to study planet formation and evolution in the far-infrared. To accomplish this, the mission combines a 1.8-meter telescope supplied by NASA Marshall Space Flight Center, a virtually imaged phase array (VIPA) provided by Cornell University/GSFC, and a kinetic inductance detector with nearly 16,000 pixels spread over four independent arrays. This is contributed by SRON, the Space Research Organisation Netherlands. NASA Goddard is supplying the 3-stage CADR and liquid helium Dewar.

The current design of the balloon gondola that contains the mirror and Dewar along with the solar panels and flight electronics is seen in Figure 2. POEMM will launch in 2029 from the Long Duration Balloon launch pad, located about eight miles from McMurdo Station on the Ross Ice Shelf, Antarctica, with a planned mission duration of 20 days. To achieve this, a super-pressure balloon is necessary.

Karwan Rostem digs a little deeper into the science. "By deploying cutting-edge technologies like high-resolution Virtually Imaged Phased Arrays (VIPAs) and superconducting detectors, POEMM is uniquely positioned to trace warm water vapor, water-ice features, and molecular gas mass (HD) in protoplanetary disks. These observations fill a crucial gap left by ground observatories (like ALMA) and space telescopes (like JWST), providing the community with data needed to answer fundamental questions about how molecular clouds collapse to form planets, how water is delivered to terrestrial worlds, and the formation history of planets like Neptune."

This is just a brief introduction into NASA's Scientific Balloon Program. If you want to learn more about the program and the science it supports, the following sites are a good start. **ww.nasa.gov/scientificballoons**, **www.csbf.nasa.gov/balloons.html**. Cheers, Mark.

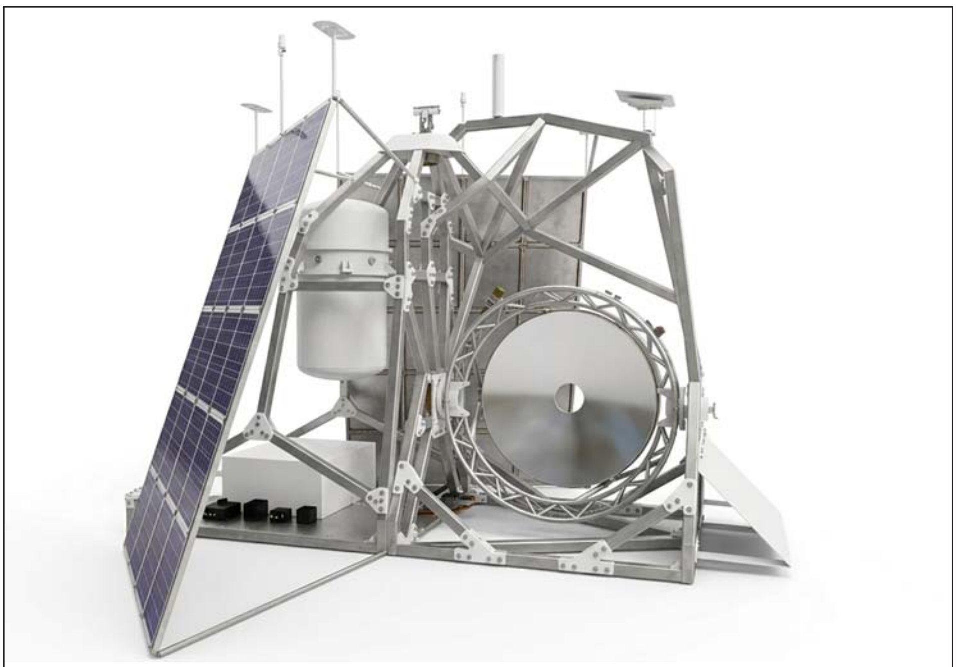


Figure 2. POEMM gondola with its 1.8 m mirror and cryogenic Dewar. *Credit: StarSpec Technologies*

Who's New in the *Cold Facts* Buyer's Guide?

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

FullCryo USA*

FullCryo Technologies USA, Texas-based, delivers global cryogenic and industrial gas solutions with in-house design, engineering, and manufacturing. Full-service capabilities backed by ~$50M in R&D, spanning technologies from 173 K to 4 K.

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***CSA CSM**

 

Zero Resistance Zone

by Quan-Sheng Shu, cryospc.com and Jonathan Demko, Le Tourneau University

Cryogenics and the Road to Superconducting Propulsion: Part II for Ships

While Part I of this series (***Cold Facts***, Vol. 42, No. 2) addressed the mass-optimized liquid hydrogen (LH_2) architectures and cryocoolers for the motor's rotors for aviation[1-3], Part II explores the ruggedized, high-torque requirements of maritime superconducting propulsion. Shipboard environments necessitate a shift toward hybrid cooling philosophies that balance the autonomous endurance of mechanical cryocoolers with the high thermal inertia of cryogenic liquids.[4-5] This article reviews a dual-source cryogenic architecture designed to maintain a 20 K MgB_2 stator and a 50 K REBCO rotor under mechanical stresses of 150 MPa. In this configuration:

- Mechanical cryocoolers serve as the primary refrigeration source, ensuring long-term autonomous operation and eliminating constant boil-off concerns.

- Cryogenic liquid buffers (such as LN_2 or LH_2) are utilized as a thermal "balance," providing rapid cool-down capabilities and absorbing transient heat loads during high-power maneuvers that might otherwise overwhelm a cryocooler.

By focusing on the integration of HTS materials within this hybrid thermal management framework, Part II of this series introduces the transition from experimental prototypes to the robust, zero-emission propulsion systems required for the future of global shipping.

From Aerial Mobility to Maritime Endurance

The transition of superconducting (SC) propulsion from aircraft to maritime vessels necessitates a fundamental shift in design priorities. While Part I detailed the weight-critical requirements of

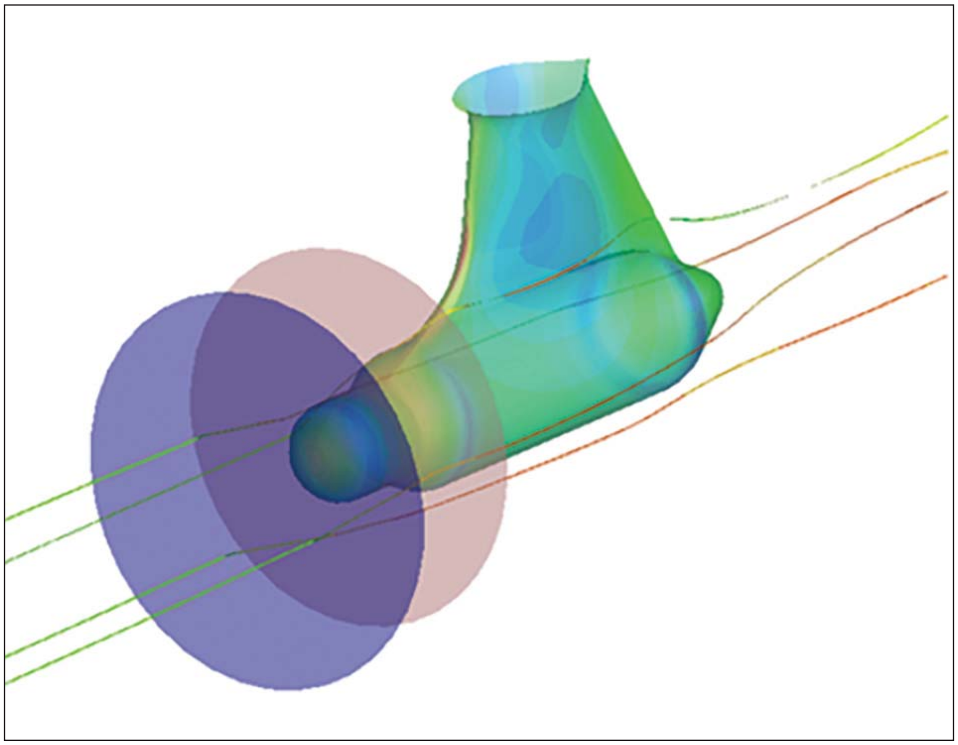

Figure 1. Flows around a podded ship propulsion system.[4] *Credit: Umemoto*

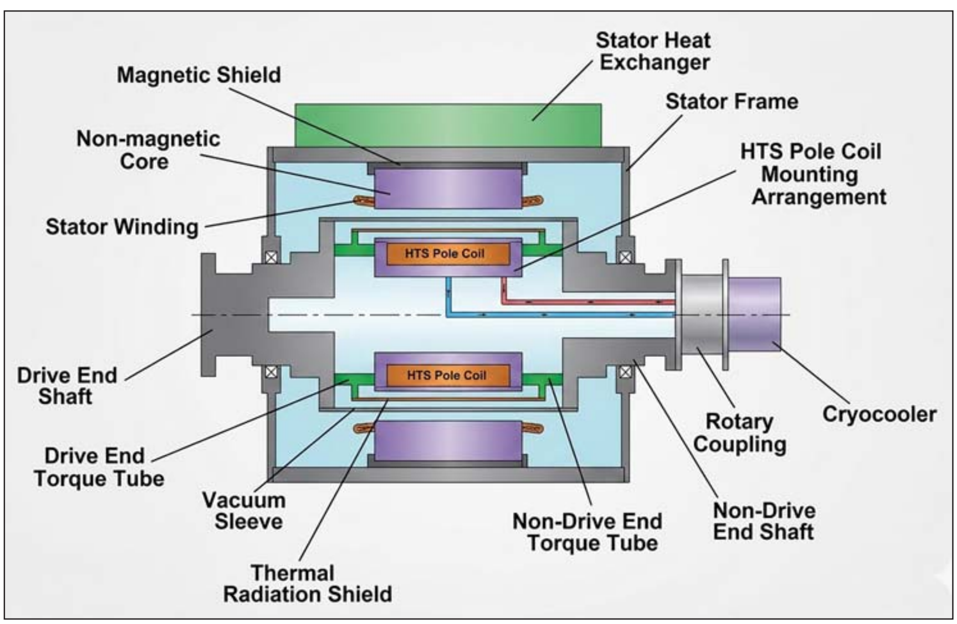

Figure 2. Schematic of a typical airgap topology based HTS motor (about 8 MW and 500 RPM). [5] *Credit: Sharma*

aviation—where specific power (kW/kg) and LH_2 integration are paramount—this article addresses the distinct challenges of high-tonnage shipping. Maritime applications demand massive torque at low operational speeds (120-250 rpm) and extreme autonomous reliability, often operating in remote environments for extended durations as show in Figure 1 and Figure 2.[4-5]

Table 1. Comparison of Marine vs. Aircraft Requirements. *Credit: Shu and Demko*

Feature	Marine (Ship)	Aircraft
Typical Power	3 MW - 40 MW	1 MW - 20 MW
Speed	Low (120-250 rpm)	High (3000-6000+ rpm)
Primary Goal	Torque Density & Efficiency	Specific Power (kW/kg)
Coolant	Cryocooler + LN_2, Helium or Liquid Hydrogen	Liquid Hydrogen or Neon

Table 2. Comparison of Marine Cooling Strategies. *Credit: Shu and Demko*

Feature	Sub-cooled LN_2	Liquid Hydrogen (LH_2)	Neon Thermosyphon
Primary Refrigeration	Stirling / Brayton Cryocooler	Multi-stage GM / Brayton	Closed-loop Ne/He Refrigerator
Cooling Philosophy	High thermal inertia (Safety)	Synergistic (Fuel + Coolant)	High-flux (Compactness)
Temperature	65 K - 77 K	20 K - 30 K	25 K - 30 K
Complexity	Moderate (Standard pumps)	High (Safety & Sealing)	High (Closed-loop gravity-fed)
Thermal Balance	Excellent (Massive buffer)	Good (Integrated fuel sink)	Low (Small fluid inventory)
Best For	Reliability/Standard ships	Hydrogen-powered vessels	High-performance Small footprint

As outlined in Table 1, the typical power rating for shipboard systems scales significantly higher, reaching up to 40 MW. This shift in scale mandates a move toward mechanical cryocooler-dominant architectures. Unlike aircraft, which lean toward open-loop liquid systems for mass reduction, ships utilize large-capacity cryocoolers supported by cryogenic liquid "balances" to manage thermal inertia and ensure operational redundancy. This hybrid approach ensures that the 20 K MgB_2 stator and 50 K REBCO rotor remain thermally stable even under mechanical stresses of 150 MPa. The selection of the cooling medium—whether sub-cooled LN_2, LH_2, or Neon Thermosyphons—is a critical decision dictated by the vessel's mission profile (Table 2). While LN_2 offers the highest reliability for standard ships, the closed-loop neon thermosyphon provides a high-performance, small-footprint alternative for specialized vessels. By centering the design on the autonomous stability of mechanical refrigeration, maritime SC propulsion can achieve the ruggedized, zero-emission efficiency required for the next generation of global shipping fleets.

Analysis of 1 MW-class HTS Motor Design for Podded Propulsion

The transition toward electric ship propulsion represents a strategic shift to mitigate maritime emissions, specifically NOx, SOx, and CO_2. Central to this advancement is the 1 MW-class high-temperature superconducting (HTS) motor, engineered for high-efficiency podded propulsion. By leveraging HTS technology, these motors achieve a significant reduction in power transmission losses, enabling a more compact architecture compared to conventional induction machines.[4]

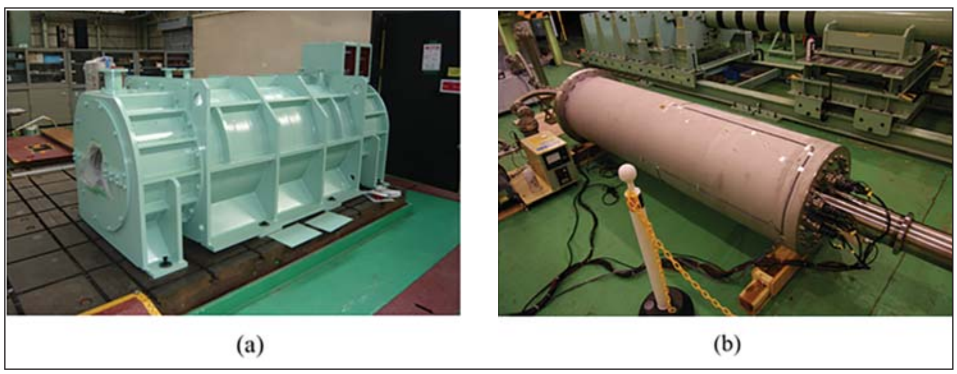

Figure 3. Main components of 1 MW-class HTS motor (a) Sator, and (b) Rotor.[4] *Credit: Umemoto*

As illustrated in Figure 3, the motor's primary architecture comprises the stator (a) and the rotor (b). The design utilizes a sophisticated cryogenic system, where the rotor core is cooled to an operating temperature of 30 K via liquid nitrogen and circulating helium gas. To optimize thermal exchange, internal cryogen piping incorporates CFD-optimized turbulence promoters, enabling the system to reach its 100 W cooling capacity. This process requires approximately three days to stabilize the rotor at its superconducting state. The 1 MW-class HTS motor represents a pivotal shift toward sustainable maritime engineering by combining high-power density with a compact, pod-ready design. Furthermore, HTS-integrated podded propulsion facilitates superior vessel maneuverability and allows for greater flexibility in stern hull optimization, effectively reducing fluid dynamic resistance in large-scale maritime applications.

Thermal Stability of a 3-MW HTS Marine Propulsion Motor

The 3-MW HTS motor test program confirms the operational viability of superconducting ship propulsion by utilizing a robust cryogenic cooling architecture.[5-6] Central to this system is a helium gas loop chilled by a Gifford-McMahon (GM) cryocooler array within a stationary cold box, which then traverses a specialized helium transfer coupling to reach the rotating HTS field coils.

To maintain stability during 3-MW load shifts, the system operates pressurized helium gas between 30 K and 50 K. This range provides a vital "temperature margin" below the critical transition of the HTS tape—typically Bi-2223 or ReBCO—which loses

▶ *continues on page 26*

superconductivity near 70 K to 90 K in a magnetic field. During an emergency "full astern" maneuver, the coils experience AC losses and eddy current heating. To prevent a quench, the system maintains a high helium pressure (up to 2.0 MPa) and a consistent mass flow (approx. 2–5 g/s) to rapidly whisk away transient heat. By successfully navigating 100-hour endurance tests and rapid load transitions, this program demonstrates that HTS technology can meet the rigorous reliability and thermal buffering standards required for mission-ready maritime service (Figure 4). The efficiency of small cryocooler (<10 kW) is illustrated in Figure 5.[8]

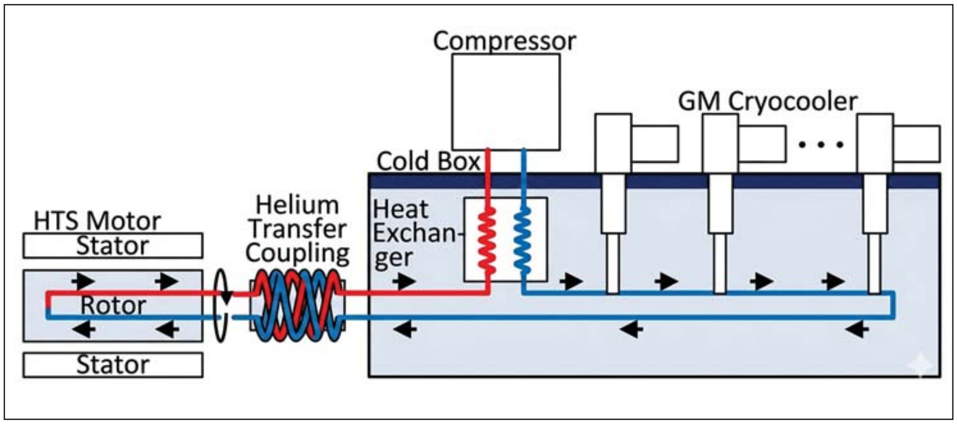

Figure 4. Cooling system schematic.[6] *Credit: Yanamoto*

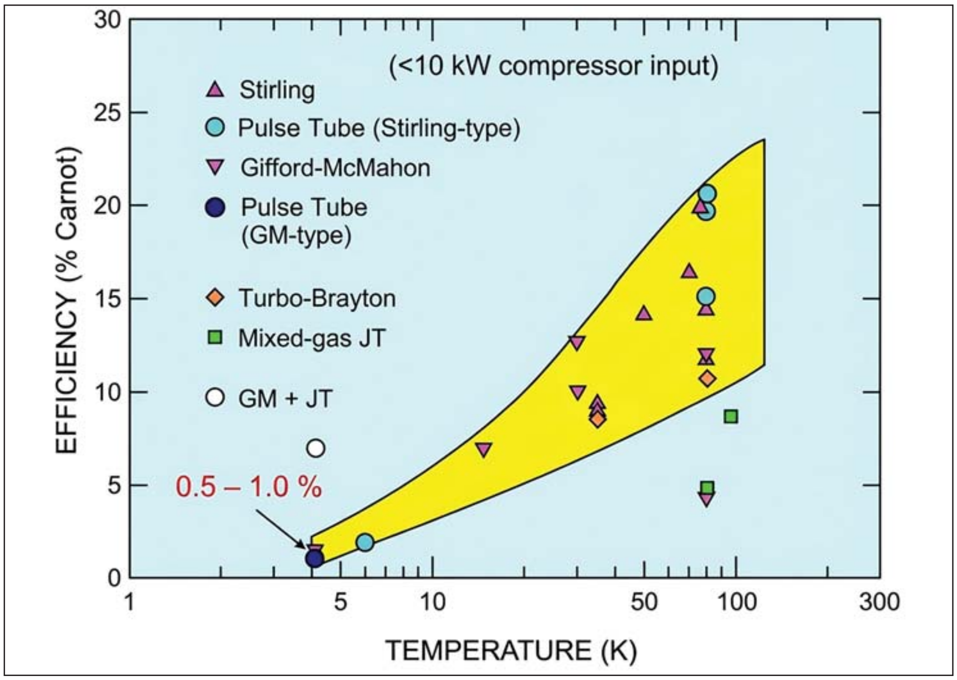

Figure 5. Efficiency of small cryocooler (<10 kW).[8] *Credit: Radebaugh*

The Hybrid Cooling Mechanism: Cryocooler vs. Thermal Buffer

In maritime SC propulsion, the mechanical cryocooler (such as the GM or Pulse Tube types shown in Radebaugh's efficiency curves) acts as the continuous active refrigeration source.[7-9] However, because these coolers have limited instantaneous "lift" or cooling power, a cryogenic liquid/gas reservoir is essential to handle high-torque thermal spikes.

- Steady-State (Base Load): During standard cruising, the mechanical cryocooler provides the primary cooling capacity. It maintains the 20 K MgB_2 stator and 50 K REBCO rotor within their superconducting transition temperatures by circulating high-purity helium gas or sub-cooled liquid.
- Transient Peak (Thermal Balance): During high-torque maneuvers (up to 40 MW), AC losses and mechanical friction can exceed the cryocooler's instantaneous capacity. Here, the cryogenic reservoir acts as a thermal "flywheel." It absorbs excess heat through the latent heat of vaporization or sensible heat rise, preventing a "quench" (sudden loss of superconductivity) while the cryocooler system recovers.

Conclusion

By combining the high-efficiency lift of modern cryocoolers with the high-capacity buffering of a cryogenic reservoir, HTS propulsion systems achieve the "mission-critical" reliability required for the open sea. This hybrid approach allows vessels to execute emergency maneuvers without risking a total loss of propulsion power, marking the final step in the transition from experimental prototypes to viable marine technology.

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CSM Cryogenic Conditioning Equipment: Ensuring Optimal Liquid Cryogen Delivery

The Purpose of Cryogenic Conditioning Equipment

When liquid cryogens such as nitrogen travel through transfer piping, they inevitably absorb heat from the environment. This heat infiltration causes the liquid's physical properties and behavior to change—most notably through vapor formation, which leads to two-phase flow. The result is pressure fluctuations, inconsistent liquid delivery, and reduced cooling efficiency at the point of use.

Cryogenic conditioning equipment addresses these challenges by ensuring single-phase, low-pressure liquid cryogen delivery. Each component serves a specific function in maintaining liquid quality throughout the transfer process.

Individual Equipment:

Working Principles CryoVent (Electronic vs. Mechanical)

The CryoVent functions as a "keep-full device" by removing vapor that accumulates when liquid in the pipeline is not in active use. Static heat leaks continuously evaporate liquid into vapor. The CryoVent exhausts this vapor to atmosphere, ensuring the pipeline remains completely liquid filled. It is typically installed at the highest points of the system, such as main risers and header ends.

The electronic version features a vacuum-jacketed venting valve and PID control loop, offering more precise control compared to mechanical float-type actuation. With variable venting control, the electronic version can respond to the transient vapor load due to cryogenic liquid demand dynamics; unlike the fixed-orifice venting characteristic of the mechanical version.

Phase Separator (Atmospheric vs. Pressure Adjustable)

The phase separator removes vapor from a two-phase liquid stream while stepping down incoming liquid pressure. The phase separator operates on principles of liquid decompression and volume expansion, with storage capacities ranging from 22-100 liters. Electronically modulated, electro-pneumatic vacuum-jacketed valves provide precise control over liquid level and pressure.

The atmospheric separator delivers subcooled liquid at 1 atmosphere; making it critical for sensitive applications such as molecular beam epitaxy or SEM/EDX analysis. The pressure-adjustable version allows for flexible pressure control based on application requirements.

Degasser

Unlike the CryoVent (which addresses static conditions) the degasser removes vapor during both static and flow conditions. As liquid velocity reduces due to sudden volume expansion, vapor separates via liquid decompression. Degassers are typically placed mid-pipeline or at the point of

Figure 1. CSM Mechanical CryoVent. *Credit: CSM*

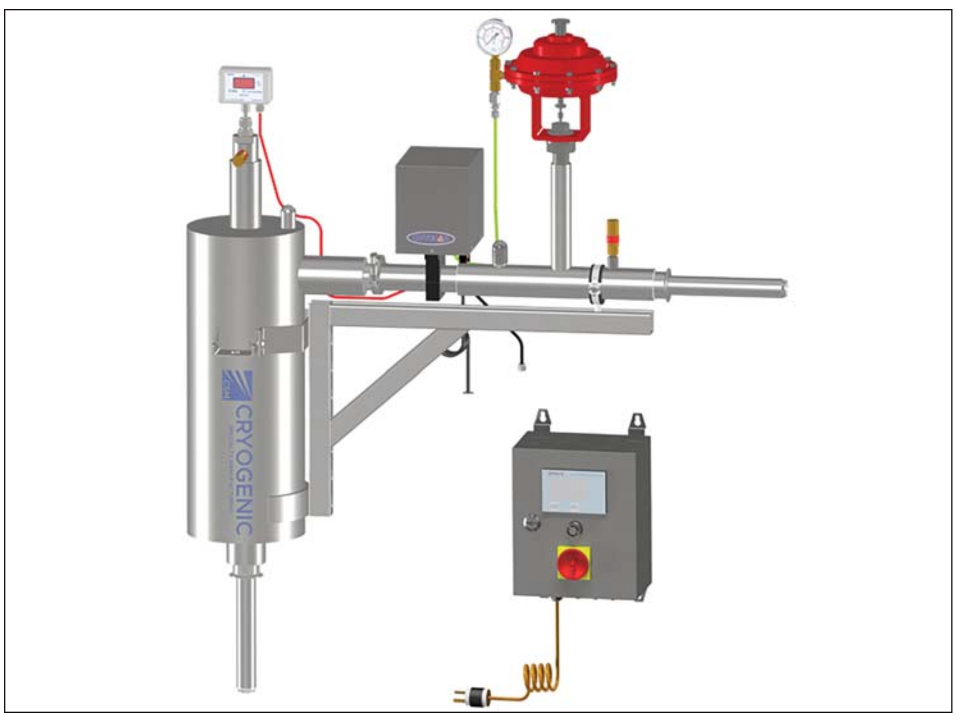

Figure 2. CSM Electronic CryoVent. *Credit: CSM*

use and are available in both mechanical and electronic versions.

Subcooler

The subcooler reduces liquid cryogen temperature below its saturation point at a given pressure. By lowering the liquid's entropy, it significantly increases cooling capacity. This makes the subcooler essential for processes requiring maximum cooling power. Subcoolers are valuable for long-distance transfer of cryogenic liquid within VJ piping, reducing the need for excessive vapor vent devices along the pipeline.

Apart from heat infiltration, a critical yet often overlooked phenomenon in cryogenic transfer systems is viscous and friction heating. This refers to the internal generation of thermal energy caused by friction between moving fluid layers (internal shear stresses) and pipe surface. In systems where liquid nitrogen flows at velocities exceeding 0.5 m/s (typically due to undersized piping or excessive use of corrugated flexible hose) the cryogenic fluid absorbs significant energy from this internal friction. This energy absorption leads to unwanted vaporization (boiling) and a corresponding reduction in cooling capacity at the point of use.

While viscous heating is often negligible in low-viscosity fluids, it becomes critically important in cryogenics. Liquid nitrogen has a very low latent heat of vaporization (approximately 199 kJ/kg). Consequently, even slight temperature increases from viscous dissipation can cause subcooled liquid to cross its saturation point, resulting in gaseous pockets and disruptive two-phase flow.

The subcooler serves as a powerful and easily deployable solution to this challenge. When integrated into a transfer system, it effectively brings viscous-heated, warmed liquid nitrogen back to its fully subcooled state, restoring its cooling capacity and ensuring reliable, single-phase delivery to the application.

The Physics: Why Conditioning Matters

During liquid cryogen transfer, heat infiltration causes several detrimental effects:

Figure 3. Atmospheric Pressure Phase Separator. Credit: CSM

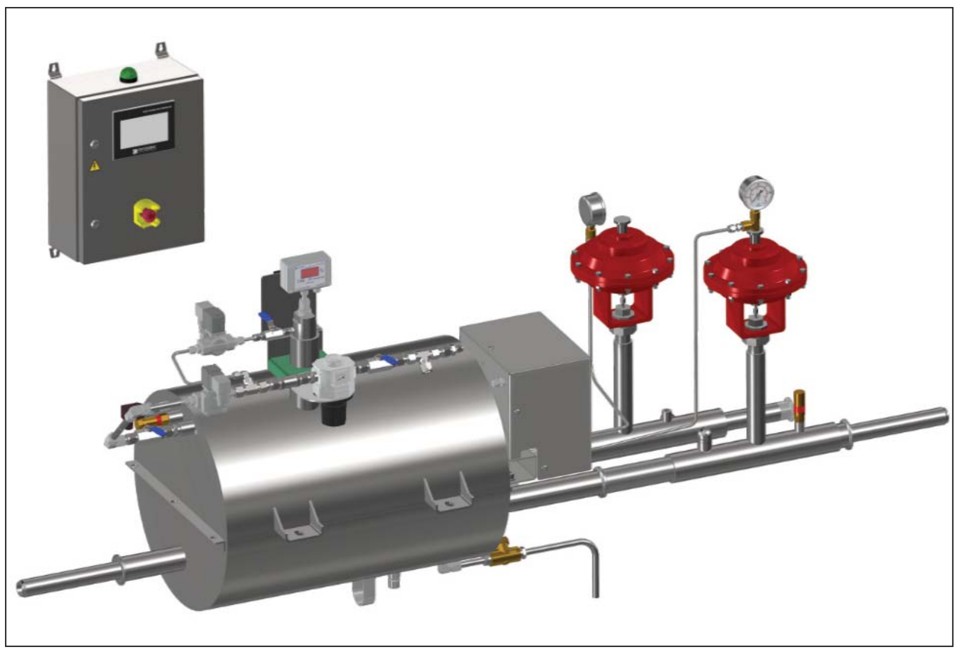

Figure 4. Pressure Adjustable Phase Separator. Credit: CSM

- Vapor formation leads to two-phase flow, creating pressure drop fluctuations.
- Inconsistent liquid delivery results in warmer liquid reaching the use point.
- Reduced cooling capacity due to latent heat of vaporization being consumed by vapor generation rather than useful cooling.

Proper conditioning directly counters these effects by removing vapor, controlling pressure, and maintaining liquid quality throughout the system.

Selection Guide

When selecting conditioning equipment, the specific application requirements should guide your choices.

For Entropy and Temperature Reduction

A subcooler is the appropriate choice when maximum cooling capacity is required. It is particularly essential for high-heat load applications where maintaining liquid

▶ ***continues on page 30***

 Continued from page 29

temperature below saturation point is critical. Example applications include semiconductor device hot and cold cycle testing, lyophilization of biopharmaceutical products, and food freezing (IQF).

For Vapor Reduction

Vapor reduction requires a combination approach. The degasser should be selected for vapor removal during flow conditions, while the CryoVent addresses static conditions when liquid is not moving through the pipeline. Proper sizing requires estimating static heat leaks and system head loss to determine the correct number and capacity of units needed.

For Pressure Control

A phase separator allows cryogenic liquid pressure control at the point of use instead of at the bulk storage tank. This gives the user a higher level of flexibility in fulfilling their process pressure needs without over-reliance on the liquid gas supplier's technical support (which can be difficult to obtain at times) or without being affected by variations in liquid supply saturation conditions or bulk tank pressure and level fluctuations.

A pressure-adjustable phase separator is particularly useful in multi-story production facilities where it is impractical to set a single bulk tank pressure to accommodate varying head pressure losses due to floor height differences.

CSM's comprehensive range of cryogenic conditioning equipment ensures reliable, high-quality liquid nitrogen delivery for even the most demanding applications. Proper equipment selection—based on thorough understanding of system dynamics and application requirements—optimizes both performance and operational efficiency. With cryogenic engineering expertise dating back to 1997, CSM stands ready to support customers in designing and implementing optimal conditioning solutions. **www.csm-cryogenic.com**

Figure 5. Degasser. *Credit: CSM*

Figure 6. CSM Subcooler. *Credit: CSM*


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Exploring Fullcryo's Helium Refrigeration and Liquefaction Platform

High-performance helium refrigerators and liquefiers have become indispensable core cryogenic infrastructure for delivering ultralow-temperature operating conditions worldwide. This is amid a tightening global helium supply and the rapid expansion of frontier low-carbon industries including fusion energy, quantum computing, and commercial helium recycling. Built on decades of advanced proprietary cryogenic technologies, Fullcryo USA provides standardized and customized helium refrigeration and liquefaction turnkey solutions for global resource recycling and cutting-edge scientific and industrial applications.

Fullcryo's core helium cryogenic product lineup covers two mainstream ultralow-temperature grades: 20 K and 4.5 K. Both systems adopt fully modular, skid-mounted configurations to enable flexible on-site integration, rapid commissioning, and minimal site adaptation for global projects.

A helium liquefaction system. *Credit: Fullcryo USA*

20 K Helium Refrigeration Series

Based on the mature reverse-Brayton cryocycle, Fullcryo's 20 K refrigeration portfolio includes both standard and custom-engineered units. Standard cooling capacity ranges from 500 W to 3,000 W @ 20 K, while custom high-capacity models exceed 3,000 W @ 20 K. Field-proven benchmark units cover 10 kW @ 20 K large-scale systems and 200 W @ 20 K compact units for laboratory scenarios.

The complete system consists of an oil removal unit, vacuum-insulated cold box, PLC intelligent control cabinet, and helium buffer tank. Inside the cold box, multi-stage heat exchangers, radial inflow turbo expanders, and room-temperature adsorption modules enable efficient closed-loop helium circulation. Cold helium absorbs process load heat and returns to the cold box for cyclic reuse; ensuring high efficiency and stable long-term operation. Typical applications include aerospace environmental simulation, large-scale aerospace testing, and spallation neutron source facilities.

4.5 K Helium Refrigeration and Liquefaction Series

Fullcryo's 4.5 K helium refrigeration and liquefaction systems feature a full-spectrum product matrix with standardized and customizable cooling capacities. The product range covers standard refrigeration power of 160 W to 1,400 W @ 4.5 K and custom high-power units exceeding 1,500 W @ 4.5 K, alongside standard liquid helium liquefaction capacity of 40–400 L/h and tailor-made high-capacity systems above 400 L/h. Built with skid-mounted modular architecture, closed-loop ultrastable cryogenic operation and industry-leading near-zero helium loss performance, this 4.5 K series delivers turnkey, low-maintenance cryogenic solutions for global advanced scientific research, fusion energy, quantum technology, and commercial helium resource utilization, serving research institutions and industrial clients worldwide.

Global Large-Scale Scientific Research Infrastructure

What do worldwide high-energy particle accelerators, synchrotron radiation facilities, spallation neutron sources, and steady-state high-magnetic-field laboratories have in common? They all require continuous and precise 4.2 K ultralow-temperature conditions to sustain the stable operation of superconducting magnets, radio-frequency cavities, and high-sensitivity cryogenic detection systems. Fullcryo's 4.5 K closed-cycle refrigeration systems provide long-term, high-precision cooling for large-scale magnet assemblies; while matching liquefaction units automatically supplement helium boiloff to guarantee non-stop operation of flagship scientific facilities. The compact, modular design enables flexible integration for both newly constructed and upgraded cryogenic stations, fully complying with the rigorous low-temperature stability and low-loss operational standards of international big-science projects.

Fusion Energy Research and Commercial Fusion Projects

Tokamak fusion devices and next-generation commercial fusion reactors depend on 4.2 K liquid helium to maintain the superconducting state of core components, including toroidal field coils, poloidal field coils, and superconducting feed systems. Fullcryo delivers graded professional cooling solutions for diverse fusion research scenarios. Standard 160–1,400 W refrigeration units are ideal for medium and small-scale fusion experimental platforms, while customized high-cooling-capacity systems over 1,500 W cater to large-scale national and international fusion test facilities. Integrated with advanced on-site helium re-liquefaction technology, the systems effectively reduce helium consumption and operational costs, supporting long-duration, stable operation for global fusion energy R&D, and industrialization projects.

A 4,000 W x 4.5 K Helium Refrigeration unit. *Credit: Fullcryo USA*

A 350 L/h helium liquefaction system. *Credit: Fullcryo USA*

Quantum Technology and Ultrasensitive Precision Detection

Superconducting quantum chips, superconducting quantum interference devices (SQUIDs), ultraweak magnetic monitoring systems, and deep-space astronomical infrared detectors all rely on stable 4.2 K cryogenic environments to suppress thermal noise and maximize detection and computing accuracy. Fullcryo's compact skid-mounted 4.5 K refrigeration systems are widely applicable to university quantum laboratories, commercial quantum computing R&D centers, and global astronomical observatories. The independent on-site liquefaction capability enables self-sufficient liquid helium supply for research facilities; significantly improving experimental continuity and mitigating operational risks and costs associated with global helium supply chain fluctuations.

Commercial Helium Extraction and Global Helium Resource Utilization

Natural gas helium extraction is a core, stable source of commercial helium resources across the globe. Fullcryo's high-efficiency 4.5 K helium liquefaction systems are specially optimized for crude helium purification and liquefaction in natural gas processing facilities. Through standardized deoxidation, low-temperature adsorption, and precision impurity removal processes, raw crude helium is deeply liquefied into high-purity commercial liquid helium that conforms to universal international industry standards. Standard 40–400 L/h liquefaction units adapt to medium and small-scale helium recovery projects, while customized ultrahigh-capacity systems above 400 L/h serve large-scale global helium industrial bases, providing reliable, cost-effective on-site liquid helium production solutions for international energy and helium resource developers.

All Fullcryo cryogenic systems feature distinct technical advantages including fast startup and shutdown response and emergency operation that requires no liquid nitrogen pre-cooling. Beyond standalone equipment supply, Fullcryo USA offers full-lifecycle global services covering cryogenic system layout design, precision piping fabrication, automatic control system integration, on-site commissioning, and long-term operational maintenance for international clients. **www.fullcryousa.com**

Product Showcase

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

Cryogenic Subcooler
Cryogenic Specialty Manufacturing

The CSM subcooler is designed to reduce the entropy of cryogenic fluids and deliver them in a stable subcooled state. By lowering the liquid temperature below its saturation point, it enhances heat absorption capacity and improves overall transfer efficiency.

This vacuum insulated, low-maintenance system handles flow rates up to 3,500 kg/hr while maintaining line pressures up to 10 bar. By minimizing vapor formation, it improves cooling performance, reduces LN_2 consumption, and ensures consistent liquid quality. The system also mitigates the effects of storage tank fluctuations in pressure, level, and Net Evaporation Rate (NER), providing a reliable and stable supply regardless of liquid source.

Typical applications include food freezing, biopharmaceutical freeze drying and blast freezing, exothermic chemical reactor cooling, precision machining of super alloys, and critical systems requiring rapid, high-capacity heat removal. **www.csm-cryogenic.com**

DHS 3000 VSD+
Atlas Copco

Atlas Copco has introduced the DHS 3000 VSD+, a dry screw vacuum pump designed for high-flow industrial applications including paper processing, conveying systems, food pick-and-place operations, and central vacuum systems. The compact, low-maintenance pump features an IE4 motor and patented asymmetrical rotor design that can reduce energy consumption by up to 50 percent compared to competing products. Its integrated intelligent control system automatically adjusts speed to match demand, helping reduce wear and extend service life. The oil-free design eliminates contamination risks, while a wear-free gearbox and air intake filter improve reliability and process safety. Quiet, vibration-free operation under a noise-reducing hood and the intuitive Elektronikon® control system enhance usability. Delivered as a plug-and-play unit, the DHS 3000 VSD+ provides an efficient, clean, and reliable vacuum solution with minimal downtime. **www.atlascopco.com**

QUPER Inverted Dilution Refrigerator
Leiden Cryogenics

QUPER is a fast-turnaround inverted dilution refrigerator designed for intuitive, ergonomic tabletop access. It enables full thermal cycling–from room temperature to base temperature and back–in under 24 hours, without the need for liquid cryogens. Engineered for high-sample throughput and fast iteration, QUPER delivers a base temperature below 25 mK and provides 300 µW of cooling power at 100 mK, while requiring only 10 liters of Helium-3. Its compact footprint and user-friendly operation make it a versatile solution for a wide range of laboratory environments. QUPER combines speed, performance, and accessibility, enabling researchers to accelerate experimental cycles. **www.leidencryogenics.nl**

Delta Unitized Liquid Methane - Series 1

Duron Cryogenics

Duron Cryogenics' continuous duty liquid methane fuel pump, the 1DU3-30M, was designed exclusively for continuous duty fuel pump applications utilized in diesel electric propulsion. Harsh conditions and long hours of operation require consistent, uninterrupted performance. The 1DU-30M is engineered for longevity to exceed industry standards by utilizing the highest quality materials and components. Its robust construction ensures reliability. Misusing a cryogenic pump that was designed for oil and gas coil tubing or fracking services can lead to premature failures when pressed into conditions that they were not intended.

The 1DU3-30M is shown cast in the -1 303 stainless steel unitized drive housing for marine installations, with vacuum jacketed 30 mm cold ends and the flexibility for vertical or horizontal orientation. Designed, engineered, sourced, and manufactured in the United States. **pdduron@cox.net**

LS Series Storage Systems

IC Biomedical

The IC Biomedical LS Series is a range of liquid nitrogen cryogenic storage systems designed for secure, high-capacity vial storage in convenient box-type racks. Ideal for laboratories, biobanks, IVF clinics, and research facilities, the LS Series offers both liquid and vapor phase storage with excellent temperature uniformity and long hold times to reduce liquid nitrogen consumption and operating costs. Constructed with a durable high-strength aluminum body and advanced insulation, these units provide reliable sample protection and efficient performance. Models are available with capacities ranging from 750 to 6,000 x 2 ml vials, allowing users to choose the right size for their storage needs. Select models can also be fitted with optional monitoring and control systems for enhanced security and compliance. **www.icbiomedical.com**

Rack-mountable Compressor for Cryomech PT205

Bluefors

Bluefors has announced a new rack-mountable, air-cooled 1.1 kW compressor that significantly expands the capabilities of the Cryomech PT205 Pulse Tube Cryocooler. The Cryomech CPA010 compressor brings even greater flexibility to the PT205, giving researchers and system designers a cleaner and more efficient way to integrate cryogenic cooling into their setups. The PT205 is ideal for applications such as superconducting nanowire single-photon detectors (SNSPDs), delivering more than 10 mW of cooling power at 2.5 K with exceptionally low vibration and long service intervals. Paired with the PT205, the new compressor maintains an energy-efficient 1.1 kW power consumption while providing a clean and organized installation option for data centers, labs, and integrated systems. With its compact size, low-vibration operation, low cost of ownership, and long maintenance interval of 40,000 hours, the powerful new combination of CPA010 and PT205 delivers long-term, hands-free operation in research and industrial environments. **www.bluefors.com**

People & Companies in Cryogenics

Two **Lawrence Berkeley National Laboratory** scientists were elected to the National Academy of Sciences for outstanding research achievements. **Gary Karpen**, a senior faculty scientist in the Lab's Biological Systems and Engineering Division and a professor at UC Berkeley, studies how genetic material's structure, organization, and maintenance influence inheritance and cell function. **Kam-Biu Luk**, a UC Berkeley professor

New NAS members Kam-Biu Luk (left) and Gary Karpen. Credit: Berkeley Lab and UC Berkeley

emeritus and retired Berkeley Lab physicist, is an experimental particle physicist focused on neutrinos—nearly massless, electrically neutral particles that pass through matter undetected. Their elections highlight Berkeley Lab's leadership in biology and physics and recognize decades of impactful contributions to science and innovation.

....

The **Underground Construction Association** has awarded the **Long-Baseline Neutrino Facility/Deep Underground**

Large particle detectors for the Deep Underground Neutrino Experiment will be placed in this large cavern in South Dakota to study the behavior of neutrinos. *Credit: Sanford Underground Research Facility*

Neutrino Experiment at the **Sanford Underground Research Facility** located in South Dakota, the prestigious 2026 Project of the Year Award. Hosted by the U.S. Department of Energy's Fermi National Accelerator Laboratory, DUNE is a cutting-edge neutrino experiment comprised of three massive caverns located a mile below the surface. The underground space will house massive detectors and an entire laboratory system dedicated to neutrino research.

....

Anna Grassellino, chief technology officer and associate laboratory director at **Fermilab**, has been appointed to the U.S. Department of Energy's Office of Science Advisory Committee (SCAC), a federal body that provides independent guidance on national scientific priorities and strategy. A key focus of her role will be supporting the

Anna Grassellino. *Credit: Fermilab*

DOE's ambitious goal of developing error-corrected quantum computers by 2028, capable of tackling major scientific challenges. An internationally recognized physicist and director of the DOE's Superconducting Quantum Materials and Systems Center, Grassellino brings extensive expertise in superconducting technologies and large-scale quantum initiatives to this influential role.

....

Meyer Tool & Manufacturing, Inc., has been named a finalist for the 2026 IMEC Innovator of the Year Award, recognizing the company's transformation into a leading advanced manufacturing and innovation partner serving cutting-edge industries such as quantum computing, aerospace, semiconductor manufacturing, and high-energy physics. The award recognizes Meyer Tool's evolution from a traditional custom fabrication shop into a prototype-to-production accelerator, helping customers bring breakthrough technologies to market faster and more efficiently. By collaborating with customers early in the design process, Meyer Tool helps reduce development timelines, improve manufacturability, and accelerate commercialization for highly complex systems operating in extreme environments.

Meyer Tool honored as a finalist for the 2026 IMEC Innovator of the Year Award. *Credit: Meyer Tool & Manufacturing, Inc.*

Meetings & Events

Applied Superconductivity Conference (ASC)
September 6-11, 2026
Pittsburgh, PA
https://www.appliedsuperconductivity.org/asc2026

European Cryogenic Days 2026 (ECD-2026)
October 13-16, 2026
Grenoble, France
https://www.ecd-2026.fr

Hydrogen Technology World Expo
October 20-22, 2026
Hamburg Messe, Germany
https://www.hydrogen-worldexpo.com

5th International Workshop on Cooling Systems for HTS Applications
October 26-28, 2026
Twente, The Netherlands
https://hts2026.com

32nd Space Cryogenics Workshop
June 9-11, 2027
Asheville, NC
https://spacecryogenicsworkshop.org

Cryogenic Engineering Conference and International Cryogenic Materials Conference (CEC/ICMC)
June 13-17, 2027
Knoxville, TN
https://www.cec-icmc.org

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