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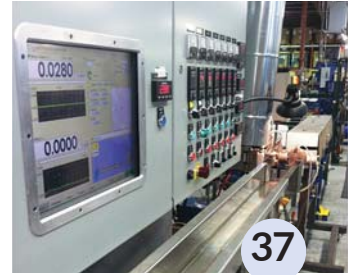
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Zhiyi Jiang, featured in *Young Professionals 2026* (pg. 8), in front of a 3000 L liquid helium storage dewar transferring liquid helium into a 100 L portable dewar. Credit: Zhiyi Jiang



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## From the Executive Director



In this month's issue of *Cold Facts*, we are proud to present our feature on Young Professionals in Cryogenics and Superconductivity. This group reflects the breadth and momentum of our field. Their work highlights not only technical excellence, but also the future direction of cryogenics and superconductivity.

As we celebrate these emerging leaders, we are also looking ahead to a strong lineup of 2026 events that continue to support education, collaboration and innovation across our community.

On June 15th in conjunction with ICC24 in Syracuse, New York, CSA will once again offer the Foundations of Cryocoolers Short Course, presented in honor of Ray Radebaugh. This course, initially created and instructed by Radebaugh, remains a cornerstone educational program for engineers, researchers and students entering or advancing within the field. Updated for 2026, the course will feature expert instruction from Peter Bradley, Franklin Miller, Mark Zagarola, and Wei Dai, covering Joule-Thomson and mixed refrigerant systems, Brayton and Claude cycles, pulse tube cryocoolers, sub-Kelvin systems, regenerators, modeling and emerging research areas. With a balance of fundamental principles and practical engineering insight, the course provides a valuable opportunity to deepen technical understanding and engage directly with leaders in cryocooler development. For details and registration, visit <https://2csa.org/x6z>.

Looking ahead to the fall, preparations are underway for the Applied Superconductivity Conference (ASC 2026), one of the premier global gatherings for applied superconductivity. This year's event takes place on September 6-11, 2026 in Pittsburgh, Pennsylvania. ASC continues to serve as a central forum for presenting advances in materials, magnets, power applications and quantum technologies. CSA will once again participate in the conference and looks forward to connecting with members and colleagues from around the world. Visit <https://www.applied-superconductivity.org/asc2026/> for full details.

During ASC 2026, CSA will present the Roger W. Boom Award, recognizing a young professional under the age of 40 who has made significant contributions to cryogenic engineering and applied superconductivity. Named in honor of Dr. Roger W. Boom, the award reflects a legacy of technical excellence, mentorship, and clear communication. We encourage members to consider nominating deserving individuals who exemplify these qualities. Full details can be found at <https://2csa.org/2qh>.

Congratulations again to this year's Young Professionals. We hope you enjoy this issue of *Cold Facts*, which showcases the innovation, expertise and forward momentum shaping our industry today. 🎉

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# YOUNG PROFESSIONALS 2026

## 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 2006 issue, the feature has presented many young persons whom we are proud to see have indeed lived up to that promise.*



**Andrew Ballard**, Mechanical Engineer, Bluefors Syracuse

**Background** - I attended Syracuse University to study physics. After receiving my bachelor's degree, I stayed on as a graduate student working toward a Ph.D. in physics. During my time as a graduate student, my priorities changed, and I left graduate school with my master's degree to begin a career in engineering. I was hired by Bluefors, then Cryomech, in 2022. That transition allowed me to take what I learned in research and apply it in a more practical, engineering-driven environment.

**Path to cryogenics** - During my time as a graduate student in physics, I was doing experimental quantum computing research. This type of research heavily relies on cryogenics, so I quickly became familiar with cryogenic and vacuum equipment. I spent a significant amount of time working directly with these systems, which helped me understand both their capabilities and limitations. That experience made the transition into cryogenic engineering feel natural.

**Mentorship** - I've been very fortunate to work with many amazing people throughout my life. I like to think every person I've ever met is a mentor in some sense, as I firmly believe every person has a lesson to teach you if you listen carefully enough. I'd like to give a special thanks to my current team manager, Tim Hanrahan, for really helping me navigate the transition from being a research physicist to a working cryogenic engineer, and for helping guide me to what theoretical tools to focus on to be successful in my role. I would also like to thank Kevin Pease, our R&D machinist here at Bluefors Syracuse, for continually teaching me how to bridge the communication gap between engineers and machinists to make theoretical ideas a reality.

**Awards** - I received an award for outstanding teaching from the physics department at Syracuse when I was teaching physics classes

early on in my graduate studies. Teaching helped me develop a stronger understanding of fundamental concepts and improved my ability to communicate technical ideas clearly.

**Contributions** - At Bluefors I've been contributing to the team making custom cryogenic systems for researchers and industry. I've been focusing on improving current products as well as contributing to the design of new products. At heart, I am an experimentalist, so I am always trying new things with our products and experimenting with running our systems in different ways to gain a deeper understanding of how they function. Beyond that, I especially enjoy when someone approaches me to understand how something works. What I love even more than figuring something out myself is sharing that knowledge and helping someone else reach that same level of understanding.

**Key developments** - In my opinion, some of the most important developments in cryogenics are the discovery of superconductivity, the pulse tube and the dilution refrigerator. The discovery of superconductivity was one of many experimental results that contributed to scientists having to totally flip their understanding of fundamental physics in the early 1900s as they were navigating this non-intuitive field of quantum mechanics. Not only was superconductivity a curiosity, but it has proven to be immensely useful. Whether dispelling magnetic fields, allowing a doctor to take an MRI of a patient, or being a foundational ingredient to many quantum computing modalities, superconductivity shows up time and time again as a key phenomenon. The pulse tube origins can be traced back to a 1964 paper by W.E. Gifford and R.C. Longworth where it was realized that through proper engineering and delivery of gas into a tube, one can establish a temperature gradient across the tube. That kicked off research that has led to the modern pulse tube refrigerator which is used all over the world. Finally, the dilution refrigerator is highly ranked because it enables access to once unreachable temperatures and is central to much of today's leading research.

**Future advances** – In the future, I hope to see advancements in cryogenics that will allow for more seamless integration of pulse tube refrigerators into dilution refrigerators for increased efficiency, reduced vibration and smaller footprints. I believe this will greatly aid the effort to develop a useful quantum computer. If quantum computing reaches the point where it can solve practical applications, it has the potential to revolutionize our world in ways we cannot yet imagine.

**Learn more** - Readers can find my LinkedIn page here: [www.linkedin.com/in/andrew-ballard-76874420b](https://www.linkedin.com/in/andrew-ballard-76874420b)



**Susiri Costa, Ph.D.**

Researcher,  
University of  
Melbourne

**Background** – I come from a multidisciplinary academic background. I completed my undergraduate studies in chemical and process engineering and chemistry at the University of Moratuwa and the Institute of Chemistry Ceylon in Sri Lanka, respectively. I hold a master's degree in financial economics from the University of Colombo. In addition, I am a past finalist of the Chartered Institute of Management Accountants and the Chartered Financial Analyst programs. I am currently completing my Ph.D. at the Department of Infrastructure Engineering at the University of Melbourne, Australia.

**Path to cryogenics** – My entry into cryogenics was somewhat unexpected in 2022, when my Ph.D. supervisor suggested exploring the hydrogen research domain. What began as an investigation into hydrogen technologies soon expanded into liquid hydrogen and ultimately broader cryogenic engineering and materials research. At the time, we had no dedicated testing infrastructure, cryogenic research team, or local expertise. These limitations made my journey challenging, yet highly rewarding as we gradually built new capabilities for cryogenic infrastructure research in Australia.

**Mentorship** – I have been fortunate to work with three highly supportive supervisors, Dr. Shanaka Baduge, Associate Professor Gang Li and Professor Priyan Mendis, who always emphasized focusing on fundamental principles and logical decision-making, while embracing both positive and negative results as part of the learning process. I would also like to acknowledge our research team and the Ph.D. candidates who joined after me, as their collaboration has also contributed to my development.

**Awards** – I received the Best Presenter Award at two consecutive Infrastructure Engineering Graduate Research Conferences in 2023 and 2024 at the University of Melbourne. In addition, our research team secured two Research Infrastructure Investment Fund Collaborative Equipment Grants and an ARENA grant valued at 3.08 million AUD to support our work on large-scale liquid hydrogen storage.

**Contributions** – Over the past four years, I have worked across multiple areas of cryogenics and liquid hydrogen research. I coordinated and served as a lead designer for the development of a novel 20 K cryogenic tensile testing cryostat, the first system of its kind in Australia. I have also investigated molecular dynamics-driven design of carbon fiber reinforced thermoplastics and conducted experimental characterization of these materials under cryogenic conditions. In addition, I contributed to the ARENA-funded megascale liquid hydrogen storage project, working on boiloff modelling, tank materials and design, insulation systems and magnetic refrigeration concepts. I have also been involved in establishing a new cryogenic research laboratory in Melbourne and in designing new testing equipment.

**Key developments** – I believe that advancements across materials discovery, fluid dynamics, computational modelling, instrumentation, safety design and system development are all important developments in cryogenics. These innovations are especially critical for applications in energy, space, quantum computing and medical technology. My work is focused on supporting liquid hydrogen applications by developing materials and testing infrastructure that enable reliable system performance.

**Future advances** – I hope to see cryogenic technologies transition from research laboratories into large-scale engineering applications, particularly in the adoption of liquid hydrogen for aviation and energy export. While the hydrogen economy depends heavily on broader economic and policy factors, I expect more consistent progress in areas such as space exploration and quantum computing, where cryogenics is already essential. I believe we will see significant developments in these areas over the next decade.

**Learn more** – My LinkedIn profile: [www.linkedin.com/in/susiri-costa](https://www.linkedin.com/in/susiri-costa)

ARENA project: <https://arena.gov.au/projects/mega-scale-liquid-h2-storage-with-super-insulated-full-containment-and-zero-boil-off>



**Guanglong Cui**, Level 3

Mechanical  
Cryogenic  
Engineer,  
Lawrence  
Berkeley  
National  
Laboratory

**Background** – I received my master's degree in cryogenic engineering from Zhejiang University in 2019. After graduation, I worked at Zhejiang Chillmaking Company, supporting the research and design of 4 K pneumatic control valves. I then joined the Shenzhen Institute of Advanced Light Source Facilities (IASF), where I spent 4.5 years working on cryogenic distribution systems and superfluid helium components. In November 2025, I began working full-time as a mechanical cryogenic engineer at Lawrence Berkeley National Laboratory (LBL).

**Path to cryogenics** – During my graduate studies, I enrolled in cryogenics courses including Heat Transfer, Engineering Thermodynamics, Principles of Cryogenics and Fluid Dynamics and Computation. After graduation, I worked extensively on cryogenic components such as cryogenic valves, superfluid helium heat exchangers,

► *continues on page 10*

check valves and turbo expanders, as well as cryogenic system design involving liquid nitrogen, supercritical helium and superfluid helium. These experiences deepened my fascination with cryogenics and strengthened my determination to continue exploring the field of cryogenic science and technology.

**Mentorship** – Professor Daming Sun was my mentor during my graduate studies, first introducing me to the world of cryogenics and providing meticulous guidance for my research. During my career at IASF, my mentor was Researcher Xilong Wang, who broadened my perspective and deepened my professional knowledge of cryogenics. Since joining LBL, I have had the privilege of being mentored by Dr. Li Wang, an exceptional expert in cryogenic system design, cryocoolers and cryostats. She has provided valuable guidance and helped me refine my skills. I sincerely acknowledge all my mentors for their support and guidance.

**Contributions** – My main contributions to the cryogenic field focus on two areas. The first is the development of DN<sub>2</sub>-DN100 cryogenic valves used at liquid helium temperatures. More specifically, my work included structural design, Joule-Thomson throttling design, thermoacoustic oscillation mitigation, thermodynamic performance analysis, and the design of test systems for flow coefficient measurements. The second area is large-scale cryogenic distribution system design, including overall system design, cryogenic safety analysis, Hampson-type heat exchanger research and development, two-phase flow calculations and helium guard design.

**Key developments** – The most important development is the rapid expansion of cryogenic systems used in particle accelerators, superconducting magnets and quantum technologies. These applications have enabled broader and deeper advancements in cryogenic technology, as such systems require high reliability, precise thermal management and stable long-term operation. At the same time, advances in cryogenic technology also drive progress in these fields, creating a mutually reinforcing cycle of development. My work has been closely related to these developments,

including LINACs and superconducting magnets.

**Future advances** – In the future, I hope to see advances in the optimization of cryogenic system design, as many applications require highly stable pressure and temperature for reliable operation. I also hope to see significant improvements in the exergy efficiency of cryogenic systems, particularly for large-scale installations, which are currently very energy intensive. Technologies such as cold compressors offer a promising path toward achieving higher efficiency, and I look forward to further innovations in this area over the next 10 years.

**Learn more** – Readers can find more information about Lawrence Berkeley National Laboratory and regular updates on recent projects at <https://www.lbl.gov>



**Zhiyi Jiang,**  
Cryogenics  
Operation  
Group  
Supervisor,  
National High  
Magnetic Field  
Laboratory

**Background** – I received my bachelor of science, master's and Ph.D. degrees from the University of Wisconsin-Madison. I worked in the Cryogenics Engineering Lab at UW-Madison from 2013 to 2024, where I developed both theoretical knowledge and practical skills in cryogenics. I currently work at the National High Magnetic Field Laboratory, where I focus on large-scale cryogenic operations.

**Path to cryogenics** – My interest in cryogenics began when I attended a Thermodynamics course taught by Professor Franklin Miller in 2013 at UW-Madison. He introduced me to the Cryogenics Engineering Lab, which became the starting point of my career in this field. That early exposure gave me both curiosity and direction, and it led me to pursue hands-on work in cryogenic systems.

**Mentorship** – During my time at the Cryogenics Engineering Lab, Professor John

Pfotenhauer and Professor Franklin Miller served as my mentors. Through weekly meetings and hands-on training, they taught me valuable knowledge in cryogenics, heat transfer and vacuum technologies. Before joining the lab, I did not even know how to properly apply Teflon tape. Under their guidance, I learned practical skills such as leak testing, vacuum pump maintenance and building cryogenic equipment. These experiences helped me gain confidence in troubleshooting and system design.

**Awards** – My work has been recognized through several publications, including “Results of a Nitrogen-Based Pulsating Heat Pipe with Varied Configurations,” “Results of a Nitrogen Pulsating Heat Pipe with Subsections in a Series Configuration,” and “Design of the Glass Pulse-Tube Cryocooler.”

**Contributions** – I successfully built a glass pulse tube cryocooler for educational purposes and developed multiple configurations of nitrogen pulsating heat pipes. In my current role at the National MagLab, I am responsible for operating, maintaining and troubleshooting the cryogenic plant that supplies approximately 22,000 liters of liquid helium to research groups. I also work to maintain a helium recovery rate above 90 percent and support the operation of high field magnets, including the 45 T and 36 T hybrid systems.

**Key developments** – I believe one of the most important developments in cryogenics is the advancement of cryocooler technology. Modern pulse tube cryocoolers have made systems such as dilution refrigerators more accessible, which is critical for quantum computing. Similarly, advances in Gifford-McMahon cryocoolers have allowed MRI systems to move toward cryogen-free operation. However, future technologies such as large-scale quantum computing and nuclear fusion will require cooling capacities beyond what current cryocoolers can provide, highlighting the need for continued development in large-scale cryogenic systems.

**Future advances** – I hope to see advancements in cryogenic heat transfer  
► *continues on page 12*

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technologies, particularly heat pipes or similar systems that can transport large heat loads over long distances efficiently. These technologies could enable more flexible cryogenic infrastructure and allow centralized refrigeration systems to support large facilities. I believe further research and development in this area will be essential for future progress.

**Learn more** – You can find my LinkedIn at [www.linkedin.com/in/zhiyi-jiang-52200285](http://www.linkedin.com/in/zhiyi-jiang-52200285) and my profile at the National MagLab at <https://nationalmaglab.org/staff/?name=ZhiyiJiang>

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**John Ketcham,**  
Sales Director,  
Scientific  
Instruments Inc.

**Background** –  
I graduated  
from Syracuse

University with a bachelor's degree in mechanical engineering. I began my career in cryogenics as a mechanical and manufacturing engineer at Cryomech, Inc., working across the product line of cryocoolers, compressors and after-cryocooler systems. I quickly realized I was not suited for sitting behind a desk or spending all my time on the manufacturing floor, and I transitioned into a sales engineer role. In that position, I helped laboratories integrate helium recovery systems to conserve this finite resource in many NMR and physics labs around the world. That role is also where I discovered my love for travel, installing systems across the globe as far away as New Zealand. Being involved in all aspects, from defining system requirements with users to installing equipment and providing ongoing support, gave me global exposure to the industry and its wide range of applications.

After about nine years, I transitioned to Montana Instruments as a sales engineer focusing on lab-scale cryostat integration. A few years later, I joined Scientific Instruments, where I quickly moved from a global business development role to sales director. Having worked hands-on across so

many areas of the industry allows me to better support the community with cryogenic thermometry and instrumentation.

**Path to cryogenics** – Ever since I was a child I remember being fascinated with space, but at that time I did not recognize the importance of cryogenics involved. In my senior year of university, which was heavily focused on heat and mass transfer, I applied for internships in the Syracuse area. I had no idea that my hometown was home to Cryomech. I applied for the position with a 3D CAD model of my guitar, hoping to work on drafting and design. That experience opened my eyes to a whole new world of cryogenics and ultimately shaped my career path.

**Mentorship** – I find myself very fortunate to be mentored by the late Peter Gifford. From the beginning of my time at Cryomech, Peter would take me into his office every morning to talk about everything from helium management in cryocoolers to the inner workings of the human psyche. The energy he brought to his company was unlike anything I had seen before. Anyone who knew him remembers his personality and passion. Beyond cryogenics, he taught me how to stand up for myself, what it means to be a leader and how to support my team. I attribute much of my passion for this industry to him.

**Contributions** – As a sales and application engineer working with helium management systems, I installed many helium recovery systems at universities around the world, achieving efficiencies of up to 95 percent. During those early years, when the industry was still transitioning from liquid cryogens to dry systems, these solutions helped laboratories sustain their research despite helium supply challenges. Today, I continue to support cryogenic companies that were founded out of those same research laboratories by partnering with them to provide high-quality cryogenic thermometry solutions.

**Key developments** – I believe the breakthroughs in efficiencies of cryocoolers have been some of the most important developments in cryogenics. Without the commercialization of pulse tube and

Gifford-McMahon cryocoolers, many users would still rely heavily on liquid cryogens. In addition, advances in dilution refrigeration have been critical in enabling technologies such as quantum computing. My work aligns with these developments by ensuring accurate cryogenic thermometry is available to support increasingly advanced systems.

**Future advances** – I hope to see faster cooldown times for cryostats so laboratories can spend more time focusing on their research and less time waiting for systems to reach their desired temperature. The industry has already made progress toward creating more user-friendly cryogenic environments, and I am excited to see how these systems continue to evolve in the coming years.

**Learn more** – You can connect with me on LinkedIn at [www.linkedin.com/in/john-ketcham-72665690](http://www.linkedin.com/in/john-ketcham-72665690) or visit my company's website at <https://www.sicryo.com>

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**Jim Lohan,**  
Senior  
Engineering  
Manager,  
Cryogenics and  
Control Systems,  
VEIR, Inc.

**Background**

– I hold a bachelor's degree in chemical engineering from Lehigh University, Bethlehem, Penn. I began my career with Linde Gas through their Career Development Program, where I rotated through roles in application technologies, project management and hydrogen fueling infrastructure. This program provided hands-on exposure to a wide range of industrial gas and cryogenic applications. After completing the program, I moved into project management where I led the delivery and installation of industrial gas systems across multiple industries. These early experiences exposed me to both the engineering and operational challenges involved in deploying cryogenic systems in real industrial environments.

**Path to cryogenics** – My work at Linde focused on liquid bulk gas systems, which  
▶ continues on page 14



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rely heavily on cryogenic liquids for storage and distribution. Through that work I became fascinated with the unique engineering challenges associated with cryogenic systems, particularly the intersection of thermodynamics, mechanical design and real-world operations. That early exposure ultimately led me to focus my career on cryogenic engineering.

**Mentorship** – Chris Ryan, my manager during my hydrogen fueling work at Linde, has been an important mentor throughout my career. Chris has a rare ability to combine strong engineering judgment with sound business thinking. He was always someone I could bring complex engineering problems to and receive thoughtful guidance. Even today, five years after leaving Linde and Messer, I still reach out to him for advice.

**Awards** – During my time at Linde and Messer, I received several internal Excellence in Engineering and Project Execution awards recognizing successful project delivery and technical innovation. While I have not yet received industry awards specifically within cryogenics, becoming more engaged in the broader cryogenic community is a goal of mine. On a personal level, I am proud to have earned the rank of Eagle Scout with the Boy Scouts of America, an achievement that continues to influence my approach to leadership and responsibility.

**Contributions** – Throughout my career I have worked on more than 100 industrial gas and cryogenic installations, supporting applications ranging from food freezing and environmental treatment systems to hydrogen fueling infrastructure. These projects have provided valuable insight into how cryogenic technologies can be deployed across a wide range of industries. I also founded a small cryogenic consulting and equipment company, JPCryo, through which I developed several products intended to improve the installation and reliability of cryogenic systems. These include a modular cryogenic bulk tank foundation system that allows tanks to be installed in less than 24 hours, as well as an improved keep-cold device for vacuum jacketed piping systems.

In my current role at VEIR, I lead the development of cryogenic systems supporting

superconducting power transmission technology. These systems include high pressure liquid nitrogen distribution systems capable of supporting transmission distances of up to 20 miles, as well as high availability cryogenic systems designed to cool large arrays of superconducting cables for next-generation data center infrastructure. These systems operate at heat loads that can exceed 500 kW at 67 K, pushing the boundaries of industrial cryogenic system design.

**Key developments** – Some of the most important developments in cryogenics are occurring within the energy transition, particularly in superconducting power transmission and fusion technologies. One challenge facing these technologies is the lack of mature cryogenic infrastructure in the 50 to 500 kW refrigeration range. Most existing cryogenic systems are either very small laboratory-scale systems or extremely large industrial systems such as air separation plants. However, many emerging technologies require reliable refrigeration systems operating between these scales. Much of my work today focuses on developing cryogenic infrastructure in this intermediate range, which I believe will be essential to enabling many next-generation energy technologies.

**Future advances** – Two areas of advancement would significantly benefit the cryogenic industry. First is the modernization of automation and controls. Many bulk cryogenic systems still rely on control architectures that have changed little since the 1980s. More advanced control strategies could improve efficiency, reliability and system visibility. Second is the development of modular cryogenic refrigeration systems in the 50 to 500 kW range that are designed for rapid deployment and lower total cost of ownership. As construction costs continue to rise, factory-built modular systems may provide a more scalable path for deploying cryogenic infrastructure. I believe meaningful progress in both areas could occur within the next five to ten years.

**Learn more** – LinkedIn: [www.linkedin.com/in/jameslohan](https://www.linkedin.com/in/jameslohan), JPCryo Website: <https://www.jpccryo.com>



**Francisco Moguel,**  
Cryogenics Controls and Instrumentation Engineer, SLAC National Accelerator Laboratory

**Background** – I earned my bachelor of science in mechatronics engineering with a minor in computer engineering from California State University, Chico. During the summer of 2022, I completed an internship with Barry-Wehmiller Design Group, and in January 2024, I began my first engineering role at SLAC National Accelerator Laboratory as part of the AD-Cryogenics Group.

**Path to cryogenics** – Coming out of college, I was seeking a role that combined mechanical, electrical and control systems, the core of mechatronics engineering. I came across a controls position with the Cryogenics Group at SLAC and decided to apply. What surprised me most was how deep and specialized the field of cryogenics really is. I had a foundational understanding of thermodynamics, but I hadn't realized there was an entire discipline devoted to it.

**Mentorship** – My mentor is Swapnil Shrishrimal, who also serves as my manager and the person who brought me onto the team. He has been mentoring me on an important US Department of Energy LCLS-II HE project, where we are architecting the cryogenic control system for two 18 kW at 4.5 K refrigeration systems supporting a superconducting linear accelerator with 60 cryomodules. Working under him has been a breath of fresh air. He has a rare ability to understand systems from electrical, process and mechanical perspectives all at once. His combination of high expectations and genuine care for his team has challenged me and accelerated my growth early in my career.

**Awards** – I received a SLAC Spot Award for taking initiative in troubleshooting specialized 2 K cold compressor electronics.

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**Contributions** – One of my major contributions has been programming the PLC that controls the cryogenic valve box and cryostat for the SLAC-PsiQuantum collaboration, a collaborative project at the intersection of cryogenics and quantum computing. This involved implementing precise control logic for temperature, pressure and flow regulation to ensure stable cryogenic conditions required for quantum experiments.

I've also been deeply involved in developing the LCLS-II HE PLC code and EPICS (Experimental Physics Industrial Control System) interfaces. My work included designing and testing control sequences, supporting system simulations and helping bridge communication between the PLC layer and the higher-level EPICS framework. Through this, I gained hands-on experience in large-scale distributed control architectures and learned how even small control optimizations can significantly affect system stability and performance.

**Key developments** – I believe quantum computing will drive some of the most important developments in cryogenics. As quantum hardware continues to advance and scale, the demand for more efficient, reliable and precisely controlled cryogenic systems will only grow. I'm particularly excited about innovations in cryogenic controls, as I see control systems playing a major role in shaping the next generation of high performance cryogenic infrastructure.

**Future advances** – I have two things I'd like to see, and they're not really related. The first is better integration between cryogenic systems and quantum hardware as that space grows. The second is something closer to my day-to-day work, more modern control architectures with AI and machine learning integration in cryogenics. I think we could see meaningful progress on both within the next five to ten years.

**Learn more** – You can find me on LinkedIn at [www.linkedin.com/in/fjmognun](http://www.linkedin.com/in/fjmognun)

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**Emmanuel Izuchukwu Nkwocha**,  
Cryogenic Controls Systems Engineer,  
SLAC National Accelerator Laboratory

**Background** – I hold a bachelor's degree in electrical and electronics engineering and a master's degree in mechatronics engineering. Professionally, I have over eight years of experience as a controls and instrumentation engineer across multiple industries, including manufacturing and oil and gas. My work has primarily focused on industrial automation, process control systems, instrumentation integration and system optimization. This background in industrial control systems prepared me well for the transition into large-scale scientific infrastructure.

**Path to cryogenics** – My entry into the cryogenics field began when I joined SLAC National Accelerator Laboratory. My work focuses on control system upgrades and automation improvements for the laboratory's cryogenic infrastructure. One of the major initiatives I am involved in is the Linac Coherent Light Source II High Energy Upgrade project, which aims to double the X-ray laser's energy and significantly enhance the facility's ability to probe matter at atomic resolution. My role includes supporting cryogenic plant controls upgrades that will enable the operation of two cryogenic plants to serve the superconducting accelerator. In addition, I contribute to the development of the Cryomodule Maintenance Facility, which is designed to test and maintain cryomodules at SLAC.

**Mentorship** – At SLAC, my manager and Cryogenic Controls Group Lead, Swapnil Shrishrimal, has been an important mentor in my professional development within the cryogenics field. Through his guidance, I gained valuable insight into the operational principles and process dynamics of large-scale cryogenic systems. His mentorship has helped me deepen my understanding of cryogenic instrumentation, process control strategies and the operational reliability

required for superconducting accelerator facilities. This guidance was instrumental in helping me adapt my industrial automation background to the specialized demands of cryogenic engineering.

**Contributions** – I have contributed to the advancement of the cryogenic field by bridging the gap between theoretical research and industrial application. My published work highlights innovations in thermal stability controls for superconducting systems, including my role as co-author of the paper "LCLS-II Cavity Heater Controls: Design, Operation and Accuracy." My research experience also includes work on cyber-physical industrial systems, including the publication "Cyber-Physical Framework for Smart Paint Manufacturing: Hybrid Integration of PLC and Recipe Management Simulation." I am currently focused on the control system architecture for the Cryomodule Maintenance Facility, a project dedicated to the rigorous testing and validation of cryomodules.

**Key developments** – One of the most important developments in cryogenics today is the increasing reliance on large-scale cryogenic systems to support superconducting technologies used in particle accelerators, quantum research and advanced materials science. Facilities such as the Linac Coherent Light Source require extremely stable cryogenic environments to maintain superconducting cavities at operational temperatures. My work focuses on strengthening the automation and control systems that ensure these environments remain stable and reliable.

**Future advances** – In the coming years, I anticipate a paradigm shift in which cryogenic infrastructure evolves from a supporting utility into an intelligent and adaptive system supporting emerging technologies such as quantum computing and next-generation accelerators. The integration of artificial intelligence and machine learning into cryogenic operations will play an important role in this transformation. AI-driven predictive maintenance and advanced data analytics could allow operators to detect anomalies early, optimize system performance and improve the reliability of complex cryogenic plants. I expect these

intelligent cryogenic control architectures to become increasingly common over the next five to ten years.

Learn more - [www.linkedin.com/in/emmanuelizunkwocha](http://www.linkedin.com/in/emmanuelizunkwocha)



**Joshua Reightler,**  
Research and Development Engineer, Sumitomo (SHI) Cryogenics of America, Inc.

**Background** - I received a bachelor of science in mechanical engineering from Wilkes University, Wilkes-Barre, Penn. in 2017. Throughout my undergraduate studies, I primarily interned in manufacturing settings and, following receipt of my degree, I originally began working in industry as a process engineer for Tredegar Corporation. I then transitioned into a design and development role with Wavefront Research, Inc., working to develop bespoke infrared imaging systems. After four to five years, I accepted a research and development position with Sumitomo (SHI) Cryogenics of America, Inc., which I continue to work in today.

**Path to cryogenics** - I was first exposed to cryogenics through my work with Wavefront Research, where our systems integrated compact Stirling cycle cryocoolers to cool optical assemblies. Developing cryostats and the precise mechanical systems within them allowed me to gain an appreciation for the design complexities associated with operating at cryogenic temperatures. That experience captured my interest and led me to pursue further work in the field of cryogenics.

**Mentorship** - Although I do not have one specific mentor that I can point to, I consider myself fortunate to have been part of several strong engineering teams throughout my career. I have been surrounded by talented engineers who have taken an active role in sharing their knowledge and supporting my professional growth. That collective mentorship has played a significant role in my development.

**Contributions** - During my time at Wavefront Research, I played an integral role in the design and production of compact cryostats that support technological research for various United States government entities. More recently, my work with Sumitomo Cryogenics has placed me in a position to lead the design of the highest capacity commercially available 20 K and 77 K Gifford-McMahon cycle cryocoolers on the market, the CH-160D3LT and CH-160D3. In addition to contributing to product development within the broader cryogenics community, I have also been engaged in research efforts supporting professional publications. I have published work investigating the use of neon as an alternative refrigerant within compressor systems designed for helium at the International Cryocoolers Conference, and I intend to publish further technical developments on high capacity cryocoolers in upcoming conferences.

**Key developments** - In many cases, I see developments in cryogenics as enabling progress in other technological fields. While increasing cooling capacity is important, efficiency, cost and system size remain significant barriers to broader adoption. I believe that the most important developments are those that help reduce these barriers, making cryogenic technologies more accessible and practical for widespread use. My work is aligned with this goal, particularly in improving system efficiency and performance.

**Future advances** - I hope to see continued advancements in cryogenic technologies related to liquid hydrogen production, storage and transportation. These areas are critical to overcoming current limitations in hydrogen fuel adoption. There are many ongoing efforts across the industry, and I view the next decade as a key period for meaningful progress in this space.

**Learn more** - Information on the products I have worked on can be found at <https://shicryogenics.com>. I also have published work in the proceedings of the International Cryocoolers Conference, with additional publications planned for upcoming conferences. 📄

## 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](http://csabg.org).

### Vacree Technologies Co., Ltd.

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### \*Milton J. Wood Company

MJ Wood Consolidated specializes in the fabrication, installation and commissioning of vacuum jacketed cryogenic piping systems and cryogenic distribution infrastructure for LOX, LH<sub>2</sub>, LN<sub>2</sub>, helium, LNG, and other industrial gases.

### \*Suzhou Bama Superconductor Technology Co., Ltd.

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# Cold Power: How Cryogenics Will Make Chicago the Taiwan of Quantum Computing

by Joe Procnunier, LJC Design & Engineering



Rendering of the planned Illinois Quantum and Microelectronics Park (IQMP) on the South Side of Chicago. Credit: LJC

Chicago is set to redefine the future of quantum computing, just as Taiwan reshaped the global semiconductor industry. In 1987, Morris Chang famously started TSMC (Taiwan Semiconductor Manufacturing Company) after working as a pivotal figure at Texas Instruments.<sup>[1]</sup> The Taiwanese government encouraged him to move to the island and promised a wide range of support. The goal of the government was to transition Taiwan from a basic manufacturing economy to advanced manufacturing focused on leading edge technology. Chang led the ITRI (Industrial Technology Research Institute).<sup>[2]</sup> Taiwan also invested in Hsinchu Science Park where TSMC would be headquartered. This ecosystem helped develop TSMC into a trillion-dollar company. A similar ecosystem and strategy are emerging to focus on the rise of quantum computing in Chicago, Illinois.

A pivotal moment is happening in the quantum industry in Chicago, where there are a confluence of leading national laboratories, higher education, incubators, industrial heritage, and governmental collaboration and incentives. The state formally created the IQMP (Illinois Quantum and

Microelectronics Park) in 2024 to be run as a URO (University-Related Organization). The IQMP is a collaboration between public and private partners with complementary expertise.<sup>[3]</sup> It is funded by hundreds of millions of dollars to support development of the technology park. A key aspect of this funding is to provide the cryogenics technology critical to the quantum computing industry. Anchor tenant of the park PsiQuantum has shared that the state is contributing funding to building out a cryogenic plant at the site.<sup>[4]</sup> This state funding is similar to strategies that the Taiwanese government initiated to help invigorate semiconductor manufacturing. Illinois also has a framework in place for collaboration between the national labs (Argonne and Fermilab), higher education, incubators, etc., through the Chicago Quantum Exchange, a community of more than 50 corporate, international, nonprofit and regional partners.<sup>[5]</sup>

Building a competitive edge with a robust cryogenics' backbone is critical for Chicago to lead the next frontier in quantum computing. Since most startup companies cannot afford robust access to the expensive hardware required to create the

liquid helium essential to stabilizing quantum hardware, the government-supported infrastructure will ultimately help companies grow out of the incubator / startup phase and grow to mature companies. McKinsey predicts the quantum computing market will grow to \$28-72 billion by 2035. In the next 5-10 years, there will be significant spending on the hardware and infrastructure to support this technology.<sup>[6]</sup> In 2025, about 80% of quantum companies were focused on full-stack quantum hardware development.<sup>[7]</sup> If the State of Illinois follows through with its announcement of funding for the IQMP site and direct funding for cryogenics, this is a major competitive advantage that will help advance the quantum computing industry locally and as a whole. Based on public reports of several well-known quantum companies setting up operations in Chicago, it is interesting to see the parallels with the semiconductor industry in Taiwan. The Hsinchu Science Park currently employs around 170,000 workers and 500 companies which grew over about 40 years.<sup>[8]</sup> The benefits the IQMP could provide to the quantum computing industry are significant and potentially follow a similar trajectory.

Given that most large-scale cryogenics installations are located at national labs, the IQMP and State of Illinois are taking on a new frontier in developing large-scale cryogenics intended mainly to help drive private company growth. With the promises of quantum computing being truly extraordinary, these investments in critical infrastructure echo earlier U.S. Department of Defense efforts such as DARPA's funding of ARPANET – the first packet-switching network which led directly to the internet<sup>[9]</sup> – and the development of GPS (Global Positioning System).<sup>[10]</sup> Both inventions changed the way we interact with the world we know today. If fiber optics and semiconductors are the backbone of the internet and GPS, cryogenics will certainly be the first infrastructure of quantum computing. Similar to other large-scale computing infrastructures, it usually takes longer to construct projects than advance smaller prototypes in a lab environment. Quantum computing centers that are first to procure and build large scale cryogenic plants will have an advantage in the market. The cryogenics industry is dominated by a small number of vendors which can result in

longer lead times and supply chain fragility. Chicago will have a first-mover advantage with the state's incentives to procure and construct cryogenic plants.

At the Chicago Quantum Summit in November 2025, the enthusiasm of hundreds of attendees shows how Chicago has emerged as an epicenter of the global advancement of quantum computing technology. As these companies scale, the cryogenics industry has a unique opportunity to grow in unison. The unity between cryogenics and quantum computing echoes similarities between large-scale labs and semiconductor manufacturing. If the quantum and cryogenics industries can truly master scalability, reliability and cost efficiency, the opportunities to grow these critical technologies are endless. 🤖

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# Cryotreatment

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

## Mechanisms Behind the Cryogenic Effect in High Manganese Steels

**H**igh manganese austenitic steels are widely used in components exposed to severe impact and abrasion, such as shovel teeth, rock crushers and grinding equipment. Their durability arises from a deformation mechanism known as twinning-induced plasticity (TWIP). As these steels deform during service, they undergo intense work hardening, allowing the surface to become progressively stronger and more wear-resistant while the core remains tough.<sup>[1]</sup>

Recent research indicates that deep cryogenic treatment (DCT) – cooling steel to extremely low temperatures – can enhance TWIP behavior and extend wear life in demanding industrial environments.

### The TWIP Mechanism in High-Mn Steels

High-manganese steels are fully austenitic at room temperature, with a face-centered cubic (FCC) crystal structure. Unlike many structural steels that strengthen through phase transformations, these alloys rely on deformation twinning.

Under mechanical stress, mirror-like twin structures form within the crystal lattice. These twins subdivide grains into fine regions that block dislocation motion. As deformation continues, twin density increases, producing strong strain hardening.<sup>[2]</sup>

This behavior is valuable in mining and mineral-processing equipment. Components such as shovel teeth or crusher liners experience repeated impacts and large plastic strains. TWIP enables high-Mn steel to adapt in service: the surface hardens under load while the interior retains toughness needed to absorb shocks.

Deep cryogenic treatment can further influence how and when these twins form.



Crusher mantles used in gold mining. Credit: J. Cahn

### Structural Effects of Deep Cryogenic Treatment

Deep cryogenic treatment cools steel to temperatures below  $-230^{\circ}\text{F}$  using liquid nitrogen. Originally used to improve wear resistance and dimensional stability in tool steels, DCT is now being explored for austenitic high-Mn alloys.<sup>[3]</sup>

Characterization studies reveal several structural changes after treatment:

- Slight contraction of the austenite lattice
- About 40% reduction in microstrain
- Nearly two-thirds reduction in dislocation density
- Formation of uniform compressive residual stresses

Although lowering dislocation density might seem counterintuitive, these changes alter how the steel responds during deformation.

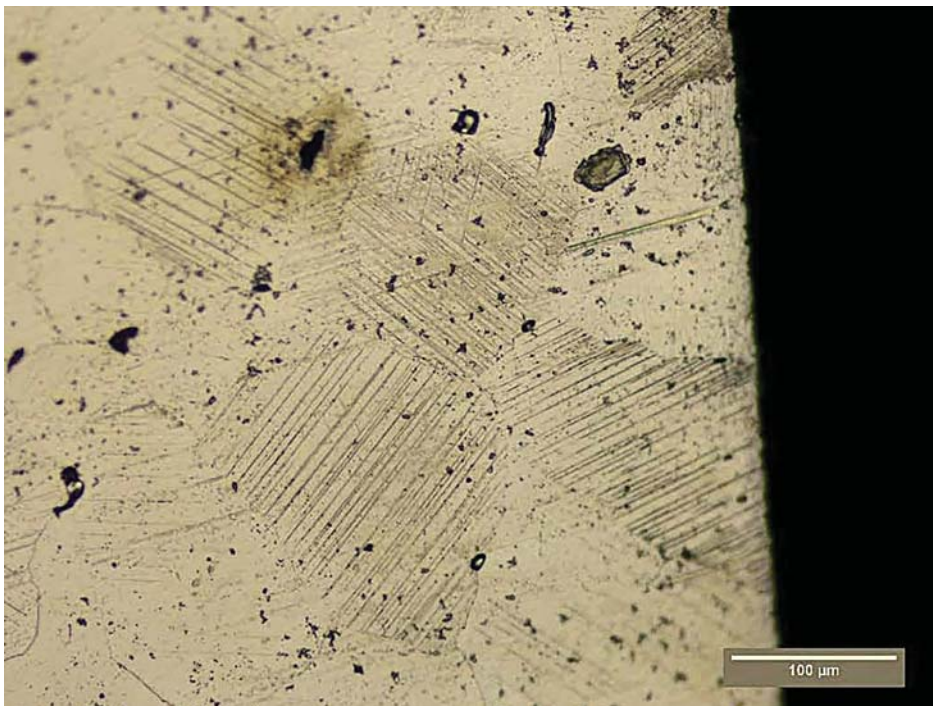
### Earlier and More Extensive Twinning

Comparisons between treated and untreated steels show that cryogenic treatment promotes earlier twinning. In treated material, deformation twins appear at about 5% strain, earlier than in conventional steel.

As deformation continues, the treated alloy develops higher twin density. Secondary and tertiary twins form, creating a hierarchical network of intersecting twins within grains.

This refined twin structure provides several advantages:

- Twin boundaries impede dislocation motion
- Strain-hardening capacity increases
- Dislocation storage during deformation improves



18% Mn twinning. Credit: J. Cahn

Although the starting defect density is lower, the treated steel accumulates dislocations more effectively during deformation. Interactions between dislocations and twin boundaries sustain high work hardening, improving resistance to abrasion and impact damage.<sup>[4]</sup>

## Thermodynamic Role of Stacking-Fault Energy

The enhanced twinning behavior is linked to stacking-fault energy (SFE), which governs deformation mechanisms in FCC metals.

In high-Mn steels, SFE determines whether plastic deformation occurs mainly by dislocation glide, martensitic transformation, or twinning. TWIP occurs within an intermediate SFE range that favors partial dislocations and stacking faults.

Deep cryogenic treatment modifies this balance through compressive residual stresses generated during cooling. These stresses alter the Gibbs free-energy conditions for stacking-fault formation.

According to the Olson-Cohen thermodynamic model, stacking-fault energy depends on the chemical driving force between phases, lattice strain energy, and interfacial energy. The compressive stresses and slight

lattice contraction produced by DCT reduce the effective SFE.<sup>[5]</sup>

Lower SFE promotes the dissociation of perfect dislocations into Shockley partial dislocations, which generate stacking faults and deformation twins. As a result, twins form more easily and propagate earlier during deformation.<sup>[6]</sup>

## Improved Toughness and Wear Resistance

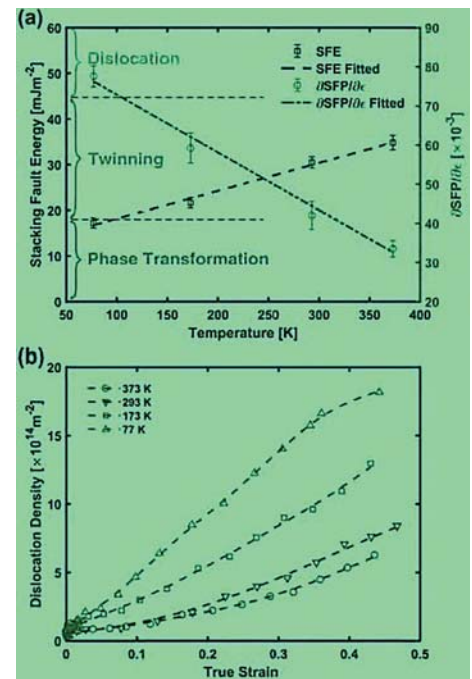
Mechanical testing confirms the benefits of enhanced twinning. Cryogenically treated high-Mn steel shows improved toughness, with Charpy impact energy increasing from about 95 J to 122 J.

Fracture surfaces reveal ductile dimple rupture with significant crack deflection. The dense twin network disrupts crack propagation paths, forcing cracks to change direction and dissipate energy.

In applications such as shovel teeth or crusher liners, this combination of higher toughness and stronger work hardening translates into longer wear life.


## A Practical Post-Casting Enhancement

A key advantage of deep cryogenic treatment is its practicality. Unlike alloy



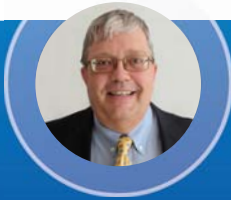
SFE and deformation pathways in TWIP steel. Credit: Tang et al, Acta Materialia

redesign or complex thermomechanical processing, DCT can be applied as a post-casting treatment to existing high-Mn steel components.<sup>[7]</sup>

By modifying the thermodynamic state of austenitic high-Mn steels and enabling more effective twinning-induced plasticity, deep cryogenic treatment offers a practical route to extending service life of critical wear components operating in harsh industrial environments. 

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# Cryo Bios

by Dr. John Weisend II, European Spallation Source ERIC, CSA Chairman, john.weisend@ess.eu, and Anne DiPaola, *Cold Facts* Editor

## Hans Quack

**F**ew engineers have had a front row seat to the development of modern cryogenic technology quite like Hans Quack. Over a career spanning industry, academia and international collaboration, Quack has contributed to many of the systems that now define large scale cryogenic infrastructure. From early work on sub-kelvin refrigeration to the design of helium plants that support major accelerator facilities, his work reflects both the technological evolution of the field and the community that built it.

Quack's entry into cryogenics began through the academic path that shaped many engineers of his generation. After earning a diploma in Process Engineering from the Technical University of Munich and a master's degree in Heat Transfer from the University of Minnesota, he joined ETH Zürich as a PhD student under Professor Peter Grassmann. Grassmann proposed a thesis focused on producing refrigeration at temperatures below 1 K using adiabatic demagnetization, placing Quack immediately within one of the most demanding areas of low temperature engineering.

Following completion of his doctoral work, Quack moved into industry in 1973 when Christian Trepp recruited him to Sulzer's cryogenics department. Sulzer had established itself as a leader in helium refrigeration and liquefaction, largely due to its expertise in expansion turbines equipped with dynamic gas bearings. These turbines were, and remain, key components in medium and large helium and hydrogen refrigerators and liquefiers.

When Trepp later succeeded Grassmann at ETH Zürich, Quack assumed leadership of the Sulzer cryogenics department. During this period the company achieved remarkable success in large scale helium refrigeration projects. Sulzer systems



were installed in facilities across the United States and Europe, including the central helium liquefier at Fermilab, large helium plants in Kansas and Wyoming and the refrigeration system for the HERA accelerator at DESY in Germany. By the mid 1980s the company could claim that more than half of the helium liquefied worldwide since the pioneering work of Heike Kamerlingh Onnes had passed through Sulzer plants.

One of the key technical advances during this era emerged during the design of the three HERA refrigerators. The team recognized that plant efficiency could be improved significantly by increasing the number of expansion turbines within the cycle. Higher efficiency reduced the number of compressors required. Because compressors were purchased components while the turbines were Sulzer's own products, the design produced both better performance and lower overall plant cost. The result was a competitive advantage that helped secure the project contract. Today the concept has become standard practice, with modern large helium refrigeration systems such as those used at CERN's Large Hadron Collider incorporating seven or more expansion turbines.

Despite these successes, the late 1980s brought a turning point. Quack proposed that Sulzer acquire CVI, an American cryogenic company that had struggled financially

after commissioning difficulties with the CEBAF refrigerator. The acquisition could have strengthened Sulzer's position in the market. Management, however, declined to invest further in cryogenics. At the time the discovery of high temperature superconductivity at nearby IBM laboratories had generated widespread speculation that low temperature refrigeration might soon become unnecessary. Newspapers predicted a future without cryogenic systems.

Instead of expanding its cryogenic activities, Sulzer chose to divest the division entirely. The department eventually became part of Linde Kryotechnik. For Quack, the decision was a difficult moment. Ironically, experience has shown that many so-called high temperature superconductors operate most efficiently at lower temperatures, which has reinforced the continuing importance of advanced helium refrigeration. The technology developed during the Sulzer years remains widely used today.

In 1992, Quack returned to academia after accepting an invitation from the Technical University of Dresden. The transition opened a new chapter in his career that combined research, teaching and international collaboration. Around the same time, Björg Wiik, director of DESY, contacted Quack with a request for assistance in designing the cooling system for the proposed TESLA linear accelerator. In return, DESY agreed to support a PhD student in Dresden. That initial collaboration led to many others. Over the following three decades Quack contributed to the planning of roughly 20 large projects worldwide, advising on cryogenic system design and specifying refrigeration infrastructure.

At Dresden, Quack taught both cryogenic engineering and conventional refrigeration technology. The contrast between these subjects offered a useful perspective. Conventional refrigeration supports everyday needs such as food preservation during harvesting, transportation and storage

before reaching household refrigerators. In comparison, cryogenics serves more specialized roles. Even in applications such as MRI systems, where superconducting magnets depend on liquid helium, the cryogenic technology itself remains largely invisible to the public. Patients undergoing an MRI scan rarely realize that they are lying within a superconducting magnet cooled by helium that may have been liquefied more than a thousand miles away.

Over the course of his career, Quack also witnessed major technological changes within cryogenic machinery. In the early 1970s many cryogenic refrigerators relied on oil bearing turbines combined with oil free piston compressors. Within 15 years that configuration had largely been replaced by gas-bearing turbines and oil flooded screw compressors, a shift that improved reliability and performance across large installations.

Looking ahead, Quack sees continued demand for large cryogenic systems, particularly in emerging areas such as fusion

power. More than ten fusion projects are currently under development worldwide, many supported by private investment. A single large fusion plant could require hundreds of tons of superconducting material along with helium refrigeration systems delivering tens of kilowatts of cooling near 20 K. Quantum computing represents another field likely to drive demand for advanced cryogenic infrastructure.

Education has remained an important part of Quack's work. Since 2008 he has helped organize the European Cryogenic Courses in collaboration with the Technical University of Wrocław and NTNU Trondheim. The three-week program covers liquid hydrogen technology in Dresden, liquid helium systems in Wrocław and LNG technology in Trondheim. Under the coordination of Christoph Haberstroh, the program continues to attract students from across the cryogenic community.

Beyond teaching and research, Quack has been deeply involved in the professional networks that connect the field. In 1990 he

succeeded Gustav and Ingrid Klipping as secretary of the International Cryogenic Committee and later helped organize several International Cryogenic Engineering Conferences in Europe and Asia. Throughout his career he has worked with colleagues across more than 20 countries and mentored doctoral students from Germany, China, Mongolia, Russia, Ukraine and the Czech Republic. Along the way, Quack also encountered many of the personalities who shaped modern cryogenics, including Kurt Mendelssohn, Nicholas Kurti, Sam Collins, Lee Gaumer, Ralph Longworth and Glen McIntosh. These connections highlight the collaborative nature of a field that has always depended on international exchange of knowledge and experience.

Hans Quack's career mirrors the trajectory of cryogenic engineering itself. From the early days of helium liquefaction plants to today's fusion and quantum technology projects, the field continues to evolve while relying on the expertise and dedication of engineers who quietly build the infrastructure that makes modern science possible. 🇩🇪

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## Extraterrestrial Specifications for Cryogenic Fluid Production

Here on our home planet, where we have been liquefying various “permanent gasses” since 1877 [1], most of us take it for granted that when we go out to buy a cryogenic liquid (or even a pure gas) we don’t have to write our own specification for what the allowable contaminants are. Instead, we pull up the Mil-specs and decide what grade we need. [2-4] These specifications have been repeatedly refined over the years as the industrial gas process plants that purify the gas and liquid products improve. This also helps the company that is designing and building a plant, as they can take appropriate air quality measurements to define what contaminants are present and build in the appropriate filtering systems accordingly. Failure to get the measurements accurate enough (or if a new industrial plant moves in changing the contaminants) can cause costly changes for a plant.

However, leaving Earth behind and looking at production on other planetary bodies, the specification process is much less well defined. For the moon, there is no atmosphere, so the fluid production must use what is in the local regolith (a word that represents what we call “dirt” on Earth, but without the organic and life compounds). We have returned samples for study back on Earth from 11 locations: the six locations for the Apollo manned missions, three locations from the Soviet Luna spacecraft, also in the 1960s, and two locations returned by the Chinese (including the first sample from the far side of the moon). [5,6] The location of these samples (see Figure 1) are not representative of the wider geology of the moon or of where NASA wants to land the Artemis missions, near the craters of the South Pole. [7] The LCROSS mission [8] did take measurements after crashing an upper stage into a polar crater, but that is just one sample. The VIPER rover, having gone through cancellation and several re-manifests in the last year,

Phase:	Solid	Liquid	Gas
Lower Relative Density	Solids that float	Liquids that rise	Gases that rise
Neutral Relative Density	Solids that form a colloid	Liquids that mix	Gases that mix
Higher Relative Density	Solids that sink	Liquids that sink	Gases that fall

Table 1: Categories of fluid interactions based on phase and density, colored by category of impact.

is currently scheduled to take in-situ measurements at the lunar poles after launch in 2027. [9] For Mars, we have samples measured robotically in the different locations where rovers have taken place in-situ. [10] The coverage of these sampled locations may not be indicative of where a production plant might be built. Thus, we are left with many unknowns even before we consider what processes might be used.

Another consideration that must be taken into account is what product the end-user can tolerate. Most studies indicate the initial user of the fluids generated on these surfaces will be returning landers through propulsion. [11] Initial studies on the actual engines themselves have shown robust tolerances to consumable impurities. [12] The subsystem just upstream of the engine consists of the cryogenic propellant liquefaction and storage systems, so exploration of the tolerance of these systems to impurities is required. Given the wide range of processes for the production of gases (electrolysis, [13] molten regolith electrolysis, [14] and carbothermal oxygen production [15]), the actual contaminants could be as varied as the sample locations across the lunar surface. Thus, a simplified method of characterization of contaminants must be identified to allow for understanding of the wide variety of possible impurities.

To accomplish this, we look at the relative impacts of different types of fluids based on their phase and relative density

and come up with the following table with four main categories. Table 1 shows the fluid impurities by phase and density grouped together by like impacts (colors).

From a liquefaction process perspective, the solids and liquids that sink (green boxes) occupy a volume at the bottom of the system and can be removed through a draining process. The solids and liquids that mix within the main fluid (yellow boxes) don’t affect the liquefaction process but may cause issues if they become too concentrated in the bulk liquid for consumption. Gases that are neutrally buoyant (grey box) will simply accumulate in the vapor space of the system and will need to be vented when they reach a certain concentration. The remaining four conditions (orange boxes) will directly affect the phase change process of the liquefaction system: Solids and liquids that rise by interrupting the phase equilibria at the interface, gases that rise and fall respectively by impeding or aiding the motion of the condensate film on the wall of the condenser. Additional considerations include, but are not limited to, the reactivity of the contaminant with the bulk fluid and the relative likelihood of the gas to dissolve into the liquid.

Measuring the effects of the four conditions as a function of contaminant quantity, especially those in the vapor phase are critical for understanding liquefaction operations and the allowable contaminants, both as they build up and interact within the system. As NASA develops liquefaction

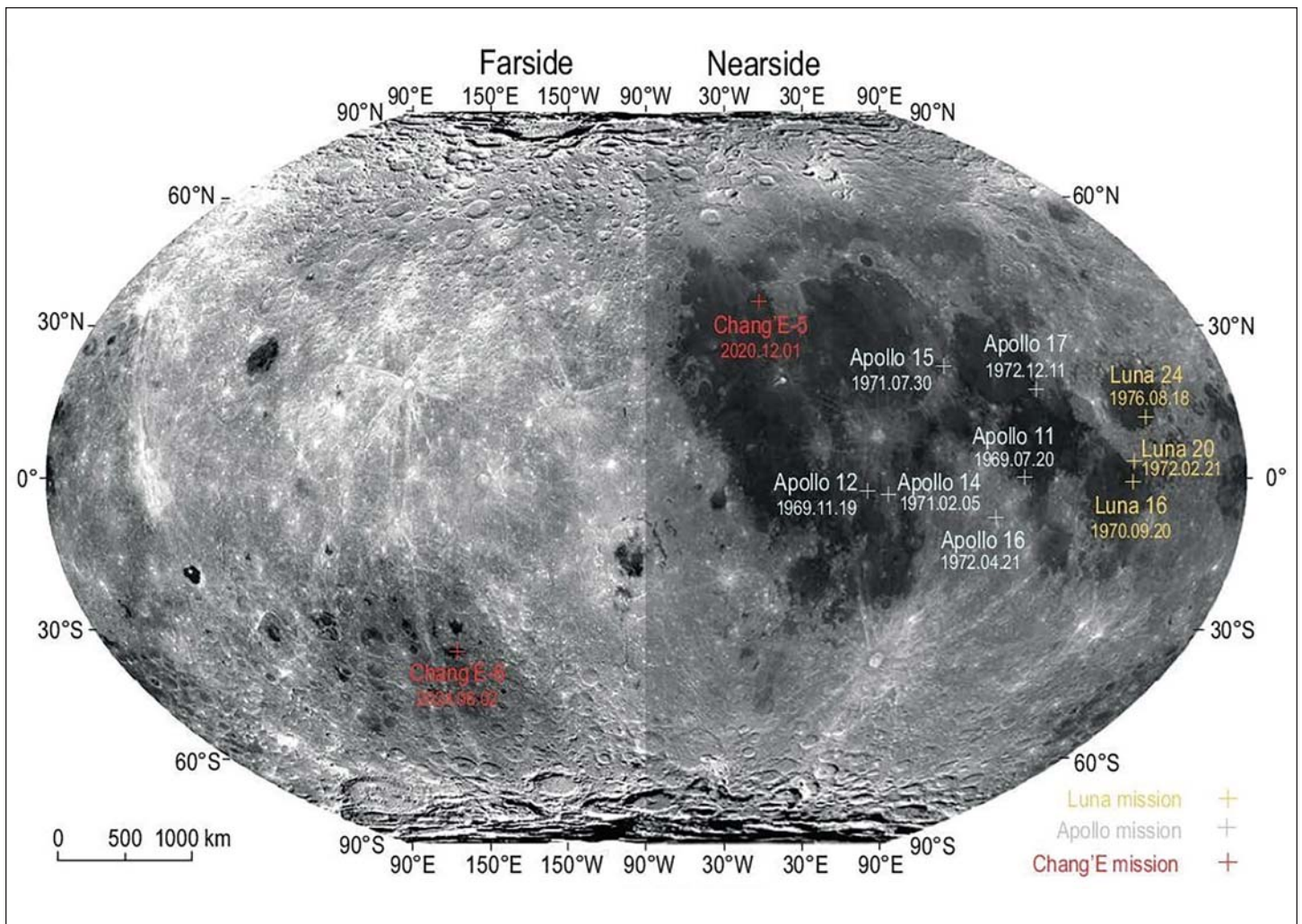


Figure 1: Map of the lunar sample return locations. [6]

operational concepts and demonstrations, these contaminations need to be taken into account. Initial CryoFILL brassboard LN<sub>2</sub> testing showed possible substantial impact of helium contamination in the ullage. [16] Further testing with helium and other contaminants is needed to understand the orange boxes in Table 1. Follow-on tests for CryoFILL have identified helium and argon as possible gases that can answer questions on the gases that rise and gases that fall items. Water vapor was considered to address solids that float, but due to concerns with build-up in undesirable locations, has been deferred to future testing. [6]

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# Zero Resistance Zone

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

## Cryogenics and the Road to Superconducting Propulsion: Part I for Aircrafts

Superconducting (SC) motors are pivotal for future transportation, offering power densities exceeding 20 kW/kg. Cooling philosophies diverge by architecture: partially superconducting aircraft designs (like NASA's HEMM) utilize integrated mechanical cryocoolers for the rotor, whereas fully superconducting aircraft favor liquid hydrogen (LH<sub>2</sub>) as a heat sink to eliminate refrigeration weight as shown in Figure 1 (A) and (B). For maritime propulsion, large-capacity mechanical cryocoolers remain the standard, as shipboard environments prioritize autonomous reliability over extreme mass reduction. This architecture supports a dual-temperature core: a 20 K MgB<sub>2</sub> stator and a 50 K REBCO rotor, managing mechanical stresses up to 150 MPa. This article reviews advances in HTS to ensure reliability. Part I of the article focuses on review of future aircraft, where the synergy among LH<sub>2</sub>, HTS materials and cryogenic systems is essential for lightweight, zero-emission flight. These achievements mark critical steps toward robust, large-scale SC propulsion.

### General Design Consideration

Over the decades, many R&D efforts, proposals, and preliminary designs have emerged from national laboratories, research institutions, universities, and industries, focusing on key components such as rotational cryocoolers, cryogenic liquid heat sinks, superconducting (SC) motors, and integrated aircraft systems (Figure 2). The general design considerations include the following (not exclusively):

- Overall concept of SC motor with aircraft
- Rotating cryocooler architecture
- Other cryogenic thermal sinks, such as LH<sub>2</sub>
- Thermal anchoring to the rotor and coils

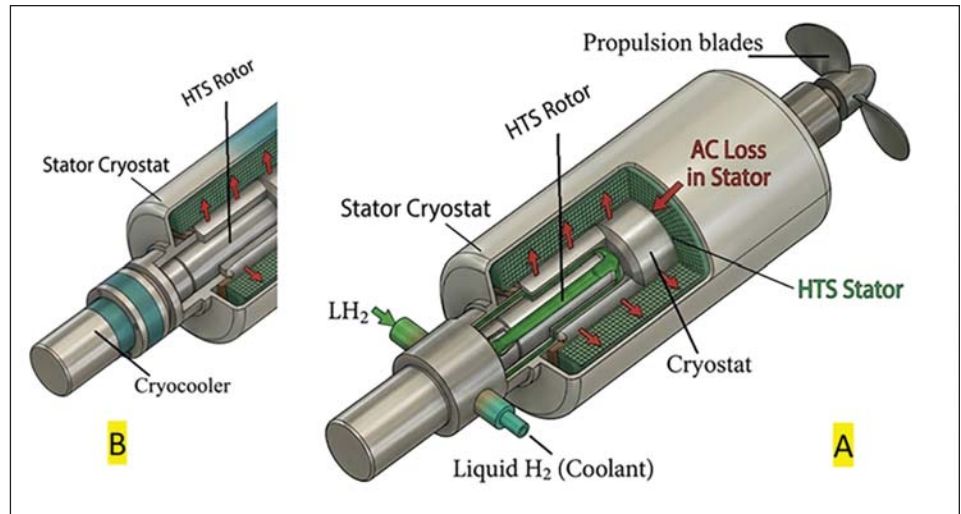


Figure 1. Simplified schematic diagram of a superconducting motor for propulsion: (A) cooled by LH<sub>2</sub>, and (B) cooled by cryocooler. Credit: Shu and Demko



Figure 2. The ESAero ECO-150 is a fully turboelectric, 150-passenger aircraft with increased fan area, high L/D wing, and both superconducting and ambient temperature systems.<sup>[2]</sup> Credit: Madavan

- Thermodynamic performance and efficiency with trade studies
- Mechanical and reliability considerations
- Comparison with stationary cryocooler approaches

### Representative Motor Thermal and Electrical Data

Megawatt-class superconducting motors for aviation employ HTS DC field coils

in the rotor and MgB<sub>2</sub> AC armature windings in the stator to achieve high power density as show in Figure 3.<sup>[3]</sup> The refrigeration challenge is driven by stringent mass limits and the distinct thermal environments required by these two superconducting subsystems. Caughley et al. presented the following representative reference data.<sup>[3-6]</sup>

*Heat Load Budget.* For a 3 MW motor, the total heat load is divided as follows:

(1) Rotor (50 K) requires 55 W of cooling (includes a 100% safety margin). Primary loads include drive shaft conduction (15 W), viscous losses from coolant circulation (5 W), and HTS joint heating (3.75 W). Use of a flux pump eliminates current lead losses. (2) Stator (20 K) requires a much higher 3.272 kW capacity (100% safety margin). The dominant load is AC hysteresis loss (~1 kW) in the coils, followed by pumping/viscous losses (~600 W) required to circulate the coolant.

*Heat Sink Temperature Choices.* Three thermal sinks are analyzed to reject the motor's heat: (1) Ambient (300 K). Readily available but leads to heavy, inefficient refrigeration systems for the stator. (2) LNG (120 K). Pressurized liquid methane offers a lower temperature sink, improving cryocooler COP. (3) LH<sub>2</sub> (23 K). Liquid hydrogen provides massive latent heat sinking (~98 kW potential), matching the fuel requirements of zero-emission aircraft.

*Cooling Methods.* (1) Rotor Cooling. For ambient sinks, a rotating Stirling cryocooler (e.g., DS30-type) is practical, weighing ~29 kg. With an LH<sub>2</sub> sink, the rotor can piggy-back off the stator's cooling loop, as 50 K is easily maintained through simple gas circulation. (2) Stator Cooling: Mechanical refrigeration at 300 K is unviable, adding ~8.9 tons per motor. The preferred method utilizes liquid hydrogen with an intermediate gaseous helium loop. By using a Joule-Thompson (JT) valve and the latent heat of LH<sub>2</sub>, the stator can achieve 20 K with high reliability and significantly lower system mass. Since the fuel H<sub>2</sub> is already at 20 - 23 K, it provides "free" cooling via heat exchangers and a simple helium loop, enabling the 30 kW/kg power density target.

## The Promise of Superconducting Motors for Aircrafts

While fully superconducting (SC) motors for aircraft face significant challenges – primarily high AC losses in the stator that demand heavy cryogenic systems – partially SC motors offer a more viable path forward.<sup>[4-7]</sup> By restricting superconductivity to specific components, engineers can maximize power density while simplifying thermal management. A primary example is NASA's High Efficiency Megawatt Motor (HEMM) as

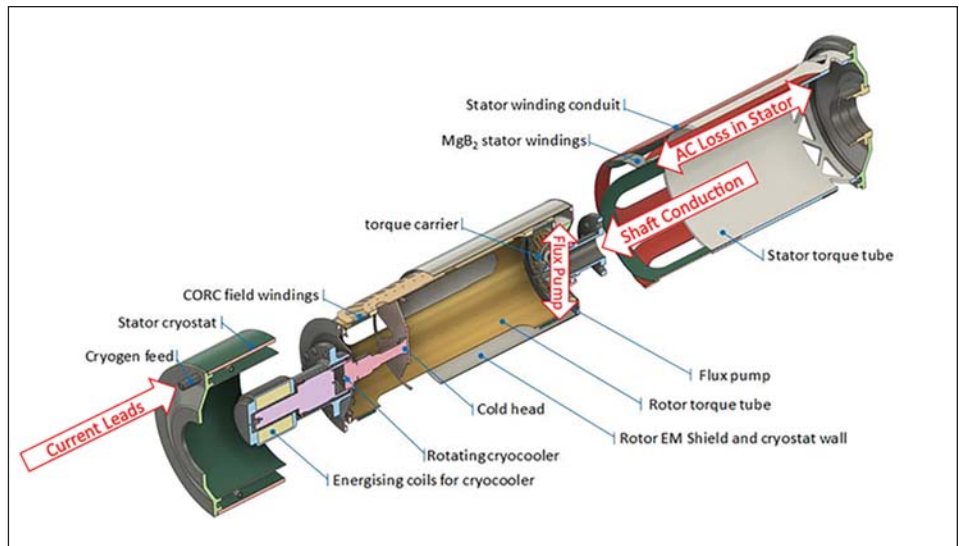


Figure 3. Exploded section view of a superconducting motor, with main heat sources indicated (red text).<sup>[3]</sup> Credit: Caughley

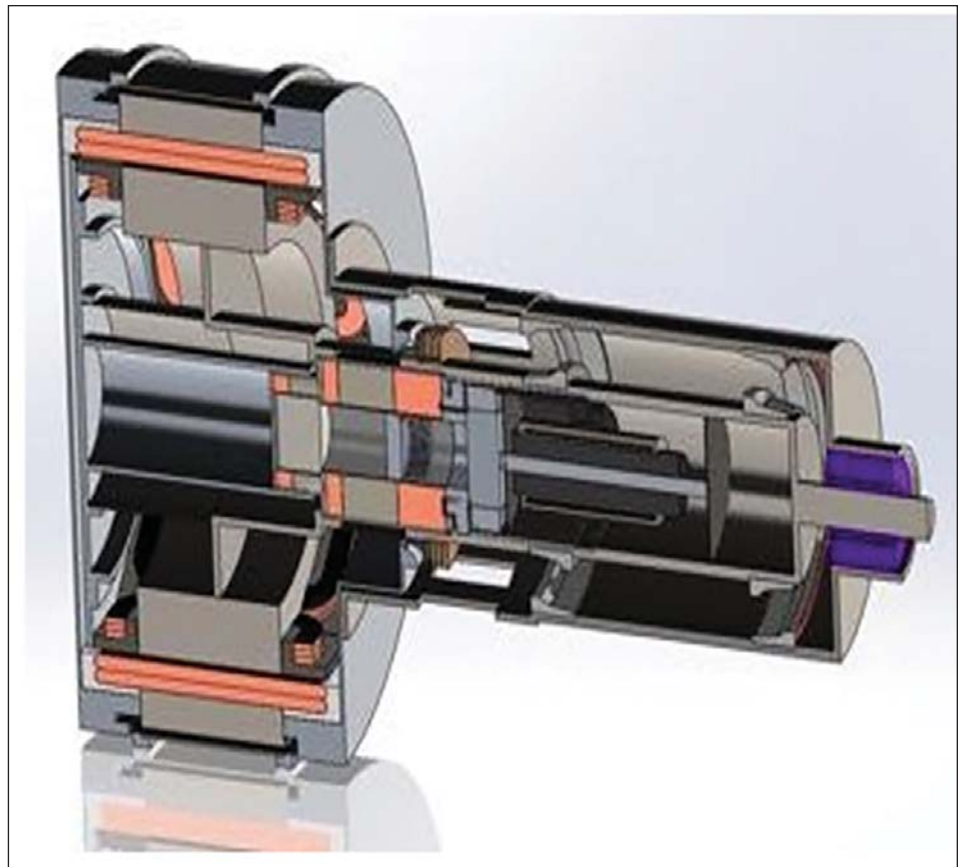


Figure 4. The HEMM 1.4 MW SC motor for aircraft.<sup>[2]</sup> Credit: Madavan

shown in Figure 4.<sup>[4]</sup> This 1.4 MW wound-field synchronous machine utilizes DC superconducting rotor windings paired with a slot-less stator. Because the rotor carries a steady DC current, it avoids the AC loss penalty, allowing for a 99% efficiency rating and a specific power of 16 kW/kg. Crucially, its self-cooled design integrates with standard aircraft cooling, bypassing the massive

weight penalties typically associated with fully SC machines.

While the HEMM is a landmark in partially superconducting (SC) motor design, several other major projects are exploring different architectures – ranging from “fully superconducting” demonstrators to

► continues on page 28

“flux-trapping” bulk magnets. The ASuMED Project (advanced SC motor experimental demonstrator), a European Union-funded project, developed a 1 MW motor that is often cited as the first “fully” superconducting motor prototype for aircraft. It uses high-temperature superconducting (HTS) windings in both the rotor and the stator (Figure 5).<sup>[4]</sup>

### Advances in Cryocooling

The use of superconductive/cryogenic components in motors/generators requires technologies to cool them to cryogenic operational temperatures. This can be achieved using individual or a combination of traditional methods including cryocoolers, cryogenic liquids, and solids cooled below melting points. To achieve cryocooling, a cooling source is necessary in addition to ancillary technologies such as cryogenic shielding, vacuum technologies, thermal engineering and control, sensors, and others. Comprehensive review articles describe cryocooler properties including cooling performance, mass and size, cost, and lifetime and reliability.<sup>[5-9]</sup> Cryocooler power density, efficiency, and size can all become critical factors affecting system viability. These factors are also referred to generally as the size, weight and power (SWaP) properties. Figure 6 plots the inverse of power density of the cryocoolers and shows that there are significant differences in machine design and impact on power densities. 📊

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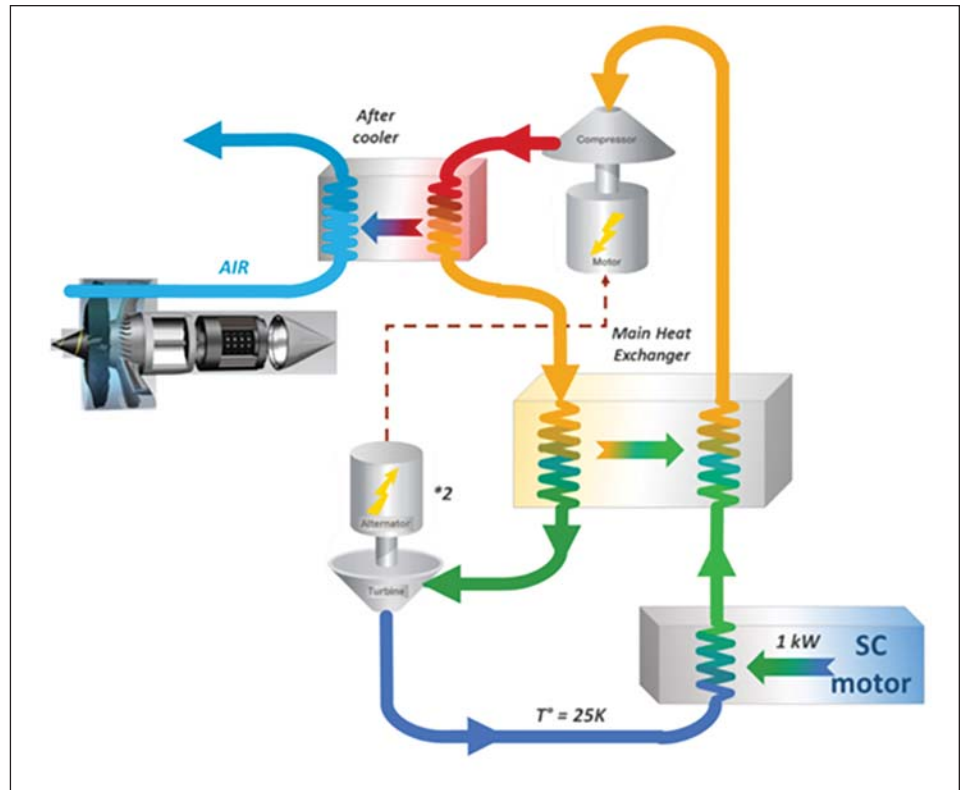


Figure 5. Schematic illustration of the cryocooler cycle for the ASuMED motor.<sup>[4]</sup> Credit: Grilli

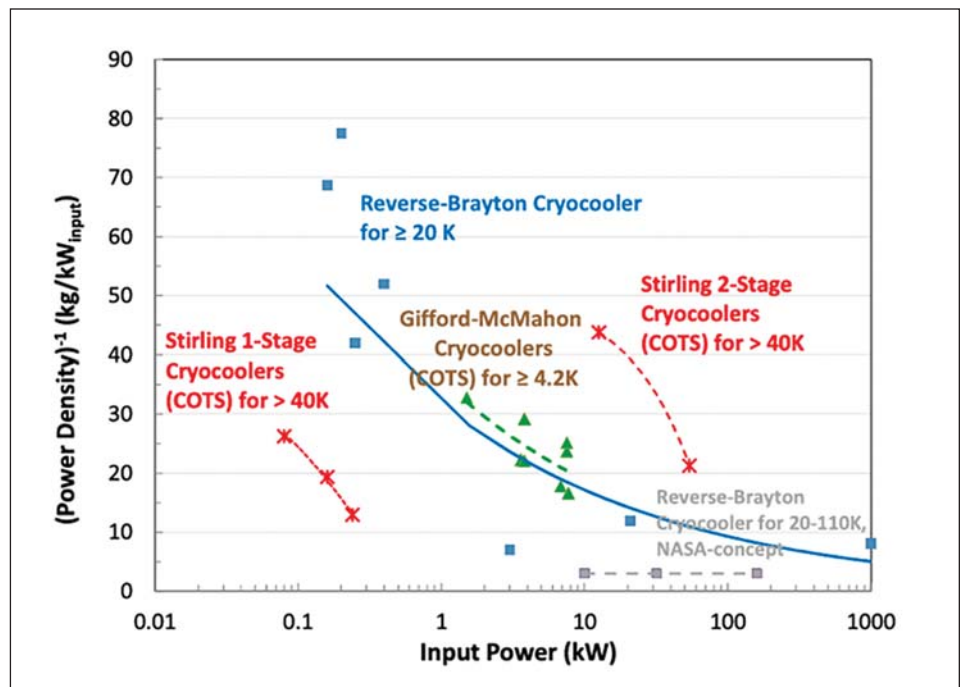


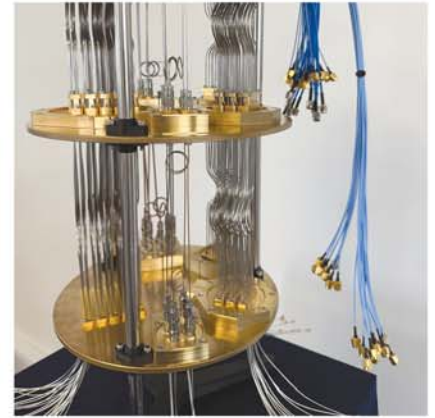
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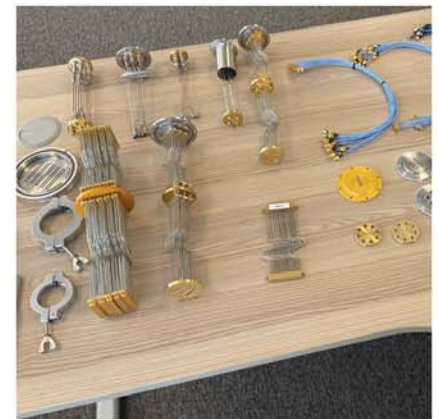
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# Cryogenics in Motion: Spaceline Delivers Advanced Nitrogen Trailer for NASA Armstrong



The cryogenic nitrogen transport and supply trailer developed by Spaceline Technologies for NASA Armstrong Flight Research Center. Credit: Spaceline Technologies

Spaceline Technologies, a fluid system engineering and manufacturing company, has completed a cryogenic nitrogen transport and supply trailer for NASA Armstrong Flight Research Center. This trailer is a mobile and standalone solution to provide pressure regulated nitrogen gas and liquid with flowrate and temperature control. Control of the trailer can be done locally through a Human Machine Interface or remotely via a computer or network connection. This system was engineered, manufactured, and tested by Spaceline Technologies in Everett, Washington.

Spaceline's employees are experts from the space launch and test industry with unique experience designing, fabricating, and operating cryogenic, high pressure gas and liquid systems and can design solutions to a customer's complex problems. This mobile cryogenic system was custom engineered to NASA's specifications including

the ability for the user to specify a cold or warm nitrogen purge depending on the end use case with a range from -60 °F to 100 °F. NASA also needed the capability to control the flowrate from 0-1000 standard cubic feet per minute. A UN T75 vacuum jacketed tank provides over 5000 gallons of onboard liquid nitrogen storage at over 150 psig. Spaceline also outfitted the system with a tiered set of ambient vaporizers coupled with an electric circulation heater for the final temperature control. Throttleable valves control the flow to each vaporizer and the heater to provide the required temperature. These flow control valves also use feedback from the onboard gas flowmeter to meet the flowrate requirement. The control system for the trailer is PLC based with an easy to use touchscreen graphical user interface that matches the process flow diagram of the system. Proportional Integral Derivative (PID) control logic is implemented on temperature and flowrate process variables to

enable automatic operation once the initial setpoints are entered.

Spaceline developed the system design through multiple iterations balancing the vaporizer and heater sizing within the size and weight constraints of an off-the-shelf road-going trailer pulled by a standard tractor. It would have been easier to meet NASA's requirements with a static system bolted to the ground, with a higher power input, larger footprint, and no restraint on system mass. Right sizing the heater and vaporizers through a bounding analysis of environmental conditions and the output requirements was key to making the system design operable (a larger circulation heater requires a larger generator which takes away available footprint from the vaporizers, etc.).

Equally important to the engineering was the activation test plan. Spaceline completed a test campaign that proved

each requirement of system operation including automatic tank pressurization, gaseous nitrogen flow and temperature control through the entire range and liquid nitrogen flow control into a test tank. Having the ability to perform these tests at our site to tune the control system, cold shock the piping and work out startup issues was key to the project's success. Spaceline has a deep test bench and can design and fabricate to a range of test requirements.

This mobile cryogenic system design is modular with options to increase/decrease flow and temperature control capacity. Spaceline is exploring building similar systems for other customers that require a highly capable cryogenic supply system with modern controls. Options include additional vaporizers, a pump package, a compressor package, and additional valves skids.

Spaceline's other product ranges include the design and fabrication of vacuum jacketed piping. They are currently fabricating a system for the NASA Glenn Research Center to connect a helium

refrigerator into a vacuum test chamber with an operating temperature of -450 °F. Spaceline is providing to NASA the completed vacuum jacketed piping system along with an engineering analysis package including relief valve sizing, flexibility analysis to ASME B31.3 using Caesar software, pipe support design and proof, leak and vacuum bakeout data.

The Spaceline team's experience base includes the design and build of complete cryogenic systems used on the launch pads of multiple commercial space companies, cryogenic and gas systems for industrial processes, and high pressure gas and liquid test stands. They are capable of taking on projects with unique requirements that need a high degree of engineering to prove out the prototype design before moving into manufacturing. Spaceline keeps engineering, fabrication, and testing under one roof and on the same team to reduce the levels of ownership, keep open lines of communication and deliver the best product to the customer. <https://spacelinetech.com>



*Piping undergoing cold shock testing.  
Credit: Spaceline Technologies*



*Graphical user interface for system.  
Credit: Spaceline Technologies*

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# There and Back Again: Reimagining Cryogenic Cooling for Scalable Arrays of Dilution Refrigerators for Future Quantum Datacenters

by B. Hansen and G. Tatkowski

Pulse tube cryocoolers are integral to current dilution refrigerator (DR) technology, which are often referred to as “dry” DRs. In this application, the cryocoolers are used to cool the two highest temperature stages of the DRs to approximately 45 K (stage 1) and 3 K (stage 2) and are integral to the precooling process of the 3-He dilution circuit required to achieve the ultralow temperatures of the dilution unit in the millikelvin range.<sup>[1,2]</sup> It wasn’t always this way. DR technology started as “wet” systems with liquid helium and liquid nitrogen transferred directly into the DR, where they provided cooling at a 77 K and 1 to 4 K stages. These systems required regular cryogen deliveries, open handling of liquids, and active management of boil-off, etc. which led to high operational overhead and safety complexity. The integration of cryocoolers into dilution refrigerators in the early 1990s represented a major technological improvement by simplifying their construction and operation from wet technology (liquid cryogen cooled) to dry technology (cryocooler-based) (Figure

1 a,b).<sup>[3,4]</sup> Since that time, the DR industry has seen significant growth, largely driven by the acceleration in quantum computing, quantum sensing and quantum networking R&D in both academia and industry. As quantum computing technology continues to advance from lab-based, benchtop experiments with 10s of qubits cooled within a single DR to fault-tolerant, datacenter quantum computers that will require 100s-1000s kilo-qubits hosted within 100s to 1,000s of DRs,<sup>[5,6]</sup> the optimal cooling scheme of the high-temperature stages of DRs is being revisited and may evolve toward quasi-wet technology (Figure 1c).

At the single-system level, pulse tube cryocoolers remain compelling. They offer turnkey operation, eliminate liquid cryogen handling, and provide sufficient cooling power at 45 K and 3 K for most laboratory-scale heat loads. However, as systems expand towards datacenter scale quantum computers that could require 100s to 1,000s of DR cryostats, the aggregate energy, cost

and operational penalties of distributed cryocoolers become increasingly significant. A DR typically requires multiple cryocoolers, each with its own compressor, power electronics, vibration mitigation and maintenance schedule. When multiplied across hundreds of systems, this results in a highly fragmented cryogenic architecture with limited economies of scale and rapidly growing infrastructure overhead.

Industrial-scale helium cryogenic plants (cryoplants) fundamentally change this equation. Large, centralized refrigerators benefit from higher efficiencies, resulting in a substantially lower inverse coefficient of performance (1/COP), a number that represents how many watts of electrical power are required to provide 1 W of refrigeration at a given temperature. Industrial scale cryoplants have a 1/COP range of ~250-450 W/W at 4.5 K and ~5 W/W at 77 K which scales with cooling capacity.<sup>[7,8]</sup> By comparison, state-of-the-art cryocoolers such as Cryomech’s PT425 have a plug power of 13

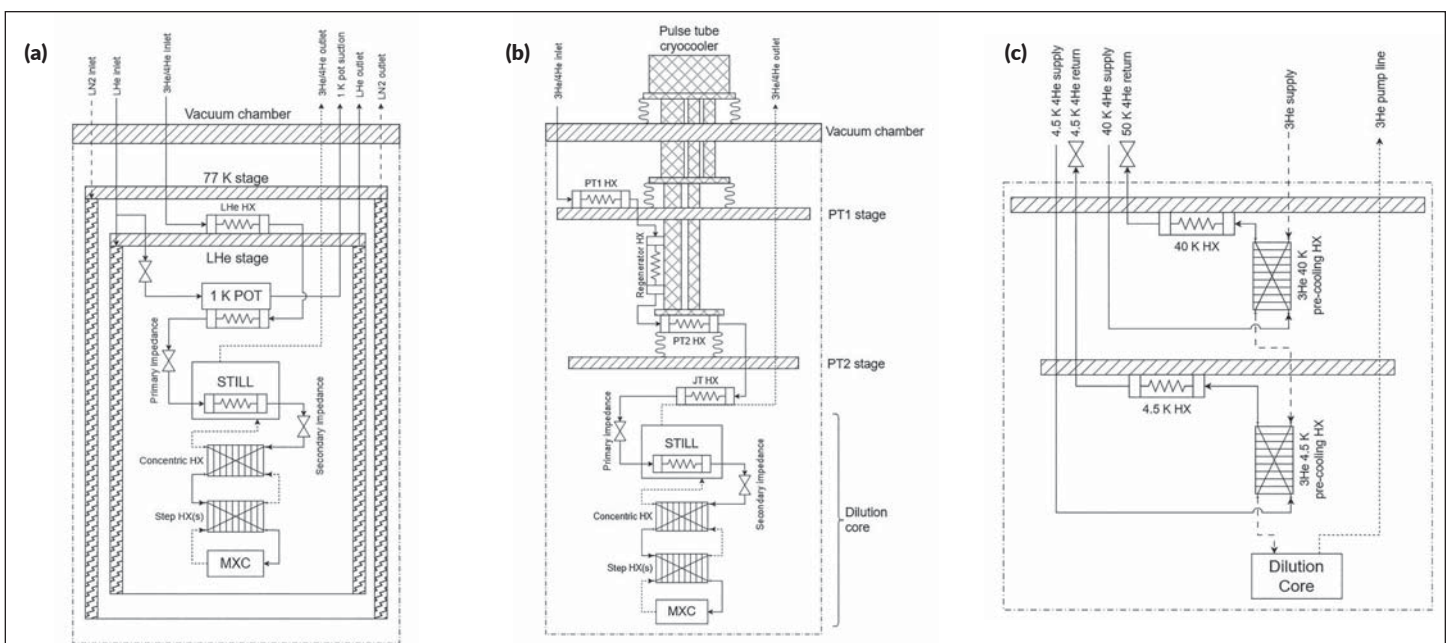


Figure 1: Process flow schematics for (a) traditional Wet DR; (b) Dry DR and (c) conceptualized quasi-wet DR for future datacenter scale quantum computers. Credit: FNAL

kW and provide 2.7 W of refrigeration at 4.2 K and 55 W at 45 K.<sup>[9]</sup> This corresponds to a 1/COP of approximately 1700 W/W at 4.5 K equivalent, which is more than four times higher than that of industrial scale cryoplants (Figure 2). The equivalent 4.5 K capacity for the PT425 is estimated by scaling the refrigeration capacity at a given temperature stage by the ratio of the ideal Carnot efficiencies at that temperature and at 4.5 K.<sup>[10]</sup>

As systems scale up, the electrical cost savings become significant, providing an attractive return on investment. For example, a system of 100 dilution refrigerators each utilizing two PT425 cryocoolers per DR (2.6 MW total plug power) would require ~2 MW more electrical power than a centralized cryoplant optimized to serve the same combined load. In addition, aggregating the cooling demand across systems enables more efficient use of utilities, such as cooling water and electrical power distribution, yielding system-level efficiency gains that grow with scale.

Beyond thermodynamic efficiency, centralized cryoplants providing closed loop, forced-flow cooling, would enable more effective heat-load management across multiple temperature stages within DRs. As these new quasi-wet DRs are reimagined, they are no longer geometry limited by the cryocooler cold head and its heat transfer surface area. Instead, the forced flow helium piping can bring the cooling directly to wherever it is needed and enthalpy recovery between temperature stages becomes more practical, providing further opportunity for optimization.

Designing the cryogenic distribution system that connects a central cryoplant to hundreds of DRs brings its own set of technical challenges. The distribution system must efficiently deliver stable, low vibration cooling at multiple temperature levels while also accommodating long distances, variable loads, and frequent connection points. Pressure drop management, flow balancing, thermal acoustic oscillation mitigation and thermal contraction will become increasingly complex as the DR array grows and the transfer line branching increases. Additionally, the system must be segmented in such a way to provide partial operation, allowing individual or smaller groups of DRs to

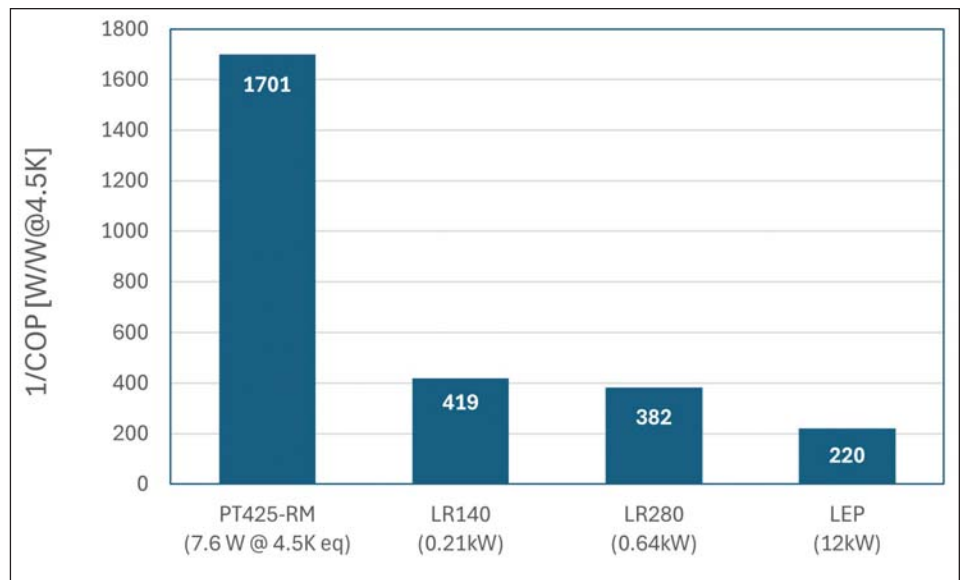


Figure 2: Comparison of the coefficient of performance at 4.5 K for the pulse tube cryocooler PT425-RM and industrial scale cryoplants. Credit: FNAL



Figure 3: Industrial cryoplant at Fermilab's Cryomodule Test Facility. Credit: FNAL

be installed, isolated, removed and serviced without disrupting the broader fleet. This segmentation is analogous to the cryogenic distribution systems being designed for PIP-II<sup>[11]</sup> and already in operation at other superconducting accelerators.<sup>[12]</sup>

A process flow scheme for an array of DRs cooled by a central cryoplant is illustrated in Figure 4. Here you have an array of m x n DRs arranged in segments with cryogens distributed via a series of valve boxes (VBs) and turnaround cans (TCs) connecting the supply and return of the 4.5 K and 40 K cooling circuits. Optimization and layout of the DR array segmentation and the internal DR cooling schemes will require a

combination of analysis and experimentation with close partnership with industrial stakeholders.

In Illinois, a strong foundation of quantum computing initiatives and enabling infrastructure is already in place. Most notably at Fermilab through the SQMS Center and the Cryogenic Technology Division, which has a long track record of national leadership in quantum computing R&D and large-scale helium cryogenics, respectively. Coupled with growing industry partnerships, Fermilab is well positioned to make major contributions to accelerating data-center quantum technology.<sup>[13,14]</sup> In addition, the

► continues on page 34

University of Illinois' Illinois Quantum and Microelectronics Park (IQMP) is designing a large-scale helium cryogenic system as part of their National Quantum Facility (NQF), which is a purpose-built system to support quantum computing R&D efforts.[15] This momentum was underscored during the recent House Committee hearing on Assessing U.S. Leadership in Quantum Science and Technology, where Rep. Foster noted that "One of the joys of representing Illinois is I get to brag about how Illinois has been a real national focal point for the development of quantum science and quantum computing. The entire state actually has become a proving ground for the field."

In addition to centralizing the 4-He cooling system, there may also be opportunities to partially centralize the 3-He gas handling and pumping system to further improve facility efficiency, operation and maintenance. By combining pumping functions such as roughing capacity or shared vacuum skids, into centralized locations, meaningful reductions in capital cost, floor space, heat rejection, and maintenance overhead could be realized compared to fully distributed one pump train per DR architectures. Partial centralization also enables more efficient operation through pump staging and variable-speed control, so that pumps run closer to optimal efficiency during different operating states. The primary tradeoff is the added system complexity and the risk introduced by a shared 3-He pump system. For example, shared pumping stages can introduce transient coupling between refrigerators with operations and events such as pump down, 3-He leaks, or operator errors on one DR can disturb header pressure and impact other DRs unless isolation is fast and reliable.

Availability is another critical consideration as quantum computing infrastructure evolves toward true datacenter operation which requires advanced levels of reliability. Centralizing the 4-He and 3-He systems further concentrates single point failures. A compressor skid trip, power loss, or control system fault can affect multiple DRs raising availability requirements, driving the need for segmentation, redundancy, robust interlocks and clearly defined fault modes. Systems will need to be configured with

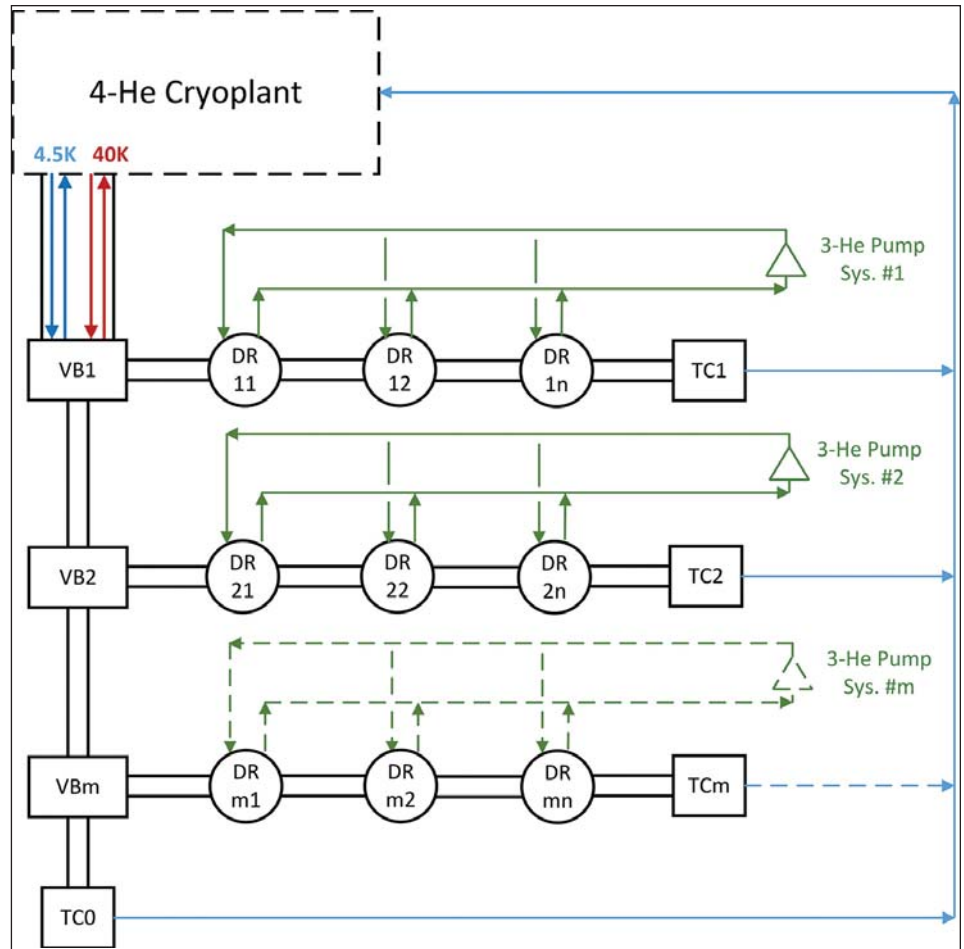


Figure 4: Conceptual layout of a matrixed array of segmented DRs. Credit: FNAL

N+1 or N+2 redundancy in critical areas to achieve Tier 3 data center reliability (>99.982%). In addition, liquid buffer volumes configured for automatic recovery strategies may be utilized to further enhance system availability and fault ride-through, protecting sensitive quantum hardware from rapid thermal excursions.

In summary, while pulse tube cryocoolers enabled the rapid expansion of dilution refrigerator technology over the past two decades, the transition to large-scale quantum systems is now driving a reassessment of the higher-temperature-stage cooling strategies of DRs and how these systems can be effectively scaled in a modular way. Quasi-wet architectures based on centralized cryoplants and forced-flow helium distribution offer compelling advantages in energy efficiency, operational cost, and scalability. With appropriate redundancy, standardized interfaces, and optimized distribution system designs, these architectures

can provide a practical and robust path forward for the next generation of quantum computing infrastructure. 🌐

References:

To view full list of references, visit <https://2csa.org/fnal-refs>





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# Pelican Wire Designs for Cryogenic and Extreme Energy Systems

As renewable energy, electrification and advanced research technologies continue to expand, the demands placed on wire and cable systems are evolving just as rapidly. Higher power densities, tighter system integration and increasingly extreme operating environments are pushing manufacturers beyond traditional commodity wire solutions.

Caleb Lemmons, Business Development Manager at Pelican Wire, says these shifts are redefining performance expectations across the industry. “Renewable energy and electrification are driving wire and cable designs to new levels of performance and durability,” Lemmons explains. “As power systems become more distributed and power-dense, there is a greater need for solutions that can handle higher currents, voltages and switching frequencies.”

These changes place greater emphasis on thermal management, dielectric performance and electromagnetic interference control. At the same time, many of these systems are being deployed in environments that challenge conventional materials. From offshore wind installations and desert solar fields to industrial facilities and arctic conditions, wire and cables must maintain reliability under constant environmental stress.

## Cryogenic Conditions Create Unique Design Challenges

Cryogenic environments present some of the most demanding conditions for wire performance. At extremely low temperatures, many common insulation materials become brittle, increasing the likelihood of damage during bending, vibration or repeated motion. Lemmons notes that thermal cycling compounds these risks.

“The difference in thermal contraction rates between conductors, insulation and shielding can create mechanical stress during temperature transitions,” he says. “Over time, that stress can lead to gradual degradation or failure.”



Resistance spools show stainless steel over braid resistance wire manufactured by Pelican Wire. Credit: Pelican Wire

Electrical performance can also be affected. Properties such as dielectric constant and insulation resistance may shift at cryogenic temperatures, which is especially critical for high-voltage applications and sensitive signal transmission. Mechanical factors like flex life and termination reliability must also be carefully addressed to ensure long-term system integrity.

## A Systems-Based Approach to Wire Design

Pelican Wire addresses these challenges through a systems-based design philosophy focused on application-specific performance rather than off-the-shelf solutions. According to Lemmons, the process begins with a detailed understanding of each application’s operating conditions.

“We evaluate temperature range, environmental exposure, voltage and current requirements and mechanical stresses,” he says. “That information guides material selection and overall construction.”

Specialized fluoropolymers and other high performance materials are commonly

used for cryogenic applications due to their low-temperature flexibility and compatible thermal contraction behavior. Conductors and shielding configurations are selected to balance electrical performance with mechanical durability and environmental resistance.

To validate reliability, Pelican Wire subjects designs to rigorous testing that reflects real-world conditions. Thermal cycling and low-temperature flexibility testing help ensure that wire assemblies will perform consistently over time, not just during initial deployment.

## Growing Demand Across Energy and Research Applications

Demand for wire solutions capable of operating in both ambient and cryogenic conditions is increasing across several sectors. Hydrogen infrastructure is one of the most prominent examples. Systems for hydrogen liquefaction, storage and transfer must function reliably as temperatures shift between ambient and cryogenic states.

“The expansion of hydrogen infrastructure is driving the need for wire that can handle repeated transitions without compromising electrical or mechanical performance,” Lemmons says.

Advanced industrial gas handling systems also contribute to this demand, such as aerospace platforms, research environments and advanced computing systems that support electrification initiatives. In many of these applications, system uptime is critical and wire failure can lead to costly downtime or safety concerns.

### Looking Ahead at Extreme Energy Systems

As energy systems continue to evolve, Lemmons expects wire and cable design to become even more specialized. Increasing power density, tighter packaging and higher switching frequencies will require enhanced thermal performance, stronger dielectric properties and improved electromagnetic compatibility.

“There is also a growing emphasis on long-term reliability and uptime, especially for critical infrastructure,” he says. “That puts more focus on engineered material systems and construction techniques that reduce the risk of failure at interfaces.”

Those interfaces, particularly between insulation, shielding and conductors, are often the most vulnerable points in extreme temperature environments. Addressing them requires a combination of materials expertise, application knowledge and disciplined manufacturing processes.

Ultimately, Lemmons believes success in this market depends on the ability to align design, materials and manufacturing with the realities of modern energy systems. “The ability to combine materials expertise with application-driven design and consistent, high-quality manufacturing will be essential,” he says.

As cryogenic and electrified technologies continue to expand, Pelican Wire’s approach highlights how thoughtful engineering at the cable level plays a critical role in enabling the next generation of energy and research systems.

[www.pelicanwire.com](http://www.pelicanwire.com)

## Wire & Cable Technology Specifications

### OPERATING TEMPERATURE RANGES

Cryogenic -273°C to -196°C	Low Temp -196°C to 0°C	Ambient 0°C to 200°C	High Temp 200°C to 600°C	Very High 600°C to 1423°C
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### ALLOY OPTIONS

**High-Temperature Heating**

Nichrome 80/20 80% Ni, 20% Cr	Max: 1200°C
Nichrome 70/30 70% Ni, 30% Cr	Max: 1250°C
Kanthal (FeCrAl) 80% Fe, 15% Cr, 5% Al	Max: 1425°C

**Cryogenic & Resistance**

Constantan 55% Cu, 45% Ni	-270°C to 600°C
Manganin 84% Cu, 12% Ni, 4% Mn	Cryogenic
Type T Wire 90% Cu, 10% Ni	-270°C to 375°C

### INSULATION OPTIONS

PTFE (Teflon) Polytetrafluoroethylene	Range: -200°C to +260°C
Silicone Rubber Polydimethylsiloxane	Range: -60°C to +300°C
Polyimide (Kapton) Polybenzoxazine	Range: -200°C to +400°C
Fiberglass E-glass	Range: -50°C to +482°C
Ceramic Fiber Alumina/Silica	Range: Up to 1260°C

### MANUFACTURING PROCESSES

Custom Engineered Wire Solution Experts

Wire specs information shows detailed wire specification information from Pelican Wire’s product lineup. Credit: Pelican Wire



Extruder view shows the extrusion line panel at the Pelican Wire facility in Naples, Florida. Credit: Pelican Wire

# IN MEMORIAM

## Remembering our Friend, Ray Radebaugh (1939-2026)



The cryogenics community lost one of its most influential figures with the passing of Ray Radebaugh in February 2026. Over a career spanning more than five decades, Radebaugh

helped shape modern cryogenic engineering through pioneering research, devoted mentorship and an unwavering willingness to share knowledge. His work on cryocoolers, dilution refrigeration and low temperature thermodynamics helped define the field, while his generosity toward colleagues and students left a lasting personal impact on generations of scientists and engineers.

After studying physics at the University of Michigan, where he operated helium liquefiers and assisted with heat capacity measurements, Radebaugh joined the National Bureau of Standards (later NIST) in Boulder in 1966. There he became a central figure in the Cryogenic Engineering Laboratory during a period of rapid growth in low temperature science and technology.

His early research focused on the thermodynamic properties of  $3\text{He}$ - $4\text{He}$  mixtures used in dilution refrigeration. His work provided essential data for systems operating below one kelvin and laid the groundwork for future advances in millikelvin cooling. In later years he became equally well known for his contributions to cryocooler technology, including work on Stirling and pulse-tube refrigeration systems capable of reaching temperatures near 4 K.

Throughout his career, Radebaugh combined deep theoretical understanding with practical engineering skill. John Pfothenauer of the University of Wisconsin-Madison recalled that Ray's abilities in the laboratory were just as

remarkable as his theoretical insights. "Although Ray's thorough knowledge of the theoretical foundations of cryocooler research was impressive," he wrote, "it was his hands-on skill in the lab that elevated him to hero status in my mind."

Radebaugh also became widely known for his commitment to education. His short courses on cryocooler fundamentals, taught at conferences around the world, helped introduce generations of engineers and scientists to the field. Weisend noted that these courses were among the most consistently well attended at major conferences. Through them, he wrote, "Ray introduced a lot of people to the technology of cryocoolers, providing valuable theoretical and practical information."

Students and younger researchers often experienced his generosity firsthand. Ryan Snodgrass of NIST recalled meeting Radebaugh while visiting the institute as a prospective postdoctoral researcher. "Ray carved out a significant chunk of his time to meet with me, even though he was already retired for a decade," Snodgrass wrote. "Whenever I had challenging cryocooler questions I could reach out to Ray. He would respond quickly, usually with enlightening thoughts and never expected anything in return."

For those who worked with him more closely, his patience as a mentor left a lasting impression. Yunda Wang of the Hong Kong University of Science and Technology (Guangzhou), who collaborated with Radebaugh during his doctoral studies, remembers long discussions in Ray's office at NIST. "He patiently explained the governing equations and modeling details to me step by step," Wang wrote. "His rigorous attitude toward scientific work is something I will always respect and learn from."

Beyond his scientific contributions, colleagues frequently remarked on his humility and warmth. Professor S. Vanapalli of the University of Twente wrote that despite his worldwide reputation, Radebaugh remained "modest and warm-hearted," always willing to engage with others at conferences and discussions. Even later in life, he remained deeply engaged with the field, attending meetings, studying posters and exchanging ideas with younger researchers.

Radebaugh contributed extensively to the cryogenic community through professional service. He played a key role in developing the International Cryocooler Conference and served the Cryogenic Engineering Conference in multiple roles, including board member and awards chair. In 2001, he received the Cryogenic Society of America's Vance Award. His involvement with CSA included workshops, lectures, and editorial contributions to *Cold Facts*. Laurie Huget, former executive director of CSA, recalled the importance of those efforts: "Ray was extremely important to the success of our Society. The courses and workshops he led all over the world were among the major drivers of our success as the world leader in low temperature physics, engineering and technology."

For many who knew him, however, Radebaugh's greatest legacy lies not only in his technical achievements but also in the spirit with which he approached science and collaboration. As Pfothenauer observed, everyone who interacted with him encountered "a warm-hearted gentle person who nevertheless exuded an excitement about anything related to cryocoolers."

His colleagues, students and friends will continue to feel his influence for many years to come. 🙏

During my PhD at the University of Colorado Boulder (2009–2012), I had the privilege of working at NIST as a visiting student, where I worked closely with Ray on research related to micro cryogenic systems. He provided important guidance throughout that period and was also a member of my dissertation committee. Ray’s accomplishments in cryogenics are well known. What impressed me most, however, was his calm and friendly personality. I still clearly remember sitting in his office – surrounded by awards and stacks of technical papers – discussing fluid modeling issues in micro heat exchangers. He patiently explained the governing equations and modeling details to me step by step. Discussions with Ray helped me a great deal and influenced the way I approach research problems.

His rigorous attitude toward scientific work is something I will always respect and learn from. At the same time, his gentle and approachable character left a lasting impression on me. I will always remember him as an outstanding scientist, a mentor and a genuinely kind person. He will be greatly missed by all of us. My thoughts are with his family and friends.

**- Yunda Wang, Ph.D.**

[The Hong Kong University of Science and Technology \(Guangzhou\)](#)



I heard with great shock that the legendary figure Ray Radebaugh had passed away in February. I had originally planned to visit Ray during the conference this year, but the gathering in Hawaii 2023, where we took the photo together, turned out to be our last one.

I first met Ray over 20 years ago. The photos show us sightseeing in the Forbidden City in Beijing. His profound contributions to numerous cryogenic technologies are, of course, globally recognized. But beyond that, he was also modest and warm-hearted. My connection with him began in the early days when we worked on pulse tube and thermoacoustic refrigerators. I remember once sending him a newly finished paper about thermodynamics on pulse tube coolers, joking that it might help him to fall asleep on his flight back to the US.

Later, as I led my team in dilution refrigeration research, I discovered that some very classic papers in the field were also authored by him. It has been my great privilege that our work over the last two decades received his generous recognition. I also deeply appreciate his support in my personal career.

I have always been inspired by his dedication. Even at an advanced age, he persisted in research, performing calculations and analyses and attending academic conferences. In Hawaii, I often saw him browsing posters and exhibition booths, engaging in discussions with others. At that time, he had gotten an injury on his face, which gave him a rugged look.

There is no better way to conclude than by quoting the CSA memorial tribute: “Many of us were fortunate to learn directly from Ray, not only about cryocoolers but about curiosity, rigor, and the joy of solving hard problems.”

He may be gone, but his spirit and influence will forever inspire generations to come. May he rest in peace.



**- Dr. Wei Dai**

[Technical Institute of Physics and Chemistry, Chinese Academy of Sciences](#)

Ray was an extremely talented and selfless scientist. When I first visited NIST as a prospective postdoc in 2019, Ray carved out a significant chunk of his time to meet with me, even though he was already retired (for a full decade by then!) and my postdoc was not to be with him, but a different group at NIST. Whenever I had challenging cryocooler questions I could always reach out to Ray. He would respond quickly, usually with enlightening thoughts, and never expected anything in return. Every time I interacted with Ray he had a smile on his face. His dedication to science – and even more so his willingness to help others – is exemplary.

**- Dr. Ryan J. Snodgrass**

[NIST Boulder](#)

It is with great sadness that we learn of the passing of Ray Radebaugh. At the CNRS-CRTBT (now Néel Institute) in Grenoble, France, many of us worked for many years on advanced cryogenics, particularly dilution refrigeration, inspired and guided by Ray Radebaugh's pioneering work.

We would like to offer our warmest and most sincere condolences to his family, friends, and colleagues.

**- Henri Godfrin**

[Institut Néel, Grenoble, France](#)

I first met Ray very early in my career, at the International Cryogenics and Refrigeration Conference in Hangzhou, China in 1989. I was still a graduate student at Wisconsin at the time and Ray and I were some of the few Americans at the conference.

I recall Ray being very friendly and supportive during that first meeting and later came to realize that Ray was naturally friendly, humble and always very supportive of students and new colleagues in the field.

Since Ray's specialty was cryocoolers and dilution refrigerators, I didn't have much direct professional contact with him until I started to help organize Short Courses for the CSA. Ray's course on Cryocooler Fundamentals was one of our first courses and from then on was almost always held at the Cryogenic Engineering Conference, the International Cryocooler Conference and even at the Applied Superconductivity Conference on occasion. Ray was always happy to teach these courses. These courses were generally the best attended of our short courses and the students were always pleased with Ray's instruction. In this way, Ray introduced a lot of people to the technology of cryocoolers, providing valuable theoretical and practical information.

Ray assisted me with a number of other activities over the years, including paper reviews, suggestions for short course instructors and background information on the early days of NBS Boulder. Ray was always cheerfully helpful.

When Anne DiPaola and I started to interview people for our Pioneers of Cryogenics column in **Cold Facts**, Ray was the first person we approached. His interview (**Cold Facts**, Volume 40, Number 4 – Sept 2024) is well worth reading. One fact that sticks out for me was that for his high school science fair project, Ray hand built a functioning air liquefier. This illustrates his early skill and curiosity.

I found Ray highly competent, generous with his time and always willing to help. His passing is a loss to all of us.

**- John G. Weisend II**

European Spallation Source ERIC

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Ray Radebaugh has been a rich resource for the cryogenics world through many decades. Even before I ever met him, I repeatedly came across his written contributions in journal articles and book chapters, such as the multiple topics he contributed to Graham Walker's "Cryocooler" volumes. Those caught my attention because of the broad scope of his interests – everything from dilution refrigeration to a rubber-band refrigerator. Learning from him in those chapters that any physical mechanism that is accompanied with a change of entropy is a mechanism that has the potential to produce refrigeration was an eye-opening inspiration.

In the summer of 1992, I enrolled in Ray's week-long cryocooler course. I was aware that he had been teaching the course for many years by that time and I was excited to finally enjoy the opportunity of consuming the full course. It was a very rewarding experience; one which launched my own research into pulse tube and JT coolers. As with all of Ray's presentations, the material was well organized, clearly communicated, and filled with lots of practical content.

Roughly a decade later my family and I lived in Louisville, Colorado while I worked with Ray and his group at NIST Boulder. During that time, I was able to learn directly from Ray about the design principles of pulse tube refrigerators, inertance tubes, and regenerators, while also observing his participation in laboratory activities. Although Ray's thorough knowledge of the theoretical foundations of cryocooler research was impressive, it was his hands-on skill in the lab that elevated him to hero status in my mind.

Both professionally and personally, Ray Radebaugh was a generous and kind person. It was my pleasure and honor to work with him. He will be missed by us all.

**- John Pfothauer**

University of Wisconsin-Madison

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In my tenure as Executive Director of the Cryogenic Society of America, we were blessed with so many persons who contributed to the success of our organization. Ray Radebaugh was one of the most outstanding. He was greatly revered and will be greatly missed.

When CSA took over the Space Cryogenics Workshop (SCW), I had a fast learning curve. The event, held in Milwaukee, was our first venture into sponsoring this collaboration. Facilitating SCW came to be a real favorite part of my job, as the camaraderie, intellectual curiosity and cutting edge science, engineering and technology were inspiring.

I had the honor of presenting the Robert Vance Award to Ray at that workshop. It felt so right to be honoring him for his many contributions up to that point, but it became even more appropriate as his years of involvement and service to CSA progressed.

Ray was extremely important to the success of our Society. The courses and workshops he led all over the world for us were among the major drivers of our success as the world leader in low temperature physics, engineering and technology. At these courses and presentations Ray made himself available to the participants in a very collaborative way. It was clear that he enjoyed sharing his deep and wide knowledge.

Personally, I want to add that Ray, on top of his erudition, was a generous, truly nice person. In his quiet way, he contributed immeasurably to our cryogenics community. And, as I found out at the Space Cryogenics Workshop in New Orleans, he was a terrific dancer.

**- Laurie Huget**

Cryogenic Society of America (retired)

I was fortunate to have Ray Radebaugh supervise part of my doctoral research, during which I worked at NIST Boulder on high frequency pulse tube cryocoolers. Ray always made time for open and thoughtful discussions, often continuing late into the night. Beyond his exceptional scientific insight, he was a genuinely kind and generous person, deeply invested in the growth of young researchers. I remain grateful for his guidance, his patience, and the lasting influence he had on my work and career.

**- Prof. Dr. ir. S. Vanapalli**  
University of Twente

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As a junior engineer I used to accompany Dr. Thomas M. Flynn when he occasionally visited his friend Ray Radebaugh in his NIST lab.

Ray typically was working on cryocoolers and he proudly showed us his test equipment setups which were a far cry from the mature technology that we see in commercial hardware today.

Ray was always pushing the boundaries. I have always had great respect for him due to both his hard work in the lab as well as for his teaching cryocooler courses. The willingness to share that knowledge with those that continue the research and the use of those technologies has been an inspiration to me as a cryogenic instructor.

I learned a lot from Ray Radebaugh and he and his talents will be missed in the cryogenic realm.

**- David J. Roth**  
CRYOCO LLC

.....

Ray gave a series of lectures on cryogenics in ZJU between 2004 and 2016, invited by Prof. Zhihua Gan. I had the privilege of attending almost all of them since 2008.

His talks broadened our horizons immensely. He provided a comprehensive overview of cryogenics from its inception and touched upon nearly every related technology and application worldwide. When I started, my knowledge was limited to pulse tube cryocoolers, but Ray taught us about all other regenerative cryocoolers, including Stirling cryocoolers. He even shared the story of a unique cryocooler developed for the Hubble Space Telescope, whose installation required a dedicated spacewalk mission! May Ray continue his speeches, surrounded by attentive audiences, in paradise.

To read the full tribute, visit <https://2csa.org/cao>.

**- Qiang CAO**  
Tongji University, Shanghai, China





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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](mailto:editor@cryogenicsociety.org).



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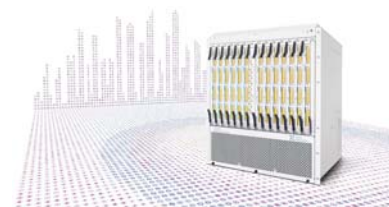
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# People & Companies in Cryogenics

Linde has delivered two large cryogenic cold boxes for installation in the underground service tunnels of CERN's High-Luminosity Large Hadron Collider (HL-LHC) project. The equipment forms part of the upgraded refrigeration system that will cool the accelerator's new superconducting magnet systems to approximately 1.9 kelvin, just above absolute zero. Recently lowered into position near the ATLAS and CMS experi-



The new cold box transported to the underground tunnel of the HLumi LHC, near the ATLAS experiment. Credit: CERN

ments, the cold boxes will operate with multiple cold compressors and helium transport lines that pre-cool helium to about 4.5 kelvin before further pressure reduction achieves the ultralow temperatures required inside the magnet cryostats. The installation marks a key milestone in the HL-LHC upgrade program, which aims to significantly increase the collider's luminosity and scientific output when it begins operations later this decade.

Researchers at DESY have reported progress on a new cryogenic platform designed to support next-generation dark matter and gravitational wave experiments. The system includes a specialized sub-cooler box capable of supplying supercritical helium through multiple transfer lines,



The ALPS cryoplatform subcooler box (ACPS) in the hall HERA North. Credit: DESY

enabling experiments with high heat loads to operate at extremely low temperatures. By integrating valves, sensors and control systems directly within the cryogenic platform, the design allows experiments to run with reduced external cryogenic infrastructure while maintaining precise temperature control. The new platform will help expand DESY's capabilities for large-scale fundamental physics experiments that require advanced cryogenic environments.

Chinese scientist **Jin Changqing**, a research professor at the **Institute of Physics of the Chinese Academy of Sciences**, has been awarded the 2026 Bernd T. Matthias Prize, one of the most prestigious international honors in the field of superconducting materials. The award recognizes his pioneering discoveries of novel superconductors using advanced high-pressure synthesis and characterization techniques. Jin's work has significantly expanded the family of known superconducting materials and deepened understanding of their properties, providing new opportunities for applications ranging from quantum technologies to high-field magnets. The Matthias Prize is presented by the organizers of the International Conference on Materials and Mechanisms of Superconductivity and recognizes outstanding achievements in superconductivity research worldwide.

Columbia University physicist **Yasutomo Uemura** has been named a recipient of the



Yasutomo Uemura. Credit: Columbia Quantum Initiative

2026 Heike Kamerlingh Onnes Prize, awarded for outstanding experimental contributions that illuminate the fundamental nature of superconductivity. Uemura will share the honor with Richard Greene of the University of Maryland. At the same time, Columbia

## Meetings & Events

### CSA's Foundations of Cryocoolers Short Course

June 15, 2026  
Syracuse, NY  
<https://2csa.org/x6z>

### 24th International Cryocooler Conference

June 15-18, 2026  
Syracuse, NY  
<https://cryocooler.org>

### ICEC 30/ICMC 2026

June 22-26, 2026  
Daejeon, Korea  
<https://icec30-icmc2026.org>

### IQT Nordics 2026

June 22-24, 2026  
Oslo, Norway  
<https://iqtevent.com/nordics>

### 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>

physicist Andrew Millis was selected to receive the 2026 John Bardeen Prize for his theoretical contributions to superconductivity. Both awards will be presented at the upcoming International Conference on the Materials and Mechanisms of Superconductivity (M2S). Their recognition highlights continued advances in superconductivity research that underpin technologies such as quantum computing and other cryogenic-based systems operating near absolute zero. 🌡️

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