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Cracking the Code to Human Organ Banking | 8

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Dr. Lakshya Gangwar is advancing cryopreservation at the human-organ scales using vitrification and nanowarming technologies demonstrating success in physical volumes and porcine livers. Credit: Lakshya Gangwar and Bat-Erdene Namsrai

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From the Executive Director

It's finally starting to feel like fall here in Chicagoland! The crisp air and changing leaves remind us that the holidays and a brand-new year are just around the corner. As we look ahead to 2026, the Cryogenic Society of America (CSA) has a number of exciting initiatives and opportunities on the horizon.

First, I encourage you to take a look at the 2026 Media Guide. Along with our long-standing print advertising options in *Cold Facts*, we are thrilled to introduce new digital advertising opportunities. These additions will help companies and organizations reach our growing audience through online platforms and targeted placements, expanding visibility across both print and digital channels. Whether you're looking to strengthen brand awareness or connect with specific sectors of the cryogenics community, these flexible options are designed to support your outreach goals. You can explore all the details in the 2026 Media Guide here: **https://2csa.org/guide**.

Meanwhile, our team is putting the finishing touches on the 2026 Buyer's Guide, CSA's trusted directory of products, services, and expertise for the cryogenics industry. This comprehensive resource features everything from adhesives, cryocoolers, and dewars to electronic controls, valves, magnets and specialty manufacturing. It also includes listings for engineering consultants, research and testing laboratories, and cryogenic transport and treatment services. If your company is included in the Buyer's Guide, please check your inbox for our recent email reminder to review your listing and ensure your information is current.

Looking ahead, CSA is also proud to partner with the newly launched Cryogenics Advancement & Research Exchange (CARE) Forum, a community created by researchers for researchers. The CARE Forum will host webinars, share the latest breakthroughs, and foster collaboration among scientists, students and professionals around the world. CSA will be supporting this effort by helping spread the word and connecting our research members with this promising new platform.

As always, I want to extend my sincere thanks for your ongoing engagement with CSA. Whether you attend our courses, contribute to *Cold Facts*, participate in conferences or share your feedback, your involvement is what keeps our society strong and vibrant. Together, we are advancing the science and practice of cryogenics and ensuring that our field continues to thrive in the years to come.

I look forward to all that's ahead and to working alongside each of you as we move into another exciting year.


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University of Minnesota Clinic and Surgery Center. Credit: University of Minnesota Medical School

Cracking the Code to Human Organ Banking

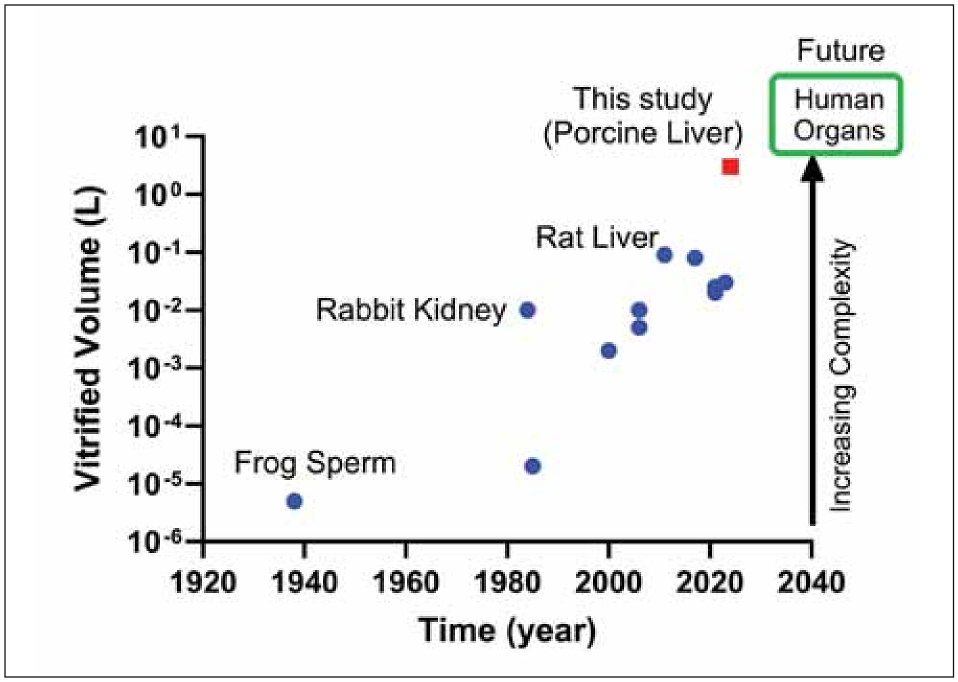
"Scale-Up"- Cryopreservation Breakthroughs at Size of Human Organs

By Dr. Lakshya Gangwar, University of Minnesota

Imagine a future where organs can be stored indefinitely "as glass," and ready to be brought back to life at a moment's notice. That's the bold horizon sketched by a new study from University of Minnesota researchers, published in *Nature Communications,* 16 8511 (2025). A team of University of Minnesota engineers and medical school researchers remarkably presents the first physical proof that samples of human size organs can be indeed cryopreserved using vitrification and nanowarming technology, a milestone on the path toward true organ banking.

Dr. Lakshya Gangwar, a *Cold Facts* 2023 Young Professionals, and a postdoctoral researcher in the Bio-Heat and Mass Transfer Laboratory at the University of Minnesota, is the lead first-author of this breakthrough study. He describes: "This research brings the field of cryobiology a step closer to cryopreserving large human-size samples. We show that vitrification and rewarming is physically achievable in volumes as large as 3 liters, paving the way towards human organ banking becoming a reality. Even though this pioneering step is achieved nearly a century after the first vitrification of a biological system, i.e. frog sperm, but now we are equipped to stop the 'biological clock' of any large biological material such as human organs and not just sperms and embryos."

To understand the motivation of this study, one has to look at organ transplantation statistics. For example, in the United States alone, more than 100,000 people are on the transplant list according to Organ Procurement and Transplantation Network (OPTN) statistics. Yet many will never get a call, not because a match wasn't found but because the donated organ couldn't be stored long enough. Today, most organs have a shelf life measured in hours such as ~6 hours for heart. When time runs out, hope is lost. Human organ banking could change everything, turning today's transplant shortage into a future of availability on-demand. The key is cryopreservation by vitrification, cooling an organ so quickly that it turns into a glass-like state without forming damaging ice crystals. But large organs are tricky. You must cool them fast to avoid ice and uniformly to prevent cracks. Hence, vitrification has worked in small samples of tissue and more recently smaller rat organs, but it has never been shown to physically succeed with an organ as large and complex as a human organ.



The importance of this breakthrough human-scale vitrification study [Nature Communications (2025), 16, 8511] on CPAs and porcine liver highlighted by the above plot as compared to vitrification advancements in field of cryobiology over time. Credit: Lakshya Gangwar

A cryopreserved CPA sample at cryogenic temperatures (-150ºC) next to a 3D printed human sized kidney showing a successful clear and transparent glassy state. This was achieved using the cooling protocols developed by University of Minnesota Twin Cities College of Science and Engineering postdoctoral fellow Lakshya Gangwar enabling the potential for vitrification of a clinical-scale kidney. Credit: Lakshya Gangwar

For decades, the dream of storing organs has been haunted by two fatal physical pitfalls: ice formation (which damages tissues) and fracturing (caused by thermal stress when cooling and warming unevenly). While small tissues and organs (1 to 10s of mL) have been vitrified or revived, scaling up to human-organ dimensions (100s to 1000s of mL) has resisted success. Conventional rewarming as in immersion in a warm bath simply can't keep up in large volumes, edges warm too fast while centers stay cold, causing cracks or internal ice. The team's prior transformative work in rat kidneys showed life-sustaining transplant utilized "nanowarming" technology: loading magnetic iron oxide nanoparticles into a cryoprotectant solution infused through tissue vasculature, then applying a radiofrequency (RF) magnetic field to uniformly heat from within the organ.

Achieving vitrification in a whole human-size organ becomes more physically challenging than a rat organ because of not being able to cool such large thermal mass (a) fast enough to avoid spontaneous ice crystallization needed for glass formation and (b) uniform enough to avoid thermal stress-induced fractures once the glass is formed. Their breakthrough study overcame physical challenges of ice and fractures by utilizing high concentrations of cryoprotective agents (CPAs) such as M22 and carefully optimized cooling protocols using principles of thermal annealing. They show that they can cool large volumes (up to 3 liters) without ice formation or cracking and even whole organs such as porcine livers (~1 liter) showing translational success of their developed cooling protocols.

To demonstrate rewarming at human-organ scales, the team partnered with AMF Life Systems, who designed a custom 120 kW RF coil capable of delivering spatially uniform magnetic fields over a 2.5 liter sample region. Using the state-of-art RF coil, the team "nanowarmed" vitrified the CPA + nanoparticle mixtures up to 2 Liter volumes very uniformly (<5°C non-uniformity) at 100s of °C/min (effectively in <2 mins).

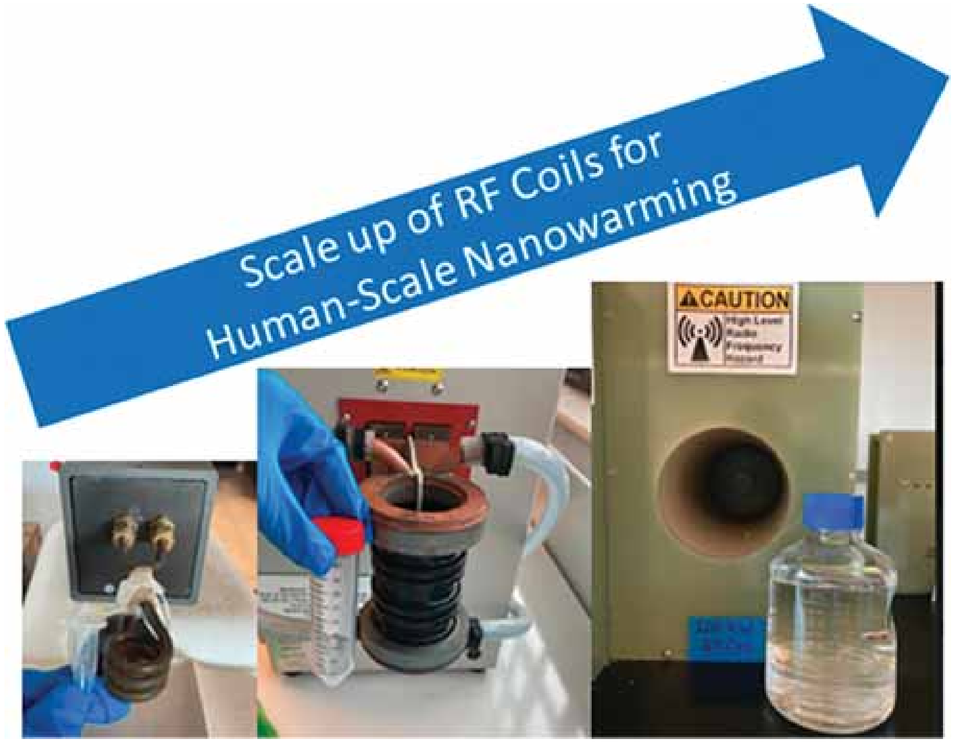
John Bischof, Ph.D., a Distinguished McKnight University Professor in the Departments of Mechanical and Biomedical Engineering and the Director of the University of Minnesota's Institute for Engineering in Medicine was one of the senior authors in this study. He stated: "careful thermal engineering allowed us to achieve vitrification up to 3 liters of CPA volume. Additionally, our results show that nanowarming is indeed scalable to the L scale which overlaps with human organ scales."

"Not only did we show vitrification in Liter scale CPA volumes but also a whole porcine liver. To our knowledge, this is the first report of a vitrified clinical-scale organ. This opens the door to storing human organs long term, a paradigm shift for transplantation," said Erik Finger, MD, Ph.D., Eunice L. Dwan Endowed Diabetes Research Chair Professor of surgery at the University of Minnesota Medical School. Dr. Finger jointly supervised this study along with John Bischof.

This research is a part of groundbreaking efforts in cryopreservation being executed at the U.S. National Science Foundation (NSF) Engineering Research Center for Advanced Technologies for the Preservation of Biological Systems (ATP-Bio). ATP-Bio center brings together 30+ leading scientists from seven institutions across the United States, all working toward transformative cryopreservation advances to a wide array of living biological systems.

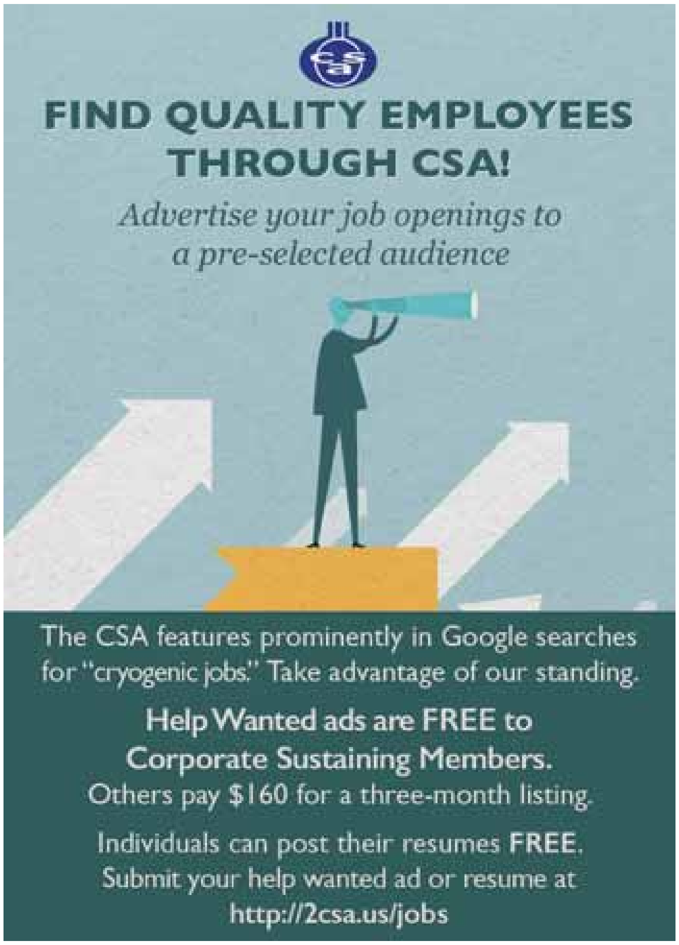
Looking forward, Dr. Gangwar concludes that the findings of this study prove that, at least on a physical level, the two core obstacles to organ cryopreservation ice and cracks can be overcome at relevant human scales. Dr. Gangwar, who was also profiled in the Young Professionals feature in *Cold Facts* (Vol 39, No 1) states that "By applying fundamental engineering principles of heat and mass transport, I want to advance the field of cryobiology and organ cryopreservation." He highlights the need for faster, uniform cooling approaches for achieving reversible vitrification of larger human organs such as hearts and lungs as crucial. As part of his postdoctoral work, he is working on next generation cooling, storage and transport devices employing a careful balance of thermal, environmental and safety properties of cryogenic refrigerants. Dr. Gangwar is driven towards securing a faculty position in mechanical engineering as he envisions applying his thermal-sciences skills and cryogenics knowledge in solving cryobiology challenges, improving biomedicine and beyond.

If successful biologically, this work could usher in the era of "**organ banking**" a world where donor organs are stored like blood in a refrigerator, ready for transplant anytime. What seems like science fiction today may become routine medicine tomorrow. This study is a landmark: the first step across a threshold long thought impassable and science fiction.



Photos of Radiofrequnecy coils at the University of Minnesota showing current scale-up from 1mL (left) and 80mL (center) to 2.5L (right). The 2.5L capacity RF coil developed by AMF Life Systems was used in the breakthrough study to nanowarm vitrified physical volumes up to 2L. Credit: Lakshya Gangwar and AMF Life Systems

Dr. Lakshya Gangwar is advancing cryopreservation at the human-organ scales using vitrification and nanowarming technologies demonstrating success in physical volumes and porcine livers. Credit: Lakshya Gangwar and Bat-Erdene Namsrai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Researchers Develop Breakthrough Tool to Enhance Precision in Cold-Temperature Cancer Surgery

by External Relations and Communications Staff, NYUAD, and Benyattou et al., 2025.[1]

Farah Benyettou, Ph.D., a research scientist in the Trabolsi Research Group at NYU Abu Dhabi. Credit: NYUAD

Researchers at NYU Abu Dhabi (NYUAD) have developed an innovative tool that enhances surgeons' ability to detect and remove cancer cells during cryosurgery, a procedure that uses extreme cold to destroy tumors. This breakthrough technology introduces a nanoscale material that illuminates cancer cells under freezing conditions, making them easier to distinguish from healthy tissue and improving surgical precision.

The research, detailed in Freezing-Activated Covalent Organic Frameworks for Precise Fluorescence Cryo-Imaging of Cancer Tissue in the Journal of the American Chemical Society, represents a significant advance in combining imaging and therapy into a single, integrated approach. The Trabolsi Research Group at NYUAD engineered a unique nanoscale Covalent Organic Framework (COF), called nTG-DFP-COF, designed to respond to extreme cold by increasing its fluorescence.

Addressing a Major Challenge in Cryosurgery

Cryosurgery has long been valued as a minimally invasive method for removing tumors, offering reduced pain, less bleeding and faster recovery compared to traditional surgical procedures. It is especially useful for patients with cancers that are resistant to other treatments. However, its effectiveness has been limited by a key challenge: under freezing conditions, it has been difficult for surgeons to accurately distinguish between malignant and healthy tissue.

Traditional fluorescence imaging—where tumors are highlighted using light-sensitive dyes—has provided valuable real-time guidance in other types of surgeries. Yet, until now, the approach had not been adapted successfully to cryogenic conditions, where extreme cold and ice crystal formation inside cells can interfere with imaging clarity.

The newly developed nTG-DFP-COF material overcomes this barrier. When exposed to freezing temperatures, it exhibits temperature-dependent luminescence, meaning its fluorescence becomes significantly brighter. This heightened contrast allows surgeons to clearly visualize tumor boundaries during the procedure, improving both the safety and accuracy of cancer removal.

How the Material Works

Developed by Gobinda Das, Ph.D., a researcher in the Trabolsi Research Group, the nTG-DFP-COF material was carefully designed for biocompatibility and low toxicity, ensuring safe interaction within the body. Its nanoscale structure makes it highly dispersible in water, enabling uniform distribution throughout tissue.

Crucially, the material's fluorescence remains stable even in the presence of ice crystals that form inside cells during freezing. This stability allows continuous, real-time imaging throughout the entire surgical process. The result is a powerful tool that merges diagnosis and treatment in a single procedure, giving surgeons an immediate and precise view of cancerous regions.

Testing of the material has demonstrated its structural stability and effectiveness across three different settings:

- In vitro, in controlled laboratory environments
- In vivo, in living organisms
- Ex vivo, in freshly harvested tissue samples

These tests confirmed both the material's targeting specificity for cancer cells and its ability to maintain performance under cryogenic conditions.

A Leap Forward for Precision Medicine

"This breakthrough bridges the gap between imaging and therapy, providing surgeons with a real-time tool to visualize and remove cancer with unprecedented precision," said Ali Trabolsi, professor of chemistry and principal investigator of the Trabolsi Research Group at NYUAD. "By integrating fluorescence imaging with cryosurgery, we are pushing the boundaries of

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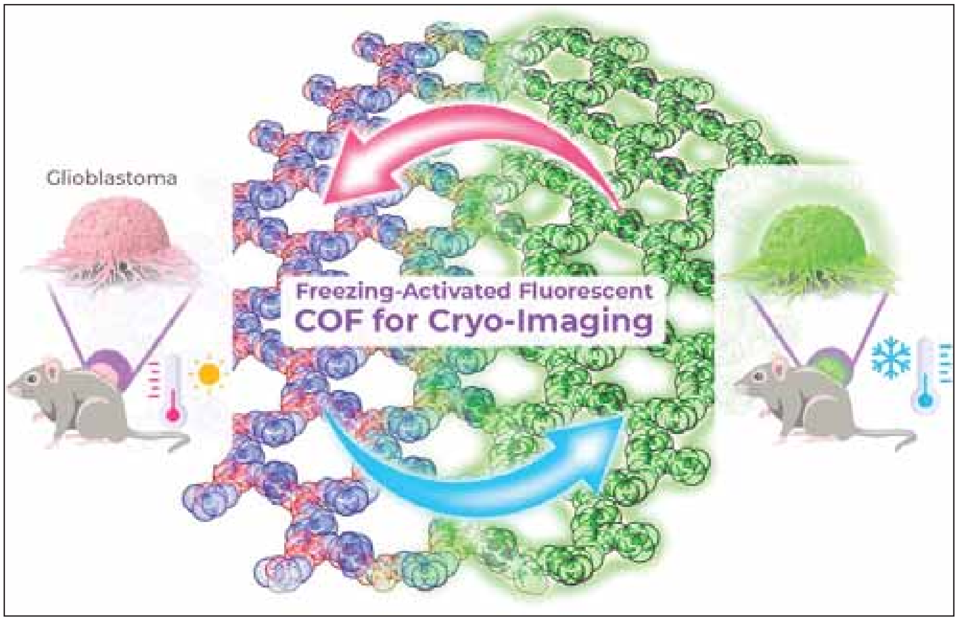
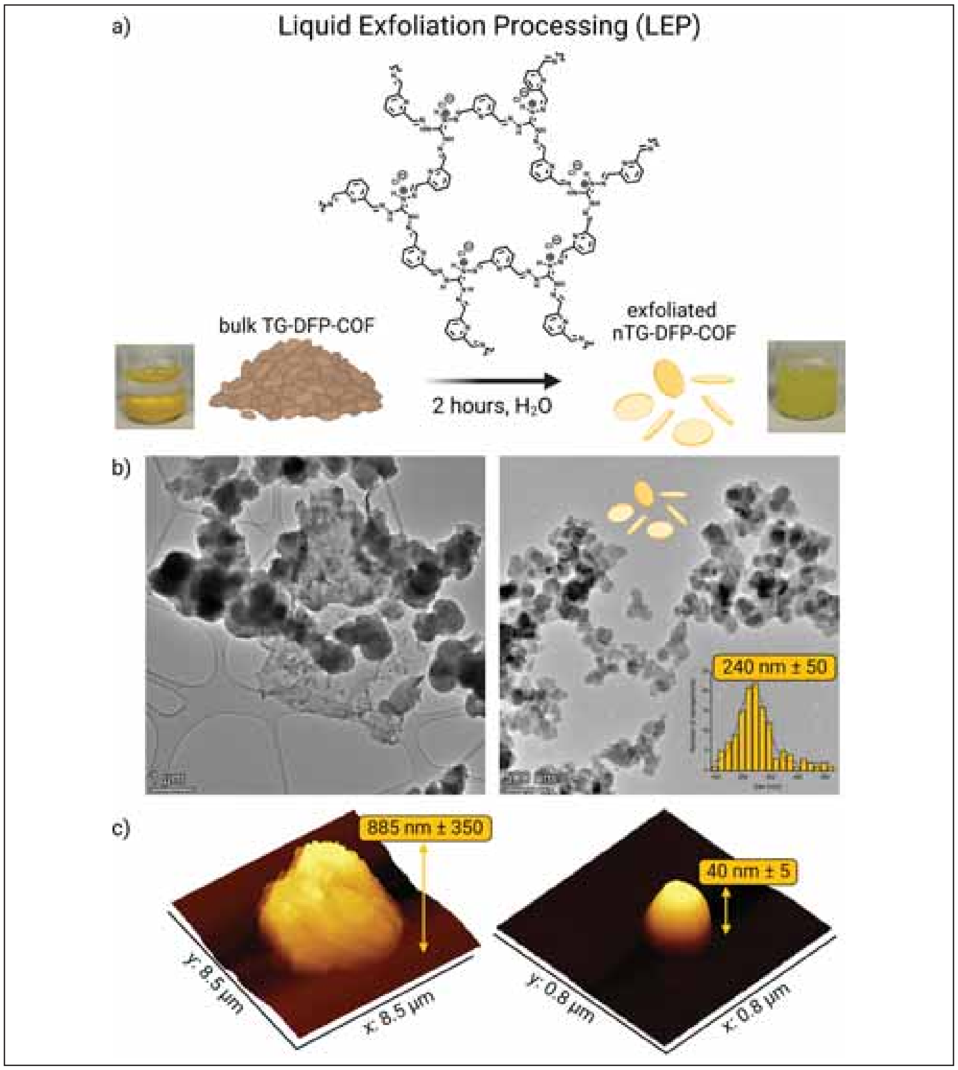


Researchers developed a biocompatible nanoscale framework that glows more brightly in extreme cold, enabling precise cancer tissue identification and improving the accuracy of cryosurgery. Credit: NYUAD



Structure and characterization of nTG-DFP-COF. (a) Liquid exfoliation transforms bulk COF into nanosheets. (b) TEM images show morphology and uniform size of the nanosheets. (c) AFM images reveal reduced height and smoother surface, confirming the material's nanoscale structure optimized for fluorescence-guided cryosurgery. Credit: NYUAD cancer treatment and offering new hope for patients with difficult-to-treat tumors."

The dual function of the material—combining therapeutic action with diagnostic imaging—has the potential to reduce the need for repeat surgeries. In traditional tumor removal, there is always a risk that small portions of cancerous tissue are left behind, requiring additional operations. By helping surgeons see exactly where the tumor ends and healthy tissue begins, this technology minimizes that risk and preserves more healthy tissue.

Farah Benyattou, Ph.D., a research scientist in the Trabolsi group and co-author of the study, emphasized the patient-centered impact of the innovation.

"We believe this is a transformative tool that could revolutionize cancer surgery," Benyattou said. "By making tumor removal more precise, this technology has the potential to reduce additional surgeries and accelerate patient recovery. It's a major step forward in treating aggressive, hard-to-target cancers."

Broader Implications and Future Directions

Beyond its immediate application in cryosurgery, the principles behind nTG-DFP-COF may influence a wide range of medical procedures. Fluorescence-guided surgery is an area of rapid growth, but until now, extreme cold environments posed a major obstacle. This discovery opens doors to new strategies for precision medicine, where therapies are tailored to individual patients' conditions with greater accuracy.

Potential future applications include:

- Expanding cryosurgical treatments to previously inoperable tumors, especially those near critical structures where precision is paramount
- Developing next-generation diagnostic tools for use in imaging and pathology labs
- Creating integrated therapeutic systems that can simultaneously detect, target and destroy cancer cells with minimal side effects

As research progresses, further clinical studies will focus on refining the material and adapting it for human trials. The ultimate goal is to create a platform technology that can be widely used across oncology centers worldwide.

This work highlights the value of cross-disciplinary innovation at NYU Abu Dhabi, combining chemistry, nanotechnology and medical science to address one of the most pressing challenges in cancer care. By enhancing precision and safety in tumor removal, the team's breakthrough could transform how surgeons approach cold-temperature cancer treatments—and bring new hope to patients facing aggressive disease.

References

[1] Benyattou, F.; Das, G.; Trabolsi, A. Freezing-Activated Covalent Organic Frameworks for Precise Fluorescence Cryo-Imaging of Cancer Tissue. J. Am. Chem. Soc. 2025, 147, DOI: 10.1021/jacs.4c13848.

Note: All figures and content discussed in this article, including Figure 1a–c illustrating the structure and characterization of nTG-DFP-COF, are reproduced or adapted from Benyattou et al., 2025.

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

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Designs and manufactures cryogenic loading arms engineered for the safe and efficient transfer of cryogenic liquids, as well as cryogenic-rated swivels and couplings designed to withstand extreme low temperature service and safety and handling accessories.

Vico Products

A manufacturer of high-performance cold-headed fasteners, Vico Products specializes in brake system fasteners, ride control solutions and assembled products. Industries served include automotive, heavy truck, military, agricultural and construction.

*CRANE Cryogenics

CRANE provides high-caliber equipment to meet and exceed industry standards, including ISO, ASME and Canadian registrations. The product line includes vacuum-jacketed piping, valves, phase separators and monitoring for various cryogenic applications.

Ravi Products

Ravi Products manufactures and exports precision brass-turned components and threaded inserts, with a product portfolio that includes heat ultrasonic, molded-in, press-in, self-tapping, expansion, aluminum, and customized brass inserts.

Cryo Diffusion

Cryo Diffusion designs cryogenic equipment with high performance super vacuum insulation. The company offers a full range of after-sales cryogenic services, including turnkey projects, installations, commissioning, on-site calibrations and repairs.

Safe Gas Systems

Assists companies in utilizing gas and cryogenics optimally, minimizing both risk and expenditure and ensuring both functionality and safety. From conventional setups to innovative bespoke designs, Safe Gas will assist you in achieving your objectives.

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Magnetic Cooling Powers Europe's First Efficient Hydrogen Liquefaction Pilot Plant

by HZDR Communications

The EU-funded HyLICAL project has reached a major milestone with the launch of Europe's first magnetocaloric pilot plant for hydrogen liquefaction. Developed within HyLICAL by the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and start-up MAGNOTHERM, the demonstrator represents a breakthrough in sustainable, energy-efficient magnetic cooling and sets the stage for large-scale industrial application.

Dr. Tino Gottschall (left) and Norman Schubert (center) with Thomas Platte (right) in front of the HyLICAL demonstrator. Credit: HZDR / M. Förster

Dr. Tino Gottschall, scientist at HZDR's High Magnetic Field Laboratory (HLD), has long envisioned a plant capable of producing 5,000 kilograms of liquid hydrogen per day – significantly more efficient and affordable than today's liquefaction methods. Together with MAGNOTHERM and other HyLICAL partners, his team is now working to prove that hydrogen liquefaction based on the magnetocaloric effect can be scaled for industrial deployment.

Since 2023, HyLICAL partners HZDR and MAGNOTHERM have worked in close collaboration, combining academic expertise and entrepreneurial innovation to advance magnetocaloric cooling technologies. "Our magnetic cooling technology represents a new type of climate-friendly and energy-efficient alternative, without compressors and environmentally harmful refrigerant gases. This will enable us to significantly accelerate the necessary climate tech transformation within the refrigeration industry," says Timur Sirman, co-managing director of MAGNOTHERM, explaining the motivation behind the collaboration.

MAGNOTHERM opened a second facility on the Rossendorf campus in 2024 and established a joint laboratory the same year, where HZDR scientist Dr. Tino Gottschall and MAGNOTHERM engineer Thomas Platte built a pilot plant for hydrogen liquefaction. At its heart is a 19-tesla superconducting magnet embedded in the floor of the HLD. By comparison, modern MRI machines in medicine use magnets with a strength of 1.5 to 3 tesla. "We can now use this plant to prove the principle and how it works," says Gottschall. The next target is to increase efficiency to produce 100 kilograms of liquid hydrogen per day to demonstrate the scalability of this technology for industrial deployment.

Europe's first demonstrator of a magnetically cooled hydrogen liquefaction plant is based on the magnetocaloric effect. This effect occurs when materials with certain properties—one example is the lanthanum-iron-silicon alloy (LaFeSi)—are placed in a magnetic field. Depending on the orientation of the magnetic moments, the metallic materials can cause a sudden drop or rise in temperature. Using this principle, it is possible to cool hydrogen to -253 degrees Celsius after pre-cooling with liquid nitrogen. Once this low temperature is reached, the gas begins to liquefy. "Our method offers significant advantages for hydrogen liquefaction," notes Gottschall. "With the MAGNOTHERM joint lab at HZDR, we aim to reduce liquefaction costs to below €1.50 per kilogram of hydrogen, compared to conventional plants."

The launch of the pilot plant is a key step in HyLICAL's mission to advance energy-efficient, compact hydrogen liquefaction technologies based on magnetocaloric cooling. By validating this approach at pilot scale, the project supports Europe's ambition to produce green hydrogen more

The HyLICAL magnetocaloric demonstrator for hydrogen liquefaction, developed by HZDR and MAGNOTHERM. Credit: HZDR / T. Gottschall

cost-effectively, reduce transport costs and accelerate the transition to a climate-neutral energy system.

Reference

Helmholtz-Zentrum Dresden-Rossendorf (HZDR). "Magnetic Cooling for Efficient Hydrogen Liquefaction: HyLICAL Partners MAGNOTHERM and HZDR Launch Pilot Plant." HZDR News, https://www.hzdr.de/db/Cms?pOid=75544&pNid=99. Accessed September 7, 2025.

Access Control for Cryogenic Freezers Is Key Factor in Safety and Quality

by Daniela Depke, Cryotherm GmbH & Co. KG

Cryogenic freezers are becoming increasingly essential in fields such as research, medicine and industry. Liquid nitrogen, for example, is widely used for long-term storage of biological and medical samples, making it indispensable in many sectors. Storing samples at cryogenic and extremely low temperatures ensures the safety of biological specimens, their derivatives, genomic material and active pharmaceutical ingredients.

However, ensuring safe storage goes beyond the cryogenic environment itself. Equally important is controlling who has access to these freezers and the samples stored in them. Unauthorized access can create significant risks. Improper handling of liquid nitrogen may cause severe cold burns or the release of large volumes of gas, posing asphyxiation hazards. The quality of sensitive materials also depends on ensuring that only trained and authorized personnel have access to the samples. Controlled access helps minimize errors in storage and sample retrieval.

In addition to protecting people and materials, operators are required to comply with regulatory standards and internal quality guidelines. Access control plays a central role in meeting these requirements, ensuring safety, accountability and traceability.

A well-designed access control system provides several advantages:

- Enhanced safety: Prevents unauthorized access, reducing risks of both people and the environment
- Quality assurance: Safeguards sensitive samples and materials against tampering and mishandling.
- Documentation and compliance: Each access event can be assigned to a specific user and tracked if needed. In research and clinical settings, documentation of the sample chain of custody is particularly critical.
- Flexibility: Access rights can be adapted quickly to changing requirements, for example in open-access storage areas.

The MD Smart ensures precise monitoring and reliable control for secure cryogenic storage. Credit: Cryotherm

Thus, access control extends beyond pure security functions, becoming an instrument for efficient and compliant operations.

The smart BIOSAFE System by Cryotherm

With this in mind, Cryotherm has developed a system that regulates access to cryogenic freezers, particularly its own BIOSAFE freezers – using RFID technology. The BIOSAFE smart control system not only monitors the freezers, for example by recording the liquid nitrogen levels and temperatures but also logs all access events. Each user is assigned a personal RFID chip that grants them access. Access rights can be individually configured, modified, or revoked at any time.

This means the freezer is secured not only by a physical lock but also by access restrictions to its control functions.

Advantages of the BIOSAFE Smart Control

- High protection against manipulation: Opening the freezer without an authorized RFID chip is impossible due to twofold access control via RFID transponder and PIN code
- Individual permissions: Specific actions, such as opening the lid or refilling liquid nitrogen, can be restricted to selected users.
- Automatic logging: Every lid opening, refilling, or other relevant action is tracked, according to GMP FDA CRF 21

part 11 and made transparent via the BIOSAFE View Info software. This enables full traceability of who accessed the freezer and when.

• Increased reliability in shared environments: In large biobanks, laboratories and research facilities, different samples can be stored in the same place without the risk of unauthorized access or sample mix-ups.

• User-friendly operation: Designed to simplify daily workflows.

Added Value for Users

While the technical features of BIOSAFE smart provide strong safety and compliance benefits, the system also delivers tangible value to everyday users. For laboratory staff, biobank managers and research teams, access control is not just a regulatory requirement but a tool that improves organization, efficiency and trust in the integrity of their work. With streamlined workflows, specific roles and permissions can be assigned, ensuring that only qualified staff handle refilling or sample retrieval. This clarity reduces errors, miscommunication and wasted time.

Equally important is transparency and accountability. Automated logging records every action, showing when and by whom a freezer was accessed. This provides reassurance to partners, funders and auditors while protecting staff with objective, traceable records.

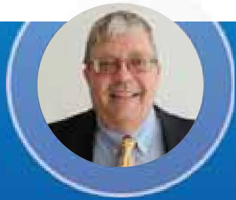
Access control also enables risk reduction and cost savings. Unauthorized handling or mishandling of cryogenic freezers can cause severe safety incident, material losses and reputational harm. BIOSAFE smart minimizes these risks, helping institutions avoid costly setbacks and maintain long-term operational stability.

From a regulatory perspective, BIOSAFE smart makes compliance simple. Chain of custody and audit requirements are documented automatically, reducing administrative burden and ensuring seamless traceability.

The system is also a future-proof infrastructure. RFID-based controls allow institutions to adapt quickly as teams expand, workflows change, or facilities scale up. This flexibility supports sustainable growth while maintaining security.

Finally, access control enhances collaboration and trust. In multidisciplinary and international projects, it ensures that sensitive samples are only accessed by authorized users, protecting investments and reinforcing confidence among partners.

By combining safety, efficiency and accountability, BIOSAFE smart goes beyond protection, delivering a secure, reliable and forward-looking foundation for working with cryogenically stored samples. **www.cryotherm.de**



Cryo Bios

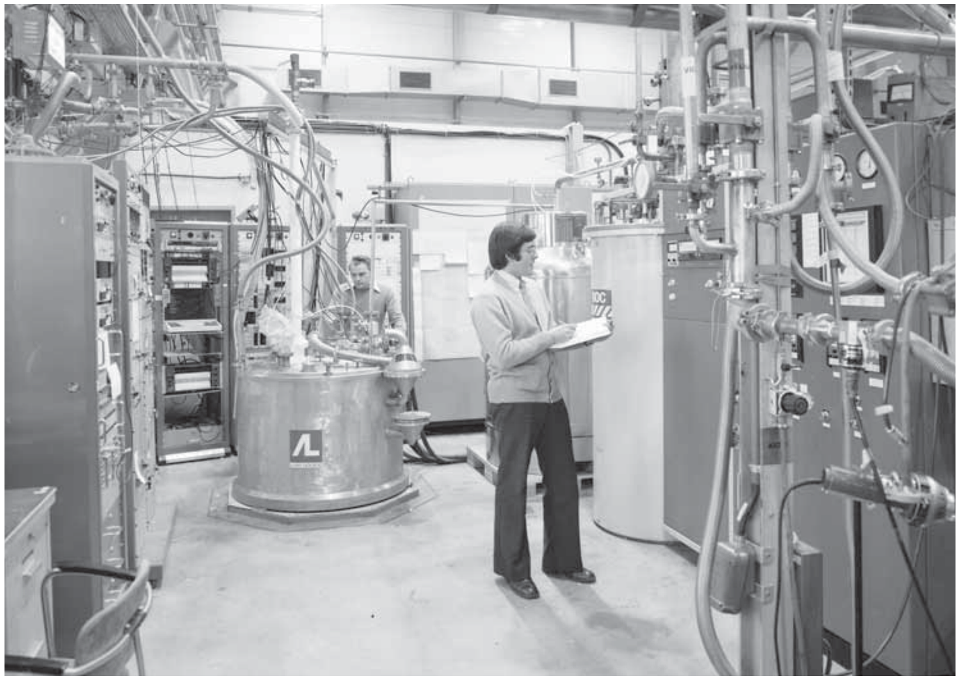
by Dr. John Weisend II, European Spallation Source ERIC, CSA Chairman, john.weisend@ess.eu, and
Anne DiPaola, *Cold Facts* Editor

Philippe Lebrun

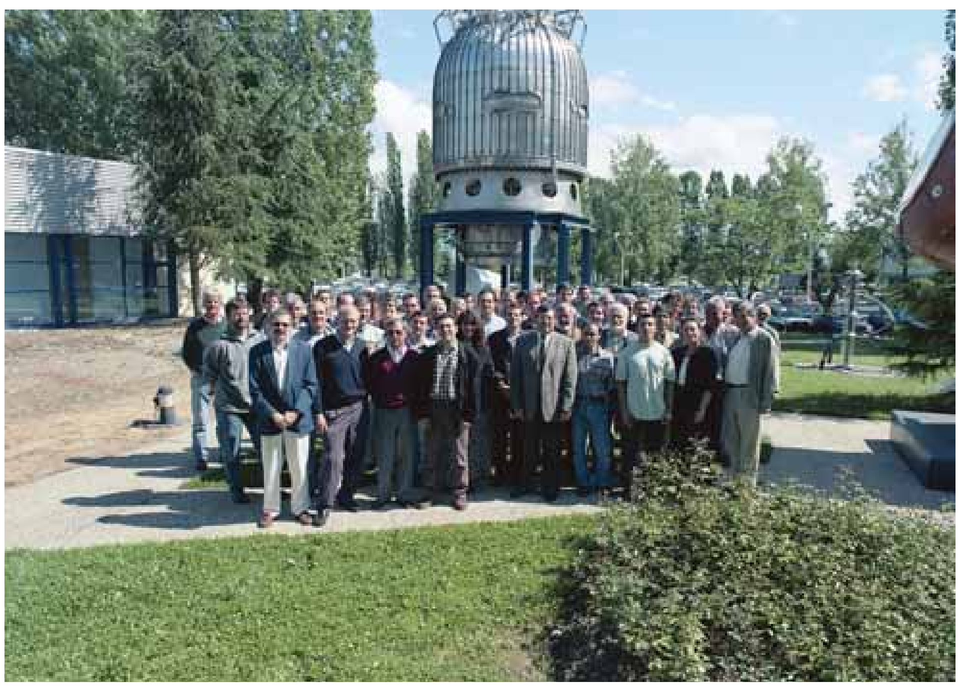
When Philippe Lebrun first encountered the word cryogenics during a graduate course at Caltech taught by Professor Jim Mercereau he could not have known how central cold would become to his life's work. At that time *cryogenics* meant low temperature physics paired with laboratory work that included measuring material properties at low temperature and experimenting with superconducting magnets. That early exposure captured his imagination and set him on a path toward building the infrastructure behind some of the most ambitious scientific machines ever conceived.

Lebrun's path soon carried him to CERN where he joined a small ambitious team tasked with developing the first superconducting magnets for the ISR proton collider. The group of young physicists and engineers faced daunting challenges as they sought to integrate the demands of accelerator physics with the potential of cryogenics. In those early years cryogenics at CERN was limited to small insertions within otherwise classical accelerator systems. That changed with the Large Electron Positron Collider which required superconducting radio frequency cavities cooled by liquid helium and later with the Large Hadron Collider which demanded thousands of superconducting magnets cooled in pressurized superfluid helium.

At CERN Lebrun worked across every aspect of cryogenics. His responsibilities included refrigeration cycles, heat transfer, fluid distribution, cryostat design, instrumentation, control systems and large scale operation. One of his most consequential contributions came in the conceptual phase of the LHC. The initial plan called for Nb_3Sn magnets cooled in normal liquid helium.



Testing superconducting magnets in the lab in 1976. Credit: CERN



The CERN Accelerator Cryogenics group in 1997. Credit: CERN

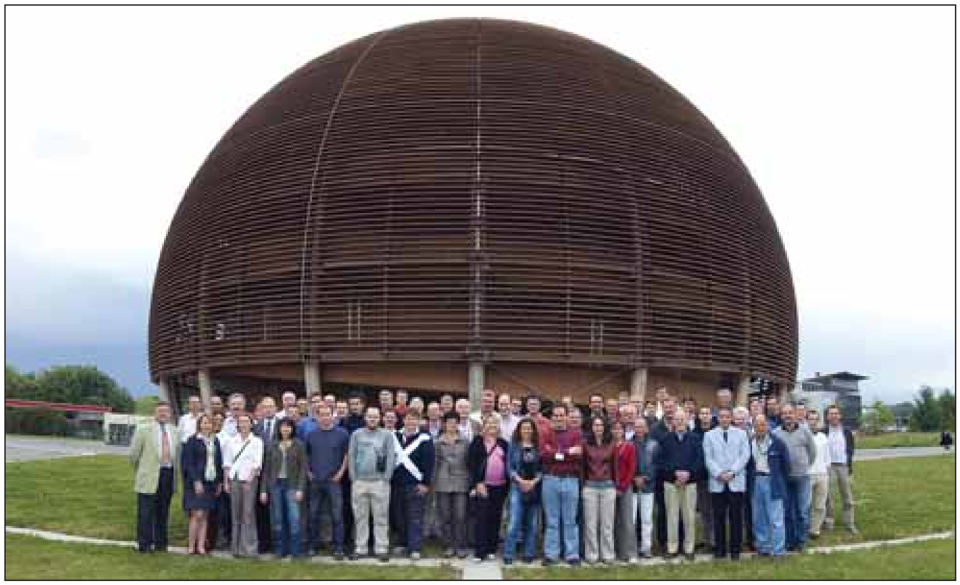
Lebrun recognized the risks of this approach and proposed a bold alternative, using Nb Ti magnets operated in pressurized superfluid helium. He and his colleagues validated the principle on prototypes and once the results were clear he persuaded CERN's management to adopt the change. He then led the structured development program that followed. The decision reshaped the project and provided the cryogenic backbone that allowed the LHC to become one of the greatest scientific instruments of our time.

Although much of Lebrun's career has been devoted to particle physics, his work has had broad impact outside the laboratory. In the 1970s he co-developed long flexible cryogenic transfer lines made from nested corrugated pipes in collaboration with Kabelmetal, now Nexans. The technology remains essential in applications such as high temperature superconducting power cables. He also played a leading role in establishing pressurized superfluid helium cooling as the standard for high field magnets, now widely used in condensed matter research and in NMR systems. These contributions show how developments in particle physics laboratories often ripple outward into industry, energy and medicine.

Over the course of his career Lebrun has witnessed dramatic changes in cryogenics. Compressors have evolved from dry piston machines to oil flooded screw systems. Expanders once simple are now supported by gas or magnetic bearings. Control systems have moved from basic PID loops to adaptive and nonlinear methods. Refrigerators that once delivered hundreds of watts now provide tens of kilowatts with far better thermodynamic efficiency and reliability. For Lebrun this arc of progress is not only about engineering but also about enabling science to push its boundaries faster and more reliably.

Looking ahead, he anticipates further improvements in both unit capacity and efficiency. These advances may draw on techniques already proven in process industries such as fluid mixtures and hydrodynamic compressors. He also sees a future in intelligent control where artificial intelligence optimizes cryogenic systems in real time to achieve new levels of performance.

Lebrun often stresses that cryogenics is not an academic discipline on its own but the application of many scientific and technical fields to low temperatures. Engineers and technicians usually enter the field from diverse educational backgrounds and must then be trained in the specifics of cryogenic work. Throughout his career Lebrun has been deeply involved in this process, lecturing in graduate courses, publishing widely, mentoring new generations and ensuring that knowledge is passed on.



The CERN Cryogenics group in 2007. Credit: CERN

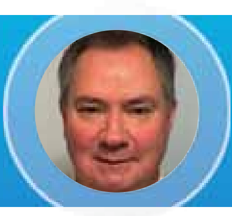
His commitment to education is matched by his service to professional societies. He has served as vice president of the International Cryogenic Engineering Committee and as president of the Cryogenics and Liquefied Gases Section of the International Institute of Refrigeration. He also chaired the IIR General Conference. He has been advisory editor for the journal *Cryogenics* and a regular participant in ICEC and CEC conferences for more than forty years. Through these roles he has strengthened the collaboration that sustains the international cryogenic community.

Collaboration across borders has been a hallmark of Lebrun's career. At CERN he coordinated bilateral and multilateral projects with partners including India's research institutions and France's CEA and CNRS. He has continued to advise large scientific projects worldwide, reinforcing the idea that cryogenics is by nature global.

His contributions have been recognized with major honors. In 2015 he received the Samuel C. Collins Award at the Cryogenic Engineering Conference and International Cryogenic Materials Conference. The award honors individuals who combine technical achievement with unselfish leadership and service to the cryogenic community. In 2016 he was presented with the Mendelssohn Award by the International Cryogenic Engineering Committee in Delhi in recognition of his lifelong impact on cryogenics and superconductivity in accelerators.

Lebrum, at right, receiving the Collins Award in 2015. Credit: Laurent Tavian

From his first experiments at Caltech to his defining role in shaping the LHC Philippe Lebrun has helped transform cryogenics from a narrow specialty into a cornerstone of modern science and technology. His legacy is written not only in the superconducting magnets and refrigeration systems that power the largest accelerators but also in the many applications that touch industries and lives well beyond physics. For a field built on the coldest of temperatures his career has been nothing short of a blazing achievement.



Space Cryogenics

by Jonathan R. Stephens, NASA Marshall Space Flight Center

A NASA Team Demonstrates the "Zero Boiloff" Storage of Liquid Hydrogen using Active Cooling and a Two-Stage Cooling Approach

To enable the long duration storage of liquid hydrogen in-space, a NASA team has demonstrated a novel approach to achieve "zero boiloff" storage using active cooling (cryocoolers) and a two-stage cooling approach. State-of-the-art liquid hydrogen storage in space currently lasts only hours, whereas NASA's upcoming long-duration missions may demand storage for months or even years. Applications requiring such extended storage must incorporate 'near-zero' leakage components (valves, pumps, flowmeters), employ an optimized set of passive cryogenic fluid management technologies to reduce environmental heat loads, and use active cooling with cryocoolers to intercept and reject heat from the propellant tanks and surrounding structure.

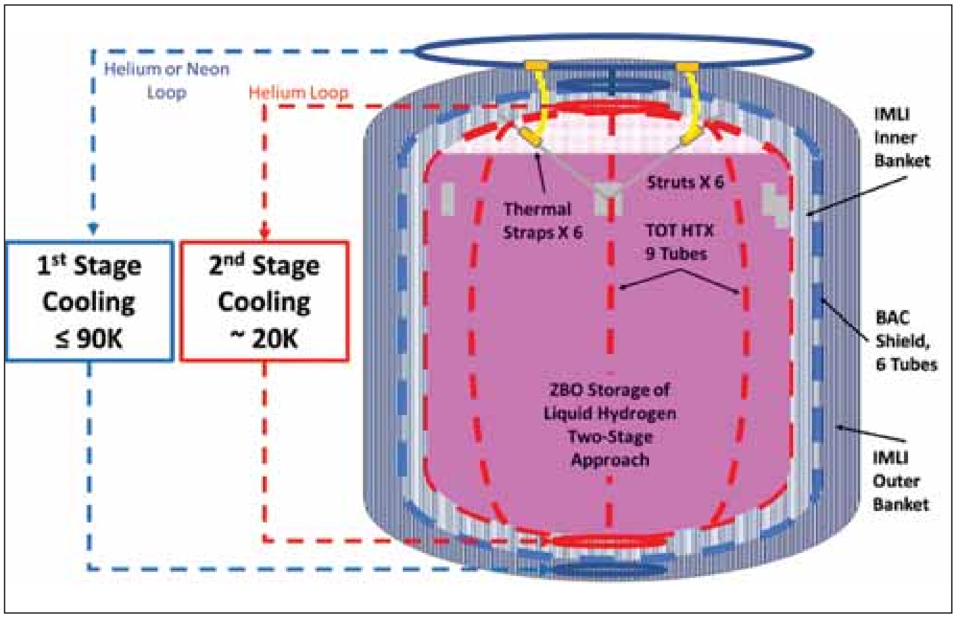


Figure 1 Two-stage cooling test article. Credit: Jonathan R. Stephens

Of course, with any cryogenic vehicle and mission, a mass and power trade should be conducted to determine if it is indeed feasible to carry the additional dry mass associated with active cooling, or if one could simply carry additional propellants to accommodate propellant loss which is typically not an option for long duration missions.

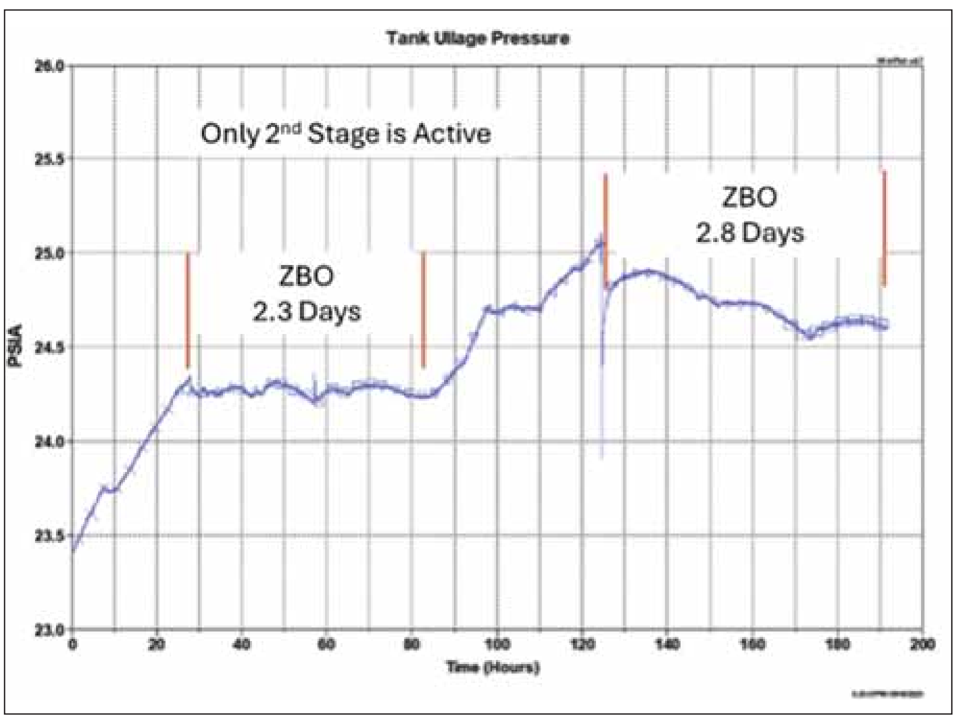


Figure 2 Zero boiloff of liquid hydrogen with single-stage active cooling. Credit: Jonathan R. Stephens

Since cryocoolers are a significant source of dry mass and require electrical power, it is essential to minimize the heat load the cryocooler is required to remove by including an optimal suite of passive cryogenic fluid management technologies. Less refrigeration requirements lead to fewer or smaller cryocoolers, hence mass and power savings. Cryocoolers operating at 20 Kelvin are required for "zero boiloff" storage of liquid hydrogen as they operate close to the hydrogen saturation temperature while their 90 Kelvin class counterparts are used for soft cryogens such as liquid oxygen, liquid methane, or liquid natural gas. With active cooling and minimal environmental heat loads, "zero boiloff" conditions for liquid hydrogen storage can be achieved with 20-Kelvin units alone, however they have a significantly larger specific mass (kg/W) and specific power (W/W) relative to their 90-Kelvin counterparts, meaning larger mass and greater electrical power required per watt of refrigeration.

The objective of the two-stage cooling approach is to decrease active cooling mass and power when "zero boiloff" storage is required. Since the specific mass and specific power associated with the 20-Kelvin cryocoolers are high relative to 90-Kelvin cryocoolers, the objective is to intercept and reject as much heat as possible with a 90-Kelvin cryocooler, then use a 20-Kelvin unit for tank heat removal and pressure control. Previous efforts ([1], [2], and [3]) have shown via analysis and testing, that this two-stage approach trades well against a single-stage approach in terms of mass and power savings.

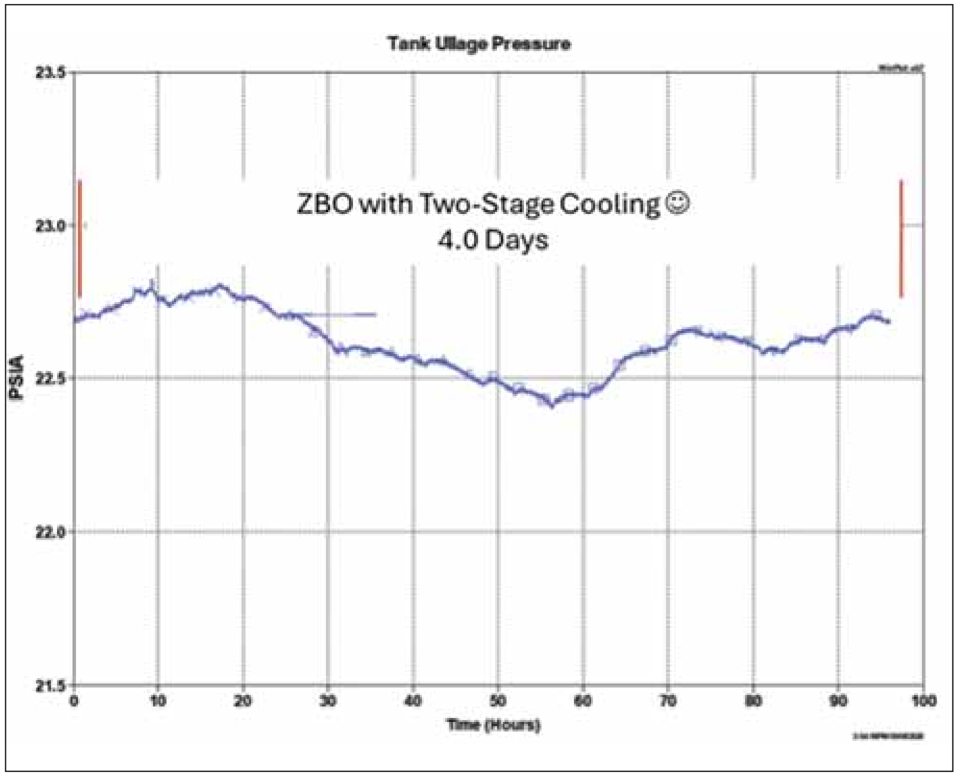


Figure 3 Zero boiloff of liquid hydrogen with two-stage active cooling. Credit: Jonathan R. Stephens

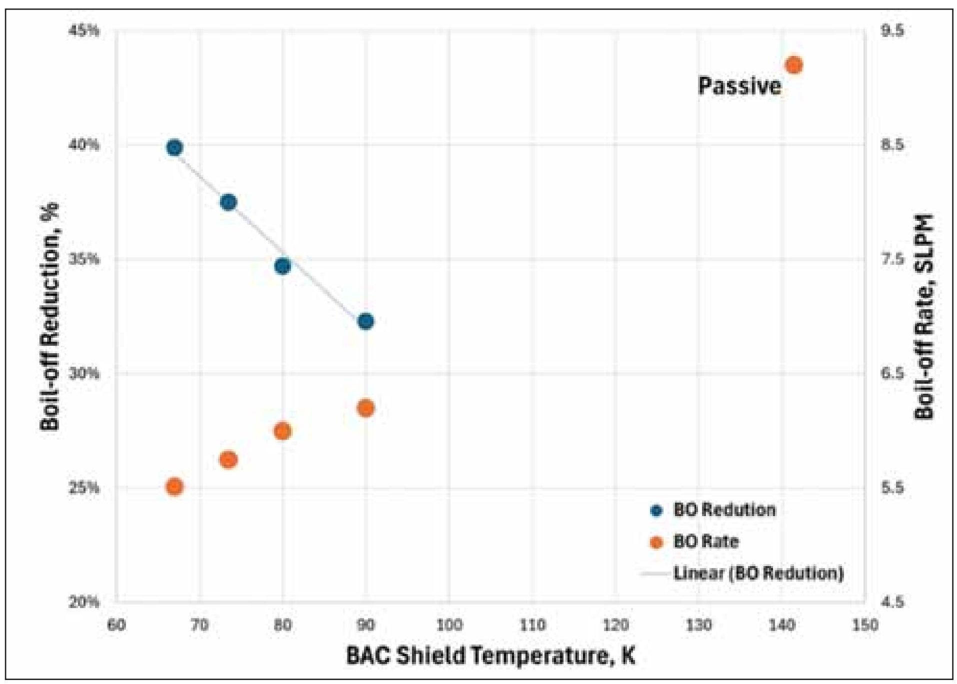


Figure 4 Zero Boiloff of Liquid Hydrogen with Two Stage Active Cooling. Credit: Jonathan R. Stephens

Test Article

Leveraging technologies and lessons learned from NASA's Cryogenic Propellant Storage and Transfer program, the test article (Fig. 1) has a fully integrated suite of required technologies which includes a propellant tank equipped with a tube-on-tank heat exchanger, a load bearing multilayer insulation inner blanket, a thin foil tube-on-shield broad area cooling heat exchanger located within the insulation and thermally strapped to the support struts and an outer multilayer insulation blanket. The thin foil tube-on-shield broad area cooling heat exchanger is connected to the first stage cooling loop of an industrial cryocooler and operates at temperatures between 67 Kelvin and 90 Kelvin, while the second stage loop is connected to the tube-on-tank heat exchanger and operates at approximately 21-22 Kelvin. The two stages are controlled independently so the test article can operate in passive mode (both stages inactive), "reduced boiloff" mode (only the first stage active), "zero boiloff" mode (only the second stage active), or "zero boiloff" with two-stage cooling mode (both stages active).

Testing and Results

In passive mode, the total heat load of the test article was measured via boiloff testing with liquid nitrogen at an environmental temperature of 292 Kelvin and with liquid hydrogen at an environmental temperature of 220 Kelvin. Heat loads were measured to be 5.8 Watts and 16.5 Watts for liquid hydrogen and liquid nitrogen, respectively. Then two "zero boiloff" demonstrations were conducted with the second stage active (see Figure 2). First, the tank pressure was maintained at an average of 24.3 PSIA for 2.3 days. During the second demonstration, the tank pressure was maintained at an average of 24.67 PSIA for 2.8 days. It was determined from the boiloff testing that an average of 5.8 Watts

▶ *continues on page 24*

 Continued from page 23

needed to be removed by the second stage to achieve "zero boiloff" conditions.

The next objective was to demonstrate the "zero boiloff" storage using the two-stage cooling approach. With both stages active and the first stage operating at 67 Kelvin, "zero boiloff" storage was demonstrated for approximately 4 days (see Figure 3).

No hydrogen was lost from the propellant tank during any of these "zero boiloff" demonstrations, however some pressure oscillations were noted. These oscillations were a direct result of some minor oscillations in the active cooling performance during the demonstration and not considered to be an issue.

To quantify the tank heat load reduction rates and electrical power savings due to heat interception by the first stage, the second stage was deactivated and a series of four "reduced boiloff" tests were conducted (see Figure 4). With the first stage operating at 67 kelvin, 73 Kelvin, 80 Kelvin and 90 Kelvin, the boiloff rates were measured and the heat load to the tank was calculated. At the lower first stage temperatures, the boiloff rates were reduced indicating a lower second stage lift was needed to achieve "zero boiloff" storage. As the first stage temperature was increased, the boiloff rates increased as did the total calculated electrical power required to achieve "zero boiloff" due to the additional cooling needed by the second stage (see Figure 5).

BAC Setpoint Temperature	2nd Stage Load	Heat Load Reduction	Electrical Power Reduction
K	W	%	%
N/A	5.76	0.0	0
90	3.9	32.3	19.4
80	3.76	34.7	21.8
73.5	3.6	37.5	23.3
66.9	3.46	39.9	25.6

*Preliminary Results (TBR)

Figure 5 Preliminary results from the "reduced boiloff" demonstrations. Credit: Jonathan R. Stephens

Summary

It should be noted that at the time this article was written, the results reported should be treated as preliminary as there is still analysis of the test results pending. However, the preliminary results look promising. Using the two-stage cooling approach with this test article in the environments tested the heat load to the second stage was reduced between 32.3% to 39.9% leading to electrical power reductions between 19.4% and 25.6%. Analysis and documentation of the test results are in-work and expected to be completed in Fiscal Year 2026. The next phase of testing will use the two "flight-like" engineering model reverse turbo-Brayton cycle cryocoolers developed for NASA in-place of industrial cryocoolers. Stay tuned!!!

Acknowledgement

The author would like to acknowledge the Two-Stage Cooling Activity Team which without their hard work this effort would not be possible: Travis Belcher, Mark Black, Ebony Bland, Harold Burtts, Hannah Cherry, Chase Crimi, John Furby, Ryan Grotenrath, Brian Hamill, Mitchell Jackson, Sarah Nguyen, Kevin Pedersen, Isabella Rieco, James Smith, Scott Tashakkor, Juan Valenzuela, Jeff Welch, David Wilkie, Robert Witbrodt and all of the East Test Area personnel at Marshall Space Flight Center, I offer a sincere thank you. I would also like to thank NASA's Technology Demonstration Mission Program and the Cryogenic Fluid Management Portfolio Project office for funding and managing the activity.

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Zero Resistance Zone

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

Thermal Shields and Anchors Part 1: Shields

The thermal management of cryogenic systems frequently uses thermal shields and thermal anchors as components to minimize the refrigeration requirements. To maintain components at cryogenic temperatures, there must be made a low loss connection to the source of the cold. The source of cooling can be a refrigerator or cryocooler, or from a supply of a cryogenic fluid such as helium, hydrogen, or nitrogen. Thermal anchoring is a feature of a design which makes a thermal connection with minimal temperature difference, i.e. a low thermal resistance, between the cold heat sink and the component being kept cold, such as a thermal shield.

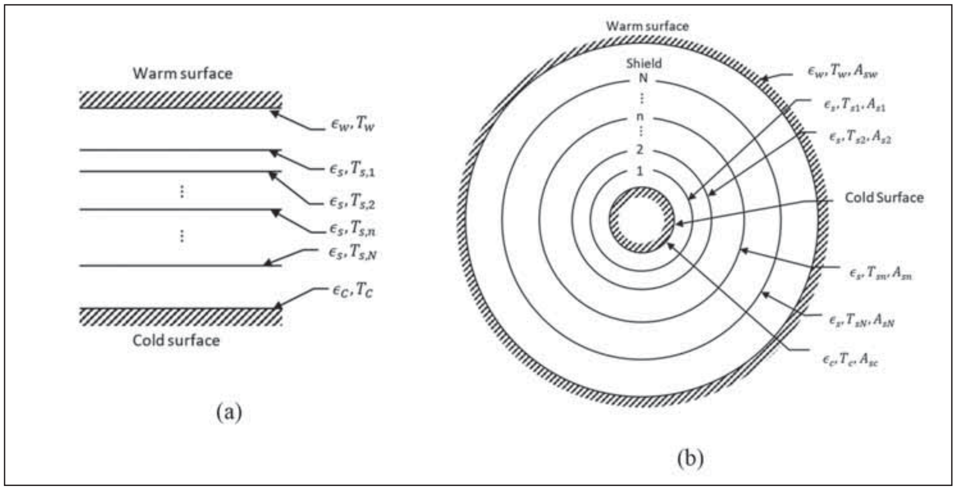

Figure 1. Thermal shield configurations for (a) planar surfaces, (b) cylindrical or spherical surfaces. Credit: Jonathan Demko

Thermal shields are placed between a high temperature boundary and a cold surface to limit the flow of heat by thermal radiation. There are two main types, floating shields which passively reach thermal equilibrium and reflect heat away from the cold space, and actively cooled shields which must be anchored to a low temperature thermal sink in order to remove the intercepted heat load reaching the shield to maintain it at the operating temperature.

1.1 Thermal Shields

Typical configurations of thermal shields can be flat plates, concentric cylinders or spheres as illustrated in Figure 1. The warm and cold surfaces may have different emissivities than the shields since these are usually a structural boundary. The shield material is selected for its thermal properties and typically has no structural or mechanical function. Thermal shields are generally made from high thermal conductivity materials such as aluminum or copper so that they are nearly uniform in temperature. Stainless steel had been used for shields that have a load bearing structural function. The cost per unit mass of a stainless-steel shield tends to be significantly higher than either copper or aluminum.[1]

Thermal shields are designed to be highly reflective (i. e. low emissivity) so that thermal radiation is mostly reflected from the shield surface so it will not be absorbed by the cold mass only to be removed by a refrigerator. The shield surface may be treated to reach lower the emissivity by polishing, electropolishing, or plating with a thin layer of highly reflective metals such as nickel, silver, or gold. When the shields are not connected to a low temperature heat sink, they can be classified as passively cooled heat shield. This is the principle behind multilayer superinsulation where the layer temperatures are a result of energy balances for each layer.

1.1 Passive thermal shields shields

A simple approach to calculate the reduction of heat transfer due to the presence of passive thermal shields can be explained using Figure 1. This figure 1a shows a simple planar shield configuration and figure 1b represents a cylindrical or spherical geometry.

The warm surface temperature and emissivity are T_w and ϵ_w respectively and the cold surface temperature and emissivity are T_c and ϵ_c respectively. Let all the shield layers have the same emissivity ϵ_s, then the heat transfer in Watts becomes:

$$Q = \frac{\sigma A\left(T_w{}^4 - T_c{}^4\right)}{1/\epsilon_w + 1/\epsilon_c - 1 + N(2/\epsilon_s - 1)}$$

where A is the surface area in square meters. If the walls have the same emissivity as the reflector shield the expression simplifies to the following:

$$Q = \frac{\sigma A\left(T_w{}^4 - T_c{}^4\right)}{(N+1)(2/\epsilon_s - 1)}$$

From these expressions it can be clearly seen that the heat transfer decreases with an increase in the number of shields. For example, the heat transfer between two concentric spheres with a warm surface at T_w=300 K with a surface emissivity ϵ_w=0.2 and a cold surface at T_c=4.2 K, with an emissivity ϵ_c=0.1, would have a heat flux of 32.8 W/m^2. The addition of radiation shields with an emissivity ϵ_s=0.05 drops the heat flux significantly as seen in Figure 2 which is the ratio of heat transfer with shields to that without any shields. From the figure it is seen that even a single thermal shield will reduce the heat flux to the low temperature to roughly a quarter of the unshielded value.

For cylindrical as well as spherical configurations, the area of the surface varies with the radius. Assuming the shield surfaces have the same emissivity, an expression for the radiation heat transfer is given by Siegel and Howell as:[2]

$$Q = \frac{A_{sc}\sigma\left(T_c{}^4 - T_w{}^4\right)}{1/\epsilon_c + (A_{sw}/A_{sc})(1/\epsilon_w - 1) + \sum_{n=1}^{N}(A_{sc}/A_{sn})(2/\epsilon_s - 1)}$$

They provide details on analyzing the case with variable shield emissivities.

1.2 Actively cooled thermal shields

Actively cooled shields require connection to a form of refrigeration or a low temperature heat sink. If a coolant is circulated to the shield some form of cooling tube is typically attached to the shield. The shield is typically a thin plate of high thermal conductivity material such as aluminum or copper. In most cases the shield is wrapped with multilayer super insulation to intercept thermal radiation from reaching the cold space. The shield can be plated with nickel to reduce the emissivity to intercept a radiant heat load.

Attachment of cooling tubes is frequently specified as shown in Figure 3a where a round tube is secured to a surface by welding or soldering. This configuration is often simple to fabricate and is satisfactory for many applications. The disadvantages are first that there may be a contact resistance between the tube and the shield surface. Second there is a thermal resistance of the tube wall which is usually small. An alternative is to attach a channel as shown in figure 3(b). This eliminates the cooling tube material thermal resistance and allows the cooling fluid to directly cool the shield surface.

The spacing of cooling tubes has been discussed by McIntosh where the maximum temperature difference on the shield, ΔT, is specified for a line spacing of 2L. The expression for ΔT is:[3]

$$\Delta T = \frac{q'' L^2}{2kt}$$

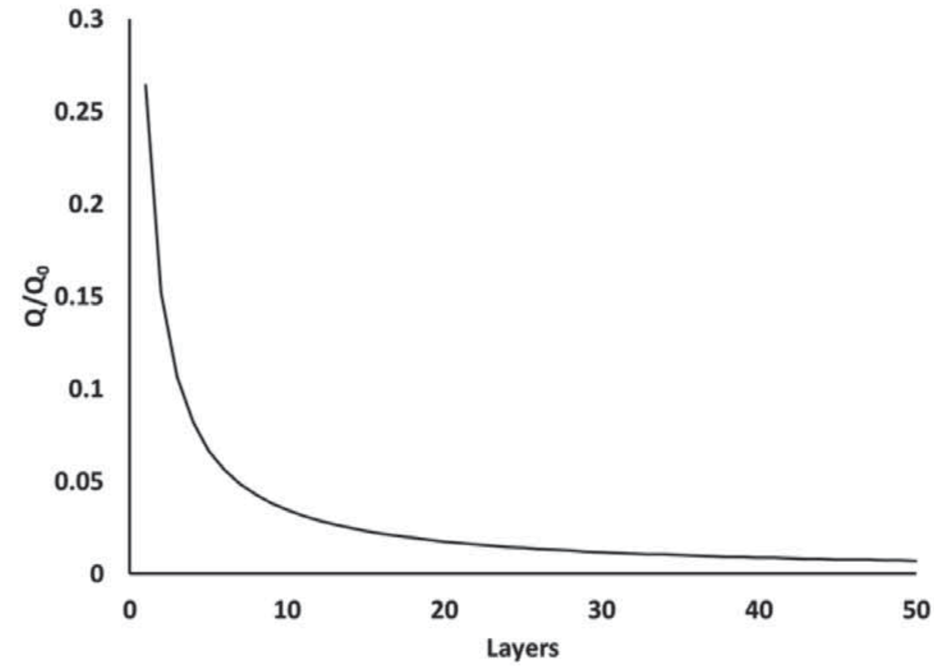

Figure 2. Ratio of heat transfer between 300 K and 4.2 K with thermal shields to that with no shield as function of the number of shields. Credit: Jonathan Demko

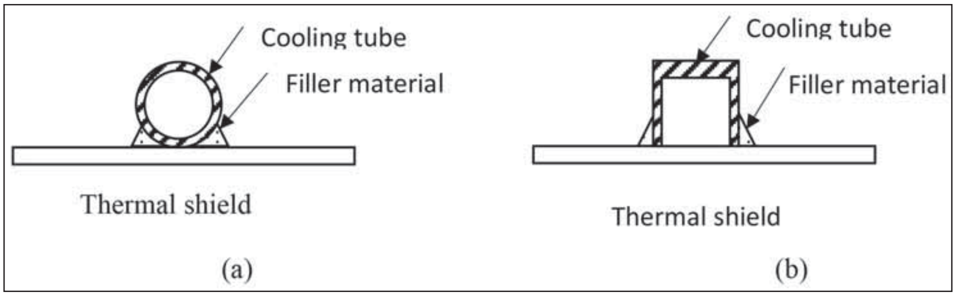

Figure 3. Simplified sketches of the attachment of a cooling tube to the thermal shield surface. (a) round tube, and (b) rectangular channel. Credit: Jonathan Demko

Where the heat flux is q''(W/m^2), k is the thermal conductivity at the shield temperature (W/m/K) and t is the thickness of the shield. The spacing can readily be determined from this equation.

Hilal and McIntosh propose a "workable" approach to reducing thermal radiation using refrigerated shields. They provide an approach for minimizing the refrigeration power required by optimizing the operating temperature of the refrigerated shields. The following results in Table 5.1 is provided by [4]

Eyssa and Okasha analyzed the optimization of refrigerated thermal shields that were covered by floating shields or multilayer superinsulation and suggests this can further reduce the Carnot cooling power.[5]

5.3 Thermal Shield For Sc Magnets And Srf Cavities

Thermal shields intercept heat radiated from the surfaces of the vacuum vessel surrounding the magnet or cavity which are at temperatures higher than the operating temperature of the devices. It is typical to have a thermal shield operating in the 50-80 K range, depending on the details of the cryogenic system. There is sometimes a second shield operating in the 5-20 K range, again depending on the details of the system and the operating temperature of the SRF devices. The shields are usually segmented to minimize thermal bowing. Material is usually aluminum or copper depending on cost, weight considerations, structural strength, ease of fabrication, attachment needs, etc.

An illustration of the use of thermal anchors and shields for a superconducting

▶ *continues on page 28*

magnet system is discussed in Nilles and provided in Figure 4.[6] This figure shows a typical configuration for a superconducting magnet used in a particle accelerator. In Figure 4 the thermal shields are anchored to coolant lines by wrapping a portion of the shield around the coolant line. Another application of a thermal anchor is illustrated in this figure where a portion of the actively cooled shields are extended to the magnet support post providing a heat station to remove conduction heating from the support.

The magnet cold mass rests on a structural support and is enclosed by a thermal shield cooled by helium gas at 20 K and a second warmer shield cooled by liquid nitrogen to 80 K. The shields are cooled by circulating these fluids through pipes anchored to the shields. The shields are typically made of aluminum in order to provide a high thermal conductivity so that the shields can be at a uniform temperature. The pipes supplying the cooling cryogenic fluid are stainless steel. These are clamped to the C shaped shield section to minimize the thermal resistance across the joint and provide adequate surface contact to transfer the heat load from the shield to the fluid.

In addition, the support post is thermally anchored to the shields to heat station the support and remove heat from the support to minimize the thermal loads to the 4 K magnet.

Thermal shields are frequently covered with MLI to reduce the amount of thermal radiation heat intercepted by the shield. The outermost thermal shield is the warmest and intercepts heat from the room temperature outer vessel. It is usually covered with 30-60 reflector layers since this is where the thermal radiation is the highest. On lower temperature surfaces, fewer layers are used, e.g. 10. Most of the rationale below about 20 K is to reduce heat load in case of loss of vacuum. Material is generally double aluminized mylar with fabric, nylon or spun-bonded material spacers. Some installations use aluminum foil. Typical heat transfer rates are ~1 W/m^2 for 30 layers from 300 K to 70 K and 50 to 100 mW/m^2 for 10 layers below 70 K.[7] Figure 5 shows the installation of a thermal shield for the ILC and the MLI blanket covering the shield.

Number of shields		$T_1(K)$	$T_2(K)$	$T_3(K)$	$T_4(K)$	Refrigeration Power (W/m^2)
Cold end temperature = 4.2 K						
1		97.82	-	-	-	1293
2		65.78	181.6	-	-	506
3		52.86	137.57	222.65	-	309
4		45.63	114.08	182.02	243.74	222

Number of shields	$T_1(K)$	$T_2(K)$	$T_3(K)$		Refrigeration Power (W/m^2)
Cold end temperature = 1.8 K					
1	81.14	-	-	-	1632
2	52.75	171.76	-	-	569
3	42.54	127.09	217.42	-	334
4	34.42	104.10	175.28	240.42	236

Table 5.1 Optimum temperatures for cooled shields and related Carnot refrigerator power from Hilal and McIntosh.[4]

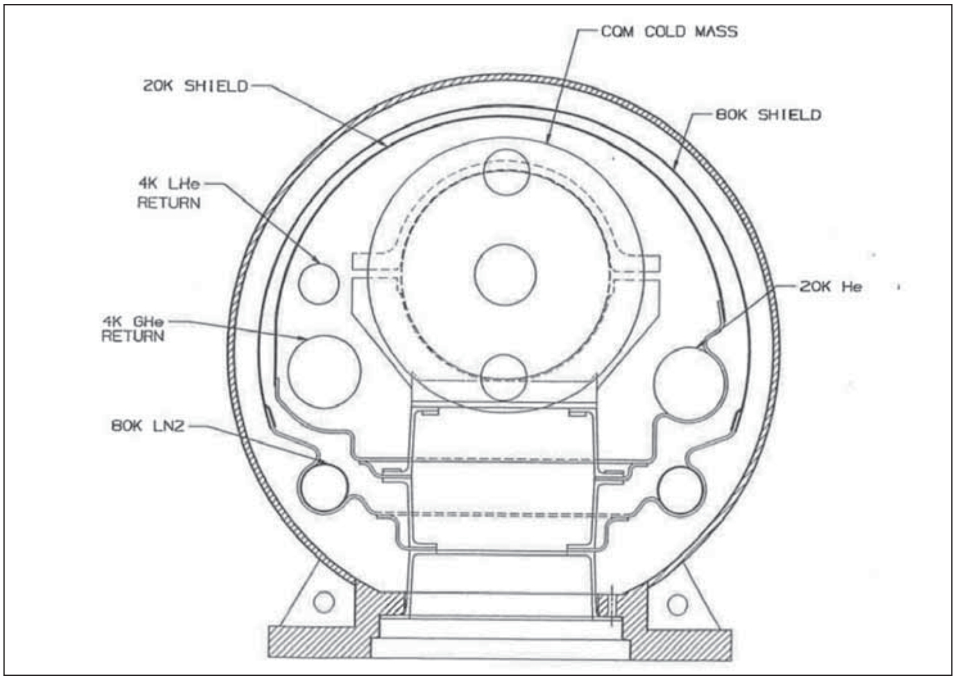

Figure 4. Typical arrangement of thermal shields and anchors for a particle accelerator superconducting magnet string.[7]

1.2 Test cryostat thermal shields

Cryostats used for testing thermal insulation utilize a special type of heat shield as discussed in Fesmire et. al.[8] The test cryostats described are used to measure the thermal performance of different thermal insulation systems between room temperature and liquid nitrogen at roughly 80 K. The test section of the cold mass assembly is surrounded by an external vessel or guard chamber that serves as a heat shield for the test section. Both vessels are filled with liquid nitrogen during a test. The outer vessel is there to absorb background heat prior to it entering the test section. This is illustrated in Figure 6.

1.2 Dewar thermal shields

Dewar shields can be built with trace cooling using boiloff of the stored cryogenic liquid (helium, nitrogen, etc.). The attachment of the trace coolant lines to the shield can be accomplished by fusion to the surface by welding, brazing or soldering as previously mentioned. For dewars, McIntosh discusses the use of an all stainless-steel trace line system which can be crimped into special 6063 aluminum extrusions.[3] This is shown in Figure 7.

1.3 Thermal shield in magnetic field

In many low temperature applications, the shield can be subject to a strong time varying magnetic field. It is necessary to prevent forming a continuous electrical conducting loop which would permit the formation of induced currents in the shield. This can be simply accomplished with a slit longitudinally along the shield forming an electrical break.

In Figure 8 a cryocooled system for measuring the voltage-current characteristics is shown where a nickel-plated copper thermal shield was used to limit thermal radiation to the test block. Measurements were made in magnetic fields up to 6 Tesla of the V-I characteristics of HTS conductor as discussed in Young et. al.[8] Thus, the magnet was ramped slowly to the maximum field and held at different levels to obtain the required data. In this situation the copper shield was slit to prevent the generation of eddy currents. The shield was wrapped with MLI, but the spacer material separated the thin reflective layers and a continuous electrical circuit is not made.

1.3.1 Thermal Shields and Anchors in Varying Magnetic Fields

Kamiya et. al. discuss the application of electrically insulated MLI, thermal shields and anchors as applied to the full superconducting tokamak referred to as the JT-60 Super Advanced (JT-60SA).[9] The superconducting coils of the tokamak are kept at 4.4 K. Thermal shields surround the magnet which are cooled by pressurized helium gas at temperatures between 80 K and 100 K. The shields intercept thermal radiation from the 300 K outer vacuum vessel.

This tokamak is operated in a pulsed mode so the shields and the MLI must have electrical breaks to prevent the development

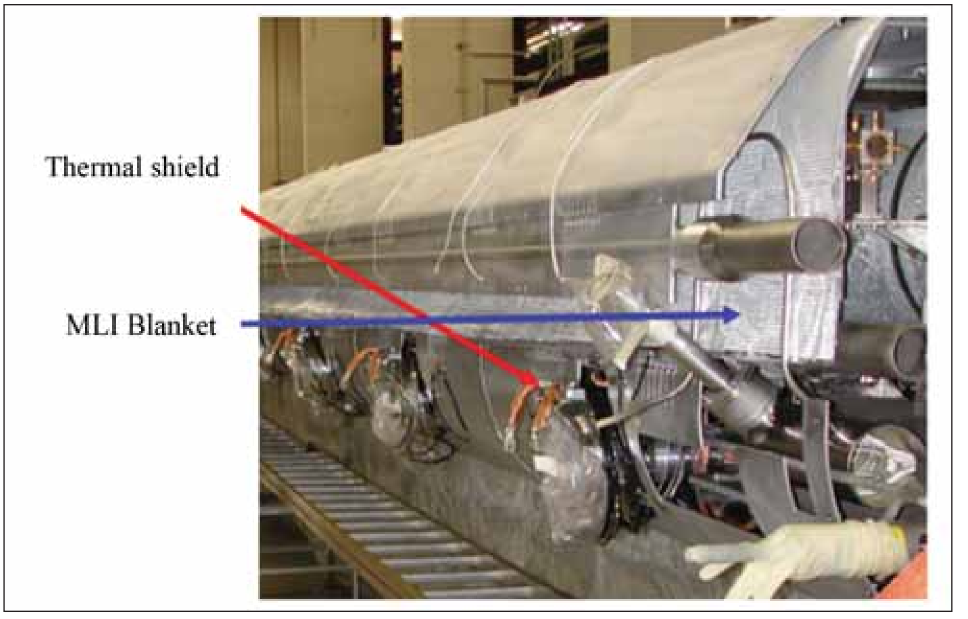

Figure 5. Thermal shields for ILC Cryomodule.[7]

of induced eddy currents which would be induced. These eddy currents can be large enough to produce significant additional joule heating and potentially damage the MLI. The shields and MLI are designed to withstand a maximum of 50 volts. This is accomplished by dividing the shield and MLI into 18 sectors in the toroidal direction and 10 sectors in the poloidal direction. Each individual MLI sector is covered with a polyimide film 25 µm thick. The reflector layers have 3 mm of non-deposited slits at 21 mm intervals to suppress eddy currents within the blankets. Special considerations are detailed regarding the joints between the sectors.

The thermal shield of the JT-60SA consists of several components including the vacuum vessel thermal shield (VVTS), the port thermal shield (PTS), and the cryostat thermal shield (CTS). The MLI is applied only to the CTS to provide access for maintenance. Figure 9 shows an isometric of the CTS, and one electrically insulated CTS sector in toroidal direction, respectively. The structure of the CTS cooling pipes and two SUS316L plates with a thickness of 1 mm on ambient temperature side (outside), and 3 mm on cryogenic side as shown in Fig. 9(c). The MLI is located on the higher temperature side. One MLI sector is designed by closely tracing one CTS sector. The cryostat is assembled around the CTS after completion of CTS. The MLI needs to withstand the heat from welding of cryostat sectors

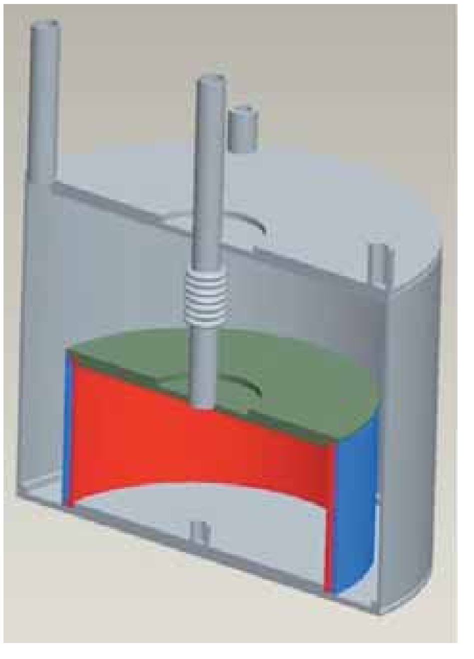

Figure 6. Cold mass assembly of a guard chamber heat shield from Fesmire et. al.[8]

through a heat-resistant insert between cryostat and MLI.[9]

1.4. Thermal Shields with Cryocooler

Figure 8 also shows a two-stage cryocooler cooling the thermal shield, the current leads, and a test sample. The test sample in the figure is a HTS tape, but could be a superconducting magnet.[10] The thermal shield is anchored to the first stage of the cryocooler and intercepts heat flowing from room temperature through the cryostat insulation, the cold mass supports, instrumentation wires and through conventional current leads that carry current into the test sample The current leads can be the largest load depending on several factors including the magnet current and surface area of the cryostat. Systems such as MRI magnets have large warm bores which results in relatively large surface area as opposed to a superconducting magnetic energy storage (SMES) magnet which is contained similarly to the figure.

The second stage of the cryocooler removes the heat flowing into the 4 K region coming from thermal radiation, conduction down the cold mass supports and instrumentation wires and conduction down high temperature superconducting (HTS) leads between the first stage of the cryocooler and the magnet The largest 4 K heat loads are from the HTS current leads and the cold mass supports.

The use of 4 K cryocoolers permits the operation of various magnet systems in a stand-alone cryogen free environment. In order to minimize the size of the cryocooler, for the most energy efficiency, a low heat leak cryostat is required. The incorporation of HTS leads permit the superconducting magnet to be operated with continuous current flow through the leads. Persistent magnets that are cooled using a 4 K cryocooler can be operated with their leads connected. Green points out that there are limits to the use of 4 K cryocoolers to cool large magnets. He suggests that the mass be less than 5 tons or the maximum lead current is between 600 A and 1000A. In general, the heat going down the leads into the magnet limits the temperature of both stages of the cryocooler.

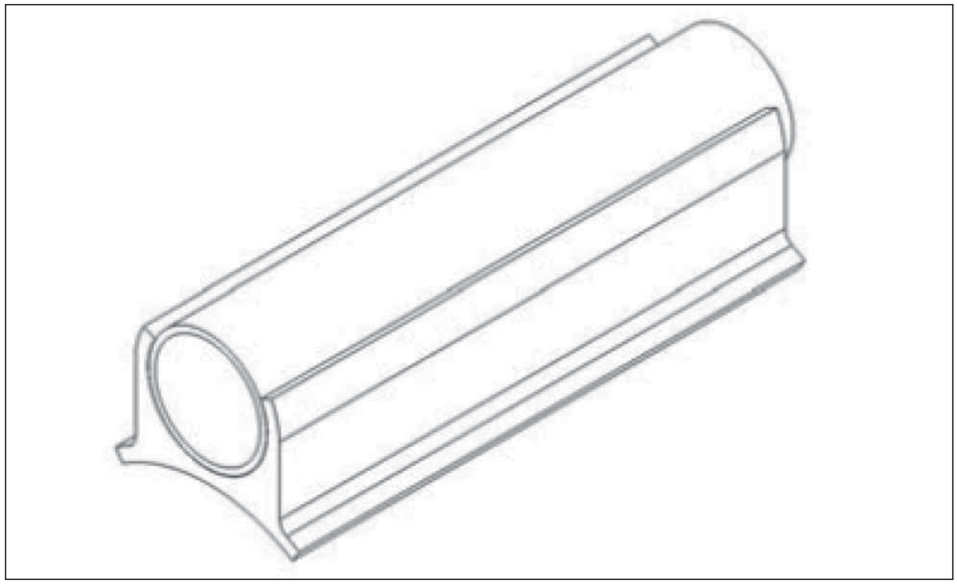

Figure 7. Stainless steel tube in 6063 Al extrusion [3]

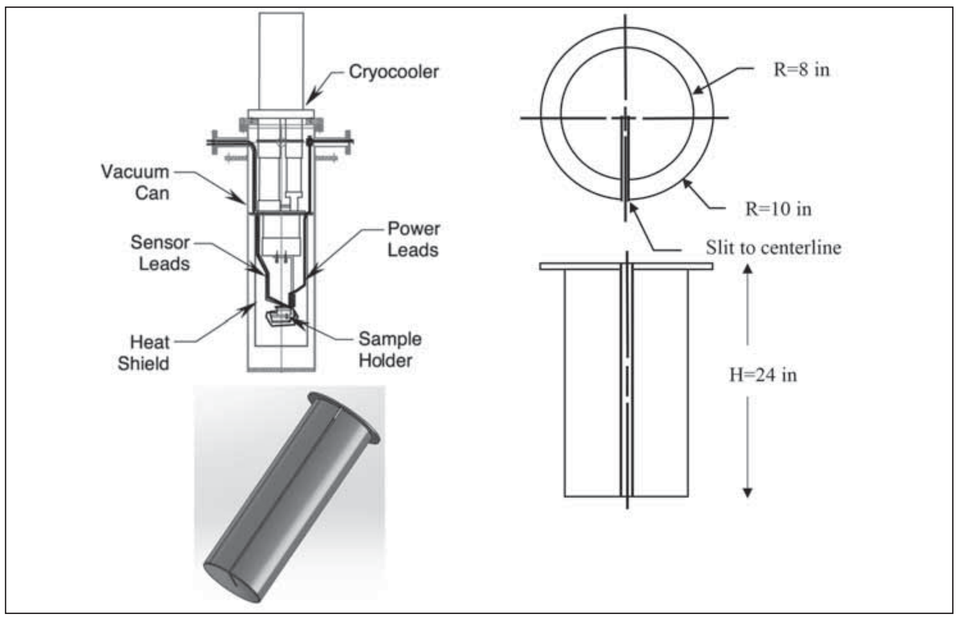

Figure 8. Measurement apparatus inside the stainless-steel vacuum vessel. Credit: Jonathan Demko

1.5 Cryogenic Shields For Cold Mass Below 1k

Experiments which must be conducted at very low temperatures, below 1 K, have especially difficult challenges due to the difficulty in providing refrigeration at these temperatures. A discussion of one such experiment, the Cryogenic Underground Observatory for Rare events or CUORE Experiment was provided by Barucci et. al.[11] The experiment uses a dry dilution refrigerator (DDR) cooling the experiment and the pulse tube (PT) refrigerator used to cool the thermal shields.

The two stages of the PT refrigerator are thermally connected to a 50 K shield by a 400 mm diameter flange and to the inner vacuum chamber (IVC) by a 340 mm diameter flange. Thermal gradients in the cold plates and radiation shields must be as small as possible so relatively thick mechanical parts (flanges, shields) are needed and also results in long precooling times. A 50 K shield intercepts the thermal radiation coming from the outer room temperature vessel. It is covered by 25 layers of MLI. The IVC and 50 K thermal shield are made from aluminium alloy Al-5083. The IVC vessel has a diameter of 330 mm, a length of 720 mm, and a thickness of 3 mm. The IVC is maintained at around 3 K.

The 3 K IVC acts as the main radiation shield for the DDR to intercept the thermal radiation from the 50 K shield. There are inner thermal shields thermally connected to the DDR providing thermal shielding to the experimental space. A total heat load of 15 W was measured on the first PT stage at 40 K, while for the second stage 0.2 W was measured at 3 K.

Thermal shields play an important role in the reduction of thermal energy reaching the lowest temperature regions of a cryogenic. These are typically made from high thermal conducting materials such as copper and aluminum. To enhance the shield performance, the surface may be polished or plated to reduce the emissivity of the shield surface.

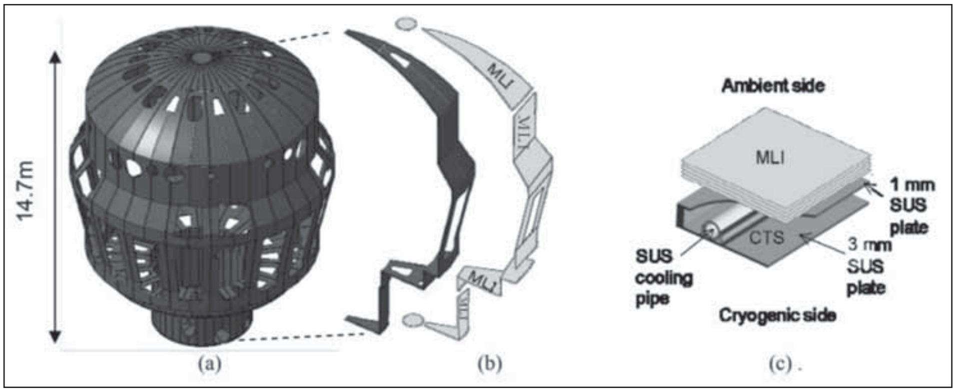

Figure 9 (a) Isometric view of the cryostat thermal shield of the JT-60SA, (b) electrically insulated MLI sectors, and (c) internal structure [9]

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Stirling's Liquid Nitrogen Solution for Smallholder Farmers Displays the Power of Cold

by Pranav Date, Stirling Cryogenics

Ministry of Agriculture, Ethiopia. Credit: Stirling Cryogenics

The Cold Chain Problem in Africa

Africa's agricultural productivity has been steadily improving, yet the absence of cold storage facilities in rural regions continues to pose severe challenges. Without reliable refrigeration, perishable goods often spoil before they can reach markets. This results in high post-harvest losses, especially for smallholder farmers who make up the backbone of Africa's food system. The consequences are significant: wasted produce, lost income and increased food insecurity for millions of households.

Cold Chain Issues

The cold chain refers to the series of actions and equipment needed to maintain perishable products at controlled temperatures from the point of harvest to the final consumer. In many rural African areas, conventional refrigeration systems are either unavailable or prohibitively expensive to install and maintain. They require continuous access to electricity, which is often unreliable or altogether absent in remote farming communities.

As a result, farmers face enormous challenges in preserving highly perishable products such as tomatoes, milk and fish. For example, tomatoes can spoil within days without refrigeration, while fresh milk quickly sours in hot climates. Fish—an important source of protein in many African diets—can become unsafe to eat in just a few hours without cooling. These losses not only weaken food security but also undermine opportunities for farmers to connect to urban and international markets.

Stirling Cryogenics' Solution

Stirling Cryogenics, a global leader in cryogenic technology, has pioneered an autonomous LN_2 (liquid nitrogen) plant that operates using the Stirling Thermodynamic Cycle. This innovative approach provides cost-effective, decentralized refrigeration solutions, particularly suited for remote farms and AI centers. Importantly, the plants are designed for low maintenance and high durability, making them ideal for environments where technical expertise and spare parts are scarce.

Stirling's technology enhances energy efficiency and contributes to sustainable agriculture. Beyond preserving crops, it also supports livestock breeding programs. By enabling the storage and transportation of frozen semen, farmers gain access to improved livestock genetics, boosting productivity and resilience in the sector.

With over 70 years of expertise, Stirling Cryogenics holds a significant presence in the global agricultural industry. More than 6,000 of Stirling's cryogenic plants have been installed worldwide. Under the brand name StirLIN, we offer a wide range of LN_2 plants producing between 3 and 50 liters per hour, delivering liquid nitrogen of up to 99.999% purity.

Why Liquid Nitrogen?

Liquid nitrogen is a uniquely versatile tool. It can flash-freeze food, preserving both quality and nutritional value. It can also cool containers for vaccines, dairy and even sensitive biological materials. For farmers, decentralized liquid nitrogen production represents a leap forward: it enables local, small-scale cold storage facilities to be established without relying on fragile central power grids. By significantly reducing spoilage rates, liquid nitrogen helps communities retain more of what they grow, thereby increasing income and resilience.

A pilot project in Uganda illustrates this potential. Partnering with a local NGO, Stirling Cryogenics deployed an LN_2 plant to assist banana farmers. Previously, spoilage rates exceeded 35%, severely reducing household income. With access to locally produced liquid nitrogen, these farmers cut spoilage to under 5%. The improvement not only benefited individual households but also strengthened the community's food supply chain and provided new opportunities to connect with buyers in urban markets.

Scalability and Challenges

Africa is home to more than 33 million smallholder farms. Each of these could

Containerized StirLIN-4 LN_2 Plant for MOA, Ethiopia. Credit: Stirling Cryogenics

Flagship LN_2 plant model StirLIN-8. Credit: Stirling Cryogenics

benefit from decentralized cold storage systems powered by LN_2 plants. However, successful scaling requires more than technology alone. Awareness campaigns are necessary to demonstrate the benefits of cryogenics to local farmers. Financial models must be developed to make the systems affordable, possibly through cooperatives or microfinance institutions. Finally, training programs are essential to equip local technicians with the skills needed to maintain and operate these systems.

Rural Empowerment

In rural Africa, cold storage is far more than just a technical solution—it is a form of empowerment. By reducing spoilage, farmers gain control over when and where to sell their produce, which strengthens bargaining power and market access. As Africa's population continues to grow, the demand for reliable food systems will only increase. Developing decentralized cold chains will therefore be vital for food security, poverty reduction and overall economic growth. With its innovative cryogenic solutions, Stirling Cryogenics is helping transform agriculture into a more efficient, sustainable and future-proof sector.

The Cryogenics Advantage

Cryogenics sits at the heart of Stirling Cryogenics' approach. By definition, cryogenics deals with temperatures below –150°C (–238°F). At these levels, many biological and chemical processes slow down dramatically, making it possible to preserve food, tissues and other perishables for long periods without degradation.

Liquid nitrogen, at –196°C, is the most widely used cryogenic fluid because it is abundant, relatively inexpensive and inert. Unlike traditional refrigeration methods that rely on compressors and chemical refrigerants, LN_2 is clean and sustainable. Once released, it naturally evaporates into the atmosphere, leaving no harmful residues.

Cryogenics also extends beyond agriculture. It plays a critical role in medicine, where LN_2 is used for storing vaccines, blood plasma and reproductive materials such as semen and embryos. In research and technology, cryogenics makes possible advanced applications like superconductivity and quantum computing.

For African agriculture, however, the relevance is immediate and practical. By harnessing cryogenics, communities can leapfrog outdated technologies and establish modern cold storage networks that are decentralized, resilient and scalable. This shift is not only about reducing food waste but also about creating a stronger foundation for economic development and improved quality of life.

Nitrofreeze Cryogenic Solutions Dry Ice Blasts for Historic Restorations

By Ryan Taylor, Nitrofreeze Cryogenic Solutions

Dry ice blasting is used in a wide range of historic restoration projects, including a recent one completed in Rockport, Mass., in July of this year. Nitrofreeze Cryogenic Solutions was contracted to dry ice blast barn board wood inside a fishing hut to lighten the surfaces and bring them closer to their original state.

Originally, the fishing hut was only a small wooden enclosure, but it will now be preserved since a fully functional house has been built around it, acting as a protective shell. This new home was completed within the last year. The fishing hut itself dates back to the early 1700s and has been exposed to environmental contaminants for nearly 300 years. Over time, this exposure caused the wood surfaces to darken significantly.

The Nitrofreeze team used dry ice blasting technology to remove a thin layer of wood, lightening the substrate and restoring its appearance to something closer to its original look from three centuries ago. Dry ice blasting is a non-toxic and non-abrasive cleaning process that uses solid carbon dioxide pellets and compressed air. The pellets are propelled at high speed and directed at the substrate — in this case, the barn board. When the pellets hit the surface, they almost immediately sublimate into carbon dioxide gas. Some of the kinetic energy transfers to the surface, removing a thin layer of wood. The minimal abrasion depends on the thermal conductivity of the surface being blasted.

Compared to other blasting techniques such as soda blasting, sandblasting or chemical treatments, dry ice blasting is completely non-toxic and non-conductive since dry ice is inert. The only waste produced is the fine layer of wood removed during the process.

The effectiveness of dry ice blasting is rooted in cryogenic science. Dry ice is the solid form of carbon dioxide and exists at a temperature of -109.3°F (-78.5°C). When these extremely cold pellets strike a surface, they cause a rapid temperature drop that creates thermal shock. In the case of historic wood, this shock causes surface contaminants to contract and loosen, making them easier to remove without damaging the underlying material.

As the dry ice pellets make contact, they sublimate instantly, changing directly from solid to gas. This phase change is critical because it expands nearly 800 times in volume, creating a gentle lifting effect that helps separate layers of dirt, paint, or buildup from the surface. Unlike abrasive blasting methods that grind away material, the cryogenic properties of dry ice allow for precise cleaning with minimal surface wear.

Dry ice blasting is used in a multitude of historic restoration projects, including one Nitrofreeze recently completed in Rockport, Mass. Credit: Nitrofreeze

Before dry ice blasting. Credit: Nitrofreeze

Because the process uses frozen carbon dioxide, there is no secondary waste stream such as water or chemical residue. This makes it especially valuable for conservation and preservation projects where maintaining the integrity of the original structure is essential. By leveraging cryogenic principles, Nitrofreeze is able to clean centuries-old materials safely, efficiently, and in an environmentally responsible way.

For this project, Nitrofreeze used a fragmenting nozzle on the dry ice blaster and passed about two pounds of ice pellets per minute through it to maintain a minimal amount of abrasion on the wood surface. This careful approach helped protect the fishing hut from further damage while achieving the desired cleaning effect. The work required blasting all wood surfaces inside the hut, including the walls, ceiling, beams, and posts.

After dry ice blasting. Credit: Nitrofreeze

Dry ice blasted versus untouched surfaces. Credit: Nitrofreeze

Dry ice blasting is a versatile tool with many applications in restoration work. Nitrofreeze also recently completed a project at the Museum of Fine Arts in Boston, supporting preservation efforts for several statues. While that project involved metal substrates, dry ice blasting can also clean many building materials, including stone, brick and a variety of wood types.

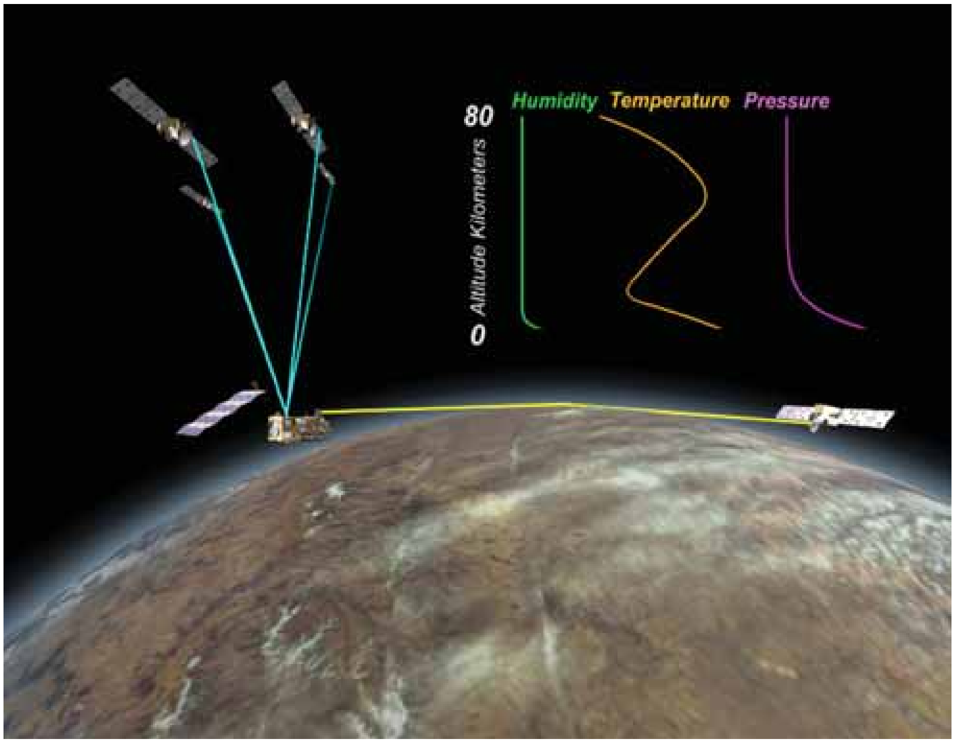
The restoration in Rockport was a success, and the customer was thrilled with the results. Dry ice blasting effectively removed layers of environmental buildup that had accumulated over the course of nearly 300 years. Nitrofreeze uses these same processes in a wide range of industries, from industrial manufacturing to food and beverage, to historical preservation. Nitrofreeze is committed to exceeding customer expectations while maintaining strict environmental standards. The company has provided dry ice blasting services in the New England area for nearly 20 years. **www.nitrofreeze.com**

Beyond Gravity Powers Europe's New Weather Satellites with Advanced Technology

by Christian Thalmayr, Senior Manager Global Communication, Beyond Gravity

In mid-August, the first in a new generation of European polar-orbiting weather satellites will launch aboard an Ariane 6 rocket from the European Spaceport in Kourou, South America. The MetOp-Second Generation (MetOp-SG) satellite will gather vital data on humidity, temperature and aerosols to improve forecasting and climate monitoring. It marks the beginning of a six-satellite program that will significantly expand Europe's ability to track global weather patterns and environmental change.

Oliver Grassmann, Executive Vice President Satellites at Beyond Gravity, described the launch as a milestone. "This new European weather satellite, together with its five counterparts, will greatly enhance forecasting accuracy and climate change monitoring," he said. "A key element of this mission is our radio occultation instrument, which provides critical weather data about humidity and temperature and underlines our role as a trusted data provider."



The weather satellite uses a radio occultation instrument from Beyond Gravity. Credit: ESA.

In addition to this instrument, Beyond Gravity supplied the satellite's six-meter-tall main structure, thermal insulation and several components for the Ariane 6 launcher. Airbus Defence and Space in Toulouse is the prime contractor for the program.

The company's radio occultation technology will fly on all six satellites, more than doubling the number of daily measurements to 2,100 per instrument and providing continuous global coverage through 2050. By measuring how radio signals bend as they pass through Earth's atmosphere, this system produces highly accurate profiles of temperature, pressure and humidity, improving models for weather prediction and climate monitoring.

The satellite itself depends on advanced thermal management to survive the harsh conditions of space. Its core structure, built at Beyond Gravity's Zurich facility, combines carbon fiber, aluminum and titanium for strength and low weight. Weighing roughly one ton, it is wrapped in multilayer insulation manufactured in Berndorf, Austria. This material shields the satellite from temperature swings of more than 400 °C, maintaining a stable interior environment for its sensitive instruments. Without this protection, the extreme heat and cold of space would compromise the satellite's ability to deliver reliable data.

The launch vehicle, Ariane 6, also relies on cryogenics and thermal technology. Its main engines run on liquid oxygen (LOX) and liquid hydrogen (LH_2), both stored at extremely low temperatures. Handling these cryogenic fuels requires specialized insulation to prevent boiloff and ensure efficient combustion during liftoff. Beyond Gravity produced high temperature insulation for both the lower and upper stage engines, as well as for the upper stage gimbal system that steers the rocket during ascent.

This insulation is designed to withstand intense conditions: while the propellants themselves are near absolute zero, the engines they feed must endure bursts of heat up to 1,500°C during launch. Beyond Gravity's materials shield the exhaust systems, preventing thermal damage and ensuring stable performance. For the upper stage, the insulation near the Vinci restartable engine is made of glass fabric and polymer films, balancing strength with minimal weight to meet strict performance requirements.

The company also supplied a gimbal mechanism for the upper stage thrust vector control system. Despite weighing only ten kilograms, this precision component must transmit forces comparable to those of a diesel locomotive as it guides the rocket into orbit.

During launch, the MetOp-SG satellite is protected by a carbon fiber composite payload fairing, produced at Beyond Gravity's facility in Emmen, Switzerland. Measuring 5.4 meters in diameter, the fairing shields the satellite from aerodynamic and acoustic forces before being jettisoned once the rocket reaches space. Beyond Gravity's site in Linköping, Sweden, also provided the payload adapter system, which secures the satellite during ascent and releases it at the exact moment it reaches its designated orbit.

The MetOp-Second Generation program will ultimately include six satellites, launched in pairs over the coming years. Together, they will continue and expand the work of Europe's first-generation MetOp satellites, which have provided global weather data since 2006. The new satellites feature a mix of A-type and B-type platforms carrying complementary instruments, including the Copernicus Sentinel-5 payload to monitor air pollutants and greenhouse gases. This cooperative mission between ESA and EUMETSAT reflects Europe's commitment to long-term environmental monitoring at a time when climate change is driving more frequent and severe extreme weather events.

Europe's weather monitoring strategy combines polar-orbiting satellites like MetOp-SG with geostationary satellites such as Meteosat. MetOp satellites, orbiting at 832 km, scan the entire planet every few days, while Meteosat satellites, stationed 36,000 km above the equator, continuously observe rapidly developing phenomena like hurricanes. Together, these systems provide the comprehensive data needed for both short-term forecasting and long-term climate analysis.

As this first MetOp-SG satellite prepares for launch, Beyond Gravity's contributions—from cryogenic insulation for Ariane 6's engines to the satellite's own thermal protection—underscore the critical role advanced materials and engineering play in space exploration. These technologies not only enable the rocket to reach orbit but also ensure the satellite can perform flawlessly once it begins its mission, delivering vital data for decades to come.

Radio occultation instrument from Beyond Gravity. Credit: ESA

Excel Loading Systems Innovates Cryogenic Fluid Transfer

by Excel Loading Systems Communications

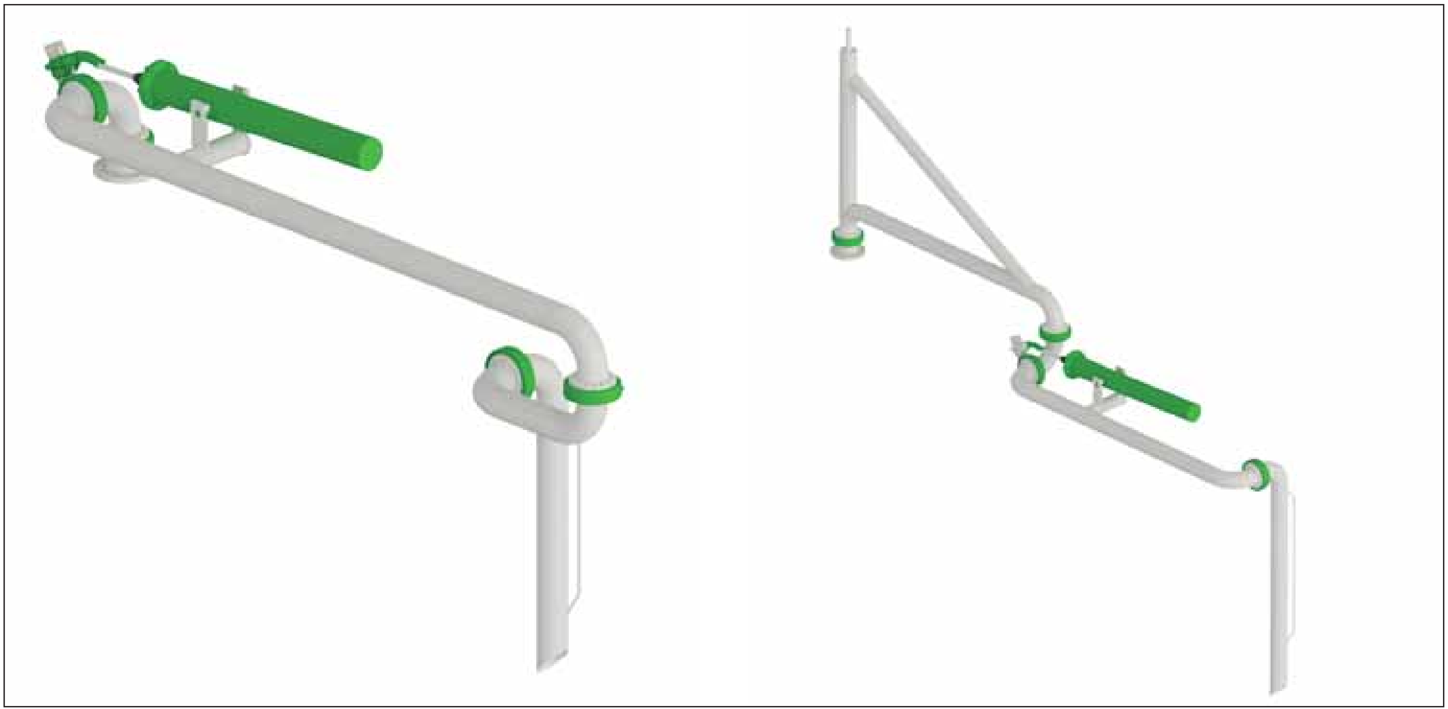
Since its establishment in 2013, Excel Loading Systems has rapidly emerged as a leading manufacturer of advanced loading arm systems, particularly excelling in cryogenic applications. Specializing in the safe and efficient transfer of liquefied gases such as LNG, liquid nitrogen, liquid oxygen and hydrogen, Excel has become a key partner for industries requiring precise and secure fluid handling.

The company's cryogenic loading arms are engineered to operate at extreme temperatures, as low as -196°C (-320°F), allowing the safe transfer of liquefied gases between storage tanks and transport vehicles, including ships, railcars and tank trucks. Maintaining mechanical integrity under such harsh conditions requires specialized materials, careful engineering and attention to operational safety. To meet these demands, Excel constructs its loading arms from stainless steel and nickel alloys, materials that resist embrittlement and corrosion while retaining strength at cryogenic temperatures.

The arms themselves feature articulated joints that provide flexibility and allow smooth movement during loading and unloading. Balancing systems using counterweights, hydraulic cylinders or spring mechanisms help operators maneuver these arms with minimal effort, even in extreme cold where manual handling would otherwise be difficult. These design elements are essential for industries such as LNG export and import terminals, industrial gas production facilities and the space sector, where handling liquefied gases safely and efficiently is critical.

A cornerstone of Excel's innovation lies in its precision-engineered swivel joints, including models such as the XL-1.0 and the high-pressure XL2.0HP. These components are critical to the performance of cryogenic loading systems, providing flexibility and smooth motion while maintaining leak-proof connections. The high-pressure swivel joints incorporate hardened ball races and corrosion-resistant seal faces to ensure long-term reliability and minimal maintenance. They allow the arms to handle not only standard cryogenic liquids but also pressurized and high-volume flows, which is particularly important for industries that demand both speed and precision in fluid transfer. Swivel joints are often the determining factor in system reliability, and Excel's commitment to engineering excellence ensures these components meet or exceed industry standards.

Safety is another central focus for Excel Loading Systems. Cryogenic fluids present unique hazards, including the risk of vaporization, rapid expansion, and fire and frostbite, making robust safety systems essential. Excel addresses these risks through emergency release systems and breakaway couplings, which allow the arms to disconnect



Variable Reach Top Loading Arm – Excel Loading Systems' cryogenic top loading arm, designed for safe, flexible transfer of liquefied gases in extreme temperatures (left) Supported Boom Top Loading Arm – Engineered for stability and ease of operation, this supported boom arm allows smooth handling of cryogenic fluids in industrial and LNG applications.
Credit: Excel Loading Systems

automatically if a vehicle moves unexpectedly or if excessive tension is applied. Both ends of the connection seal upon disconnection to prevent spills and protect personnel.

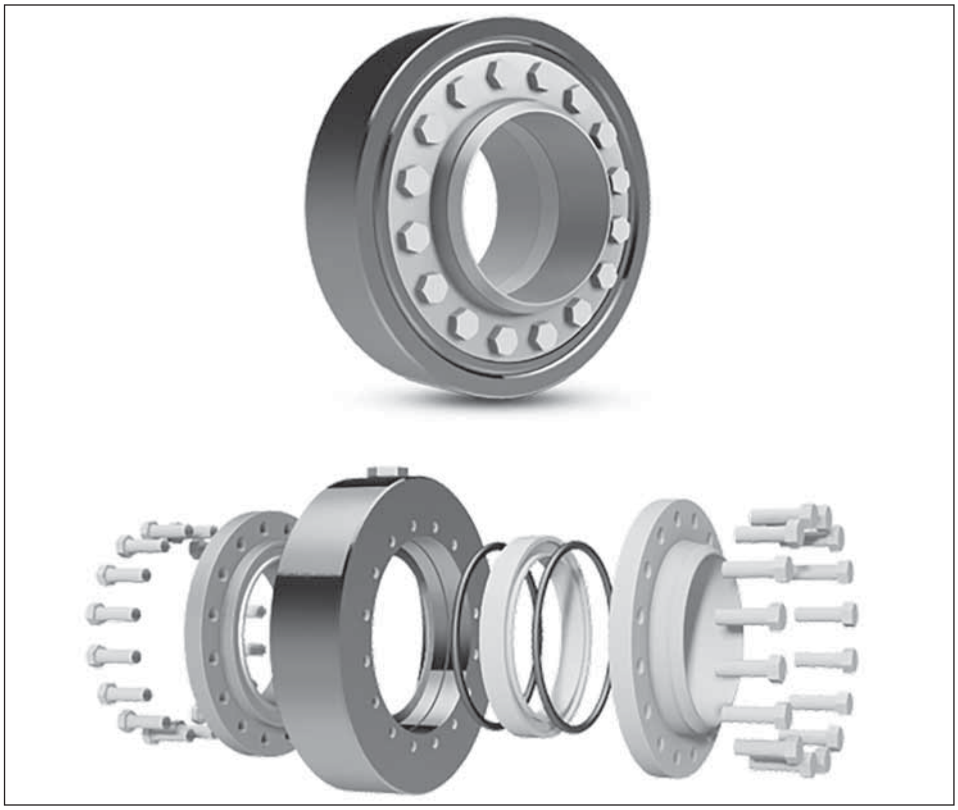
Temperature sensors are integrated throughout the arms to provide real-time monitoring of the fluid during loading and unloading, and emergency shutoff valves and fire and gas detection systems provide additional layers of protection. Operators are trained and equipped with personal protective equipment such as cryogenic gloves, face shields and insulated clothing, all of which contribute to safe operation in extreme environments.

Excel also distinguishes itself through its commitment to quality and service. All standard swivels, elbows, pipes and spring components are manufactured in the United States, ensuring traceability and strict adherence to quality standards. The company provides rapid shipping and expedited delivery options, often outperforming competitors in lead times and offers in-field replacement, adjustment and factory refurbishment services to maintain operational continuity. This combination of engineering, manufacturing excellence and responsive service reinforces Excel's reputation as a reliable partner for industries that rely on cryogenic processes.

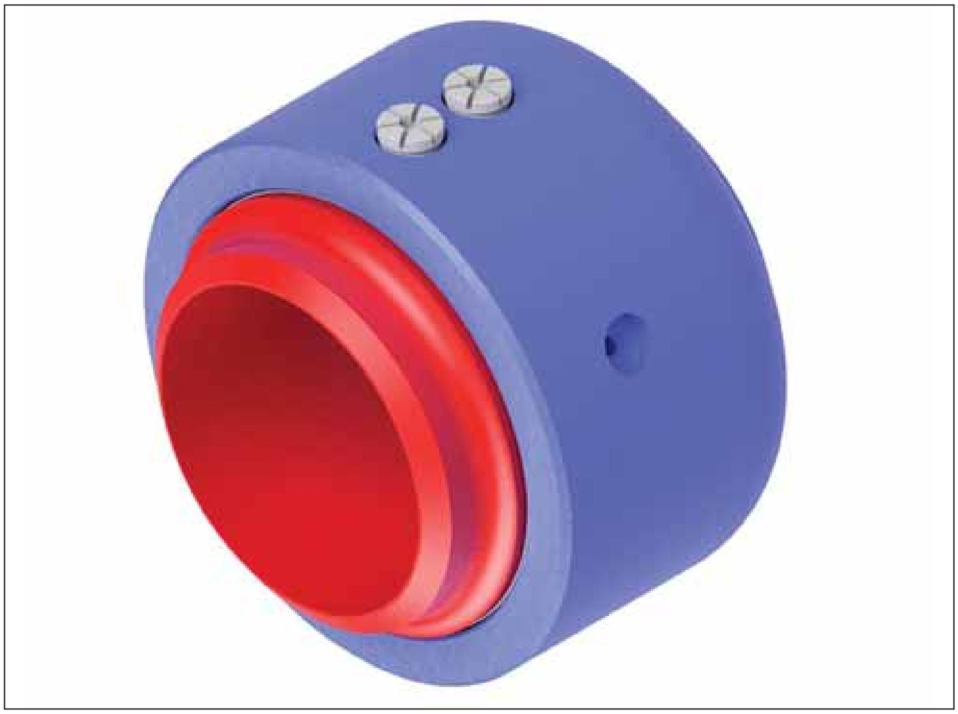
Applications of Excel's cryogenic products are diverse and critical. In LNG terminals, their loading arms facilitate the safe and efficient transfer of liquefied natural gas between storage tanks and cargo ships. In industrial gas facilities, they handle large volumes of liquefied nitrogen, oxygen or argon for production, storage and distribution. In the space industry, Excel's equipment supports the fueling of rockets with liquid oxygen and hydrogen, where reliability and safety are paramount. Across these applications, Excel's products are designed to maintain the integrity of the fluid, prevent leaks and ensure the safety of operators and infrastructure.

Through continuous innovation, attention to material selection, engineering precision and a strong focus on safety, Excel Loading Systems has become a benchmark in cryogenic fluid transfer solutions. Their products combine durability, flexibility and reliability to meet the stringent requirements of some of the world's most demanding industries.

By delivering high-quality cryogenic loading arms and swivel joints, along with exceptional service and support, Excel ensures that liquefied gases are transferred safely, efficiently and reliably, solidifying its position as a trusted leader in the field.



Stainless Steel and Carbon Swivel Joints – Precision swivel joints, built from stainless steel or carbon materials, ensure leak-proof movement and reliability under cryogenic conditions. Credit: Excel Loading Systems



High Pressure Dual Race Swivel Joints – Dual race high-pressure swivel joints designed to handle pressurized cryogenic fluids with maximum durability and minimal maintenance. Credit: Excel Loading Systems

Zero-Loss Liquid Hydrogen Storage and Transfer Technology Transforms the Hydrogen Economy

By Greg Gosnell, CEO of GenH2 Corp.

Subcooled hydrogen prevents pump cavitation, reduces maintenance and extends equipment life. Credit: GenH2

Hydrogen is essential to reducing carbon emissions and transitioning away from fossil fuels. Yet storage and transfer losses of up to 40% have limited its cost-effectiveness and slowed adoption. The key to unlocking hydrogen's potential lies in Zero-Loss Controlled Storage Technology. By minimizing loss, liquid hydrogen (LH_2) can achieve its promise as a scalable alternative fuel for transportation, backup power and long-duration energy storage. Applications range from refueling infrastructure for heavy-duty trucking, mass transit, aviation, maritime and rail, to remote power systems, R&D and back-up energy storage. The most effective way to reduce storage and transfer losses is through refrigerated storage systems that are capable of keeping liquid hydrogen in an optimal state of pressure and temperature.

The LH_2 Challenge

Because LH_2 naturally evaporates under normal conditions, storage systems must be engineered to prevent venting of boiloff gases. Attempting to store LH_2 without proper control is like trying to stop water from boiling on a hot stove.

To maintain hydrogen in its optimal liquid state, advanced zero-loss technology utilizes refrigeration to remove heat and control pressure within the bulk storage tank. These controlled storage systems can preserve LH_2 indefinitely and deliver it to the end-use application when it is needed, without loss. The foundations of refrigerated storage were developed in support of the NASA space program and, building on that foundation, GenH2 has extended the technology into commercial hydrogen infrastructure products backed by numerous patents and patents pending.

Cryo Turbo Refrigeration

Liquid hydrogen storage has always been challenged by boiloff gas (BOG), where hydrogen escapes as it warms—especially during tank filling, storage and refueling. Conventional storage systems only remedy for venting during filling is to allow extremely high pressure to build in the bulk storage tank. This appears to be effective at a point in time, but because there is no way to relieve that pressure without active heat removal, the liquid hydrogen becomes saturated and the losses are magnified during transfer and dispensing.

GenH2's controlled storage is the only technology available that utilizes active heat removal to control the temperature and pressure inside the liquid hydrogen bulk storage tank, preventing losses before they occur. Other hydrogen loss mitigation techniques involve capturing hydrogen gas <u>after</u> it has been vented (boiloff gas management). There is a very distinct difference between preventing loss and boiloff gas management that attempts to deal with the losses after they have occurred.

If you can't prevent loss and can only capture vented hydrogen gas, there are a couple of options that are commonly pursued and neither one is ideal.

1. One approach to boiloff gas management is to reliquefy the captured hydrogen gas and put it back in the bulk storage tank. The problem with this approach is that the amount of power needed to reliquefy hydrogen is too high to make it viable. The power requirement to reliquefy hydrogen is significantly higher than operating a controlled storage system that prevents the losses from occurring in the first place.

▶ *continues on page 42*

2. Another approach involves storing the vented hydrogen in gaseous form and dispensing gas to gas. Not only does this approach require an additional storage vessel, gas compressor and more physical space (almost doubles the refueling station footprint), but it is also very energy-intensive, unreliable and requires extensive corrective maintenance.

Fuel station operators with experience storing hydrogen gas for dispensing have almost universally concluded that it is not a viable approach and have changed direction to store and dispense liquid hydrogen. Liquid hydrogen fuel station operators are becoming more aware of the significant hydrogen losses during operations and already knowing that boiloff gas management is not a workable solution, are starting to require refrigerated storage technology specifically for loss prevention vs. boiloff gas management. Following is an excerpt from a Transit District's recent RFP for its bus refueling station:

*"The loss of hydrogen has been attributed to boiloff from circulation of hydrogen back to the storage tank during refueling activities and refueling of the liquid storage tank. The loss of hydrogen has been in excess of 40%, resulting in operational costs that are not sustainable with the District's goal of future zero emission fleet expansion. We are seeking proposals from qualified bidders to design, build and install a fully functional state-of-the-art **refrigerated hydrogen storage system** to substantially reduce or possibly eliminate all hydrogen losses associated with liquid hydrogen refueling."*

Breaking Barriers

By solving the boiloff problem, controlled storage removes the final obstacle to widescale LH_2 adoption. Key benefits include:

- **Zero Loss:** Active heat removal and pressure control eliminate loss from tank filling to dispensing.
- **Lower Pressure, Higher Efficiency:** Reduced-pressure storage simplifies filling and eliminates venting.
- **Cost Savings:** Zero-loss systems boost fuel station efficiency and cost competitiveness.

The RS1500 system prevents losses before they occur by removing heat. Recaptured losses typically cover system investment within two years in most cases. Credit: GenH2

- **Reliability:** Subcooled hydrogen lessens pump cavitation, reducing maintenance and extending equipment life.

Benefits By-the-Numbers

For hydrogen station operators, product loss is the single biggest challenge. In a typical 18,000-gallon LH_2 bulk storage tank installation, venting up to 40% of the hydrogen can cost millions of dollars annually. Here's an example of fueling station economics with hydrogen losses, with very conservative assumptions for hydrogen loss:

Amount Dispensed: 3,000 kg/day
Cost of Liquid Hydrogen Delivered: $8/kg
Average Loss of Hydrogen: 25%
Loss in Revenue: $2,184,000/year
Cost of Electricity: $.15/kWh

Clearly, these are not numbers that are going to support growth of the hydrogen infrastructure and, until this problem is addressed, hydrogen will not be able to compete with diesel as a fuel source for mobility applications. Refrigerated controlled storage promises to do just that.

Summary of the Impact

- **Compelling ROI:** Recaptured losses cover system investment in under two years in most cases.
- **Lower Price at the Pump:** Elimination of hydrogen losses allows for more competitive pricing.
- **Higher Reliability & Uptime:** Protects pumps, reduces downtime, improves customer experience.
- **Scalable Future-Ready Design:** Modular systems grow with demand without redesign.

Adopting controlled storage is a strategic investment that eliminates significant financial losses, protects critical infrastructure and enables competitive hydrogen pricing. Deploying zero-loss LH_2 storage and transfer technology is critical to the development of a practical, resilient and scalable hydrogen economy. *https://genh2hydrogen.com*

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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.

DELTA Modular Liquid Hydrogen -series 4

Duron Cryogenics

Duron Cryogenics' high pressure, modular pump assemblies, the 4DM3-88H and 4DM3-100H, utilize specific design and materials for liquid hydrogen service. Of note is the full floating -3 titanium suction valve plate for reduced moving mass and better valve dynamics. The 88mm and 100mm fluid ends do not have plate springs. Duron's test results of various spring designs demonstrated that springs were at best adequate in narrow margin operating conditions. The full floating valve plate design produced increased performance across a wide speed range. The dynamic soft materials are sourced specifically for LH_2 service. Duron Cryogenics' products are designed, sourced, and produced in the U.S. **Americapdduron@roadrunner.com**.

Clean ID

Penflex

Penflex has expanded both its Clean ID metal hose line and its helium mass spectrometer testing capacity to better support the unique needs of cryogenic customers. Built using the latest corrugation forming technology, Clean ID is manufactured without any internal tooling, lubrication, or fluid, allowing users to streamline post-production cleaning processes—or skip them all together. The product line now includes 1-1/4" - 2" hose. To meet growing demand for helium mass spec testing, Penflex has invested in new machines, more dedicated floor space and increased testing gas inventories. The upgrades enable faster throughput and improved lead times for users with these testing requirements. **www.penflex.com**

Model 10007X Process Probe

CryoTechnics

The CryoTechnics Model 10007X Process Probe is a rugged, high-performance cryogenic temperature sensor engineered for precision in the most extreme environments. Featuring a gold-plated copper probe tip, it delivers industry-leading thermal response times as fast as 100 ms, ensuring fast, accurate and repeatable measurements from room temperature down to 1.5 K. Its stainless steel housing with hermetically sealed connectors provides durability and compatibility with a wide range of cryogenic fluids, flows and system geometries, making it ideal for both pressurized and evacuated applications. Designed for mission-critical industries, the Model 10007X excels in environments where speed, reliability and accuracy are non-negotiable, such as aerospace, aviation and advanced research. Backed by CryoTechnics' AS9100-certified engineering expertise, customers gain more than hardware: full support in FEA, CFD and thermal modeling to reduce development risks and accelerate integration. The 10007X delivers uncompromising performance for today's most demanding cryogenic measurement challenges. **www. cryotechnicsus.com**

Solutions for Plastics Processing

Edwards Vacuum

The EXDM extruder degassing system features a robust, dry-running EDC claw vacuum pump, delivering reliable performance with low maintenance and operating costs. Its modular design allows seamless integration into both new and existing extrusion lines, ensuring effective removal of gases and volatile contaminants. The EDS dry screw vacuum pump is optimized for the production of compounds and masterbatches, offering direct commissioning, flexible process adaptation and consistent, energy-efficient operation. For advanced vapor management, the Polycold® MaxCool cryocooler provides rapid and efficient capture of water vapor - the most reactive contaminant in vacuum systems - achieving up to 95% removal. With cooling capabilities ranging from -98°C to -145°C and pumping speeds up to 400,000 l/sec, MaxCool improves throughput, product quality and separation efficiency. **www.edwardsvacuum.com**

People & Companies in Cryogenics

Commonwealth Fusion Systems announced that its ARC fusion power plant in Chesterfield County, Virg., is moving closer to the grid after the county's Board of Supervisors unanimously approved a conditional use permit. This approval follows the planning commission's earlier unanimous decision and officially zones the James River Industrial Center for fusion energy generation, marking the first property in the United States zoned specifically for a fusion power plant. The company plans to move forward with additional approvals for construction, grid connection and operation, which will allow ARC to deliver 400 megawatts of clean power in the early 2030s. Building on lessons from its SPARC demonstration machine under construction in Massachusetts, Commonwealth Fusion Systems emphasized its commitment to engaging with community members, businesses and government officials as part of its outreach efforts, calling this milestone an important step toward bringing commercial fusion energy to the grid.

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The **Cryogenic Society of America** (CSA) is pleased to announce a new collaboration with the **Cryogenics Advancement and Research Exchange** (CARE). CARE's mission to advance cryogenic science and foster research aligns closely with CSA's long-standing commitment to uniting professionals in cryogenics and superconductivity through education, technical exchange, and industry growth. Founded in 1964, CSA is a non-profit technical society that supports the community through publications, training, and events—including Cold Facts, our flagship bimonthly magazine recognized worldwide as the leading resource for updates on cryogenic technologies and applications. Through this partnership, CSA and CARE will engage a broader audience of researchers, engineers, and industry professionals shaping the future of cryogenics. More details will be shared soon.

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Danfoss has announced the acquisition of Palladio Compressors, a strategic move that broadens its compressor portfolio to better serve large-scale HVAC/R systems utilizing natural and low-GWP refrigerants. The addition of Palladio's advanced screw compressor technology strengthens Danfoss' position in the industrial heat pump and large commercial refrigeration markets, aligning with its LEAP 2030 strategy to accelerate decarbonization and energy efficiency. Building on a successful partnership, the integration of Palladio's technology enhances Danfoss' capabilities to deliver competitive, high-performance solutions across diverse applications. The newly branded Danfoss Screw range will benefit from increased investment in research, development and production, while Palladio Compressors officially joins the Danfoss Commercial Compressors division as of October 1, 2025.

From left, Fabio Klein, President of Danfoss Commercial Compressors, seals the deal with David Candio, CEO of Palladio Compressors. *Credit: Danfoss*

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Cryoport, a company specializing in temperature-controlled supply chain solutions, has opened a new cryogenic logistics facility in Louvres, France, near Paris Charles de Gaulle Airport. Operated through its subsidiary Cryoport Systems, this marks the third location in its Global Supply Chain Centre (GSCC) network. The facility currently supports logistics for biopharma clients working in areas such as cell and gene therapies, biologics, animal health and reproductive medicine. Cryoport plans to expand the site's capabilities to include biostorage, BioServices, QP drug management and Importer of Record (IOR) services. CEO Jerrell Shelton said the new site enhances Cryoport's ability to serve European and global markets as part of its broader strategy to provide integrated, end-to-end logistics for advanced therapy programs.

....

The **U.S. Defense Advanced Research Projects Agency** (DARPA) has selected **PsiQuantum** to advance to the final validation phase of its Utility-Scale Quantum Computing program, marking a major step toward practical, large-scale quantum systems. PsiQuantum's photonic-based approach—using light particles as qubits—promises faster processing and lower error rates than traditional superconducting systems. The validation phase, conducted at the Department of Energy's SLAC National Accelerator Laboratory, will test the scalability of PsiQuantum's cryogenic module, while the company expands its manufacturing base in Milpitas, California, to enable modular, fault-tolerant quantum architectures. DARPA's assessment will examine system reliability, error correction and energy efficiency, supported by new quantum data centers in Chicago and Brisbane to foster research collaboration. With global competition intensifying—particularly from China, the U.K. and the EU—the program underscores the U.S. push to secure leadership in quantum technology for defense, energy, healthcare and finance. If successful, PsiQuantum's photonic platform could position the U.S. at the forefront of a quantum revolution, transforming industries and strengthening national security.

Meetings & Events

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/

Cryogenic Engineering and Safety Annual
5-Day Course
August 3-7, 2026
Golden, CO
https://cryocourses.com/

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

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