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An artist's rendering of the COSI satellite. Credit: Northrop Grumman Systems Corporation

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From the Executive Director

As we look toward the second half of the year, I'm excited to share several updates from the Cryogenic Society of America (CSA) and give you a glimpse inside this packed issue of Cold Facts.

First, please join us for CSA's virtual short course, "**Cool Fuel — The Science and Engineering of Cryogenic Hydrogen**," on Tuesday, July 22, from 10 a.m. to 2 p.m. Central time. Jacob Leachman and Konstantin Matveev, professors at Washington State University, will serve as our expert instructors. Participants will gain a foundational understanding of cryogenic terminology, learn practical design rules for cryogenic systems and develop computer models. Register now at **2csa.org/cool-fuel**. Can't attend live but want the recording? Register anyway; the link will be sent to all registrants.

I also invite you to explore our new "**Cold Facts Digital**" site at **cold-facts.org**. The clean, mobile-friendly layout makes it easy to read and share select articles from each issue. Industry news from our digital newsletter, the CryoChronicle, is posted there as well. In the coming months we'll roll out digital advertising opportunities to help companies reach our growing global audience of cryogenics professionals. Stay tuned.

This month's *Cold Facts* showcases the breadth and impact of cryogenic technology. Stories cover aerospace, telescopes and satellites, astronomy and astrophysics, refrigeration and liquefaction, LNG, air-separation technology and commercial gases.

Have an idea for a future issue? Let me know at **megan@cryogenicsociety.org**.

Thank you for being part of our community. Your engagement helps us advance knowledge, collaboration and excellence across the cryogenic sciences.

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

Visit out our new, mobile-friendly Cold Facts digital site at https://cold-facts.org. *Credit: CSA*


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Cryogenic Breakthroughs in Aviation and Maritime Transport

by Air Liquide Communications Team

Turbotech, Safran and Air Liquide have successfully ground tested the world's first liquid hydrogen-fueled turbine engine for light aviation, marking a key milestone in the BeautHyFuel project aimed at developing zero-emission aircraft propulsion. Credit: Air Liquide

Aviation and maritime transport are entering a new phase in the global decarbonization effort, and at the heart of this shift is cryogenics. Two recent developments from Air Liquide – one in liquid hydrogen propulsion and the other in cryogenic gas reliquefaction – show how cold technologies are heating up in the race toward sustainability.

In collaboration with Turbotech and Safran, Air Liquide has validated the feasibility of a liquid hydrogen-fueled gas turbine for light aviation. This major step forward was carried out under the BeautHyFuel project, launched in 2022 to explore hydrogen propulsion for small aircraft. By September 2024, the group had successfully completed ground testing of a turbine engine powered entirely by liquid hydrogen. The tests were conducted at Air Liquide's Grenoble Technologies Campus using an integrated system that replicated all the major functions of an actual aircraft propulsion chain.

What makes this project unique is the shift from gaseous to liquid hydrogen – a cryogenic milestone. Liquid hydrogen's high energy density makes it particularly attractive for aviation, but it comes with steep challenges: maintaining fuel at -250°C, integrating safe and efficient onboard storage, and adapting turbines to handle cryogenic fuel flows. Air Liquide's cryogenic storage and delivery system played a central role, supplying the engine with stable, precisely metered liquid hydrogen throughout the test cycles.

Hydrogen, particularly in its liquid state, offers compelling benefits for aviation: zero CO_2 emissions at the point of use and significantly higher energy per unit mass compared to kerosene. Yet the switch to liquid hydrogen isn't without trade-offs. Combustion can still generate nitrogen oxides (NOx), and the extreme cold required for storage and delivery demands robust cryogenic infrastructure – both in the air and on the ground.

That's where Air Liquide's broader cryogenic capabilities come into view. In a separate but thematically aligned development, the company announced a record order intake in 2024 for its proprietary Turbo-Brayton cryogenic system – nearly 70 units for maritime applications. Originally developed for the space industry, the Turbo-Brayton system has since been adapted to help LNG carriers and bunker vessels manage boiloff gas, turning what was once a loss or hazard into a usable asset.

The Turbo-Brayton solution offers continuous reliquefaction of evaporated LNG and can operate without preventive maintenance, making it an appealing "plug and play" option for shipbuilders and operators. It consumes less power than comparable systems and has a compact footprint, important for vessels where space is at a premium. In essence, the Turbo-Brayton system allows cryogenic storage to function not just as a passive container but as an active energy management system.

Taken together, these two developments underscore a broader shift: cryogenic systems are no longer niche technologies, they are becoming foundational tools in the pursuit of decarbonized transport. Whether

Air Liquide set a new record in 2024 with nearly 70 orders for its Turbo-Brayton cryogenic solution, widely adopted by the maritime industry to efficiently reliquefy boiloff gas on LNG carriers and support sustainable marine transport. Credit: Air Liquide

enabling liquid hydrogen aviation or managing LNG on the seas, Air Liquide's recent projects illustrate how cryogenics is moving out of the lab and into commercial-scale deployment.

These advances are not only technologically significant; they are also timely. As regulations tighten and net-zero targets loom, industries are increasingly looking for proven solutions that can be scaled quickly. The successful ground test of a liquid hydrogen-fueled turbine – and the commercial traction of the Turbo-Brayton system – show that cryogenics is up to the task.

What comes next is equally important. Continued investment in green hydrogen production, robust infrastructure for cryogenic distribution and further integration of cryogenic systems into transportation platforms will determine how quickly these technologies can make a measurable impact. But for now, these milestones offer a compelling look at how cryogenics is fueling the future – quietly, and at -250°C. **www.airliquide.com**

Example of a large-scale cryogenic cooling infrastructure which will achieve the required 4 Kelvin range (-269°C, -452°F), similar to the Brisbane plant. Credit: Linde

Powering the Future: Linde Engineering and PsiQuantum Build One of the World's Largest Cryogenic Plants

by John van der Velden, Linde Engineering Media Relations

In a milestone collaboration that underscores the accelerating momentum behind quantum computing, Linde Engineering has signed on to deliver one of the world's largest cryogenic cooling plants for PsiQuantum's first utility - scale quantum computer. The facility, to be constructed in Brisbane, Queensland, marks a turning point not only in computing technology but also in how infrastructure will support the next frontier of scientific advancement.

The cryogenic plant will provide ultra-low temperatures—down to 4 Kelvin, or -269°C – needed to operate PsiQuantum's revolutionary new Omega photonic chipsets. These chipsets are housed in specialized cryogenic cabinets and will eventually be networked together using conventional optical fiber, forming a massive quantum computer designed to tackle problems beyond the reach of classical systems.

PsiQuantum, a California-based company co-founded by quantum physicist Jeremy O'Brien, has long staked its vision on photonic quantum computing. Unlike matter-based qubits that demand even colder environments and are notoriously difficult to scale, PsiQuantum's photonic qubits operate at relatively warmer temperatures, allowing for more scalable infrastructure. "Photons don't feel heat the way matter-based qubits do," O'Brien explains. "Our systems can run 100 times warmer – and we appreciate collaborating with a world-class firm like Linde Engineering to deliver industrial-scale systems with proven technology."

The engineering feat is significant. Cooling a quantum computer at scale is a complex challenge that only a few companies globally are equipped to address. Linde Engineering brings a track record of over 500 cryogenic plant installations worldwide, supporting industries ranging from semiconductors to scientific research facilities like particle accelerators and fusion reactors. “We are proud to help PsiQuantum realize their ambitious vision,” said John van der Velden, Senior Vice President of Global Sales & Technology at Linde Engineering. “This collaboration demonstrates how combined expertise can drive advancements in technology and innovation.”

Quantum computers process information using qubits, which can exist in multiple states simultaneously – a property known as superposition. This allows them to solve complex problems such as simulating molecules, optimizing logistics networks or cracking encryption codes at a pace unimaginable for classical machines. But these quantum states are fragile, easily disrupted by heat and electromagnetic interference. That’s where cryogenics comes in: by maintaining a constant, ultracold environment, the system ensures qubits can perform reliably.

Brisbane’s selection as the home for this landmark project also reflects Australia’s rising prominence in the global quantum technology landscape. With a strong academic base, emerging talent pipeline and growing commercial interest, the region is becoming a hub for quantum innovation. The PsiQuantum-Linde partnership is expected to catalyze local supply chains and create new research and development opportunities within Australia’s technology sector.

Beyond the technical achievement, this initiative represents a broader movement: quantum computing is shifting from a speculative technology to an engineered reality. As photonic qubits and cryogenic infrastructure mature, we edge closer to deploying quantum systems capable of transforming fields such as healthcare, clean energy, advanced materials and secure communications.

PsiQuantum’s approach, rooted in established semiconductor manufacturing and scalable photonic systems, suggests that industrial-grade quantum computing could arrive sooner than many predicted. With Linde’s engineering muscle providing the thermal backbone, the Omega chip’s cold environment is ready to support the heat of global innovation. **www.linde-engineering.com**, **www.psiquantum.com**

A Linde expert checking a coldbox, similar in size to the application in Brisbane. Credit: Linde

Meyer Tool Builds the Impossible, Empowering Illinois Manufacturing

by Christian Cunningham, Meyer Tool & Manufacturing Inc.

Meyer Tool & Manufacturing, Inc., a long-standing leader in cryogenic, pressure and vacuum technologies, has reached a major milestone in its growth journey. The Illinois Department of Commerce and Economic Opportunity (DCEO) recently approved the company for participation in the Manufacturing Illinois Chips for Real Opportunity (MICRO) program. This recognition not only highlights Meyer Tool's deep roots in Illinois manufacturing but also affirms its growing role in the global advanced technology supply chain.

Located in Oak Lawn, Ill., Meyer Tool has carved out a specialized niche in high precision fabrication for industries and institutions that require mission-critical performance. From national laboratories to semiconductor innovators, Meyer Tool's customers rely on the company for custom-engineered solutions. Now, with its acceptance into the MICRO program, Meyer Tool is positioned to expand its capabilities, grow its workforce and increase its impact.

As part of the MICRO agreement, Meyer Tool has committed to retaining and increasing full-time employment and investing a minimum of $2.5 million in capital improvements. These investments will support facility upgrades, state-of-the-art manufacturing equipment and employee development – all crucial for driving innovation and meeting customer demands. "Our investment, made possible with support from DCEO, will help us grow our workforce, strengthen our operations and support the local economy," said Eileen Cunningham, president of Meyer Tool. "After 55 years supporting R&D efforts in Illinois and around the world, our legacy of building the impossible is stronger than ever."

That legacy began in 1969 when Meyer Tool was founded to support the growing research infrastructure surrounding Illinois' national laboratories. Over the decades, Meyer Tool has earned a reputation for excellence in custom engineering, precision machining,

Welder at Meyer Tool & Manufacturing, Inc. assembling then welding custom cryogenic piping inside a large cold box in their Oak Lawn, Ill. facility. The company supports advanced research with in-house welding, machining and testing capabilities. Credit: Meyer Tool & Manufacturing, Inc.

welding and testing. Its work includes critical components for particle accelerators, high vacuum systems and cryogenic technologies. The company's collaborative approach, robust quality systems and technical expertise have made it a trusted partner for both scientific and industrial clients.

The MICRO program is part of Illinois' broader effort to align its manufacturing capabilities with national priorities, including domestic semiconductor production and clean energy innovation. DCEO Director Kristin Richards emphasized the importance of these efforts: "Manufacturing is in our state's DNA, and at DCEO, we're committed to investing in Illinois' world-class workforce. This MICRO agreement will drive economic growth and create opportunities for hard-working Illinoisans."

The MICRO Act was designed to encourage strategic investments that generate lasting economic benefits, and Meyer Tool's mission aligns closely with those goals. With expertise at the intersection of cryogenics, ultrahigh vacuum and pressure technologies, the company plays a crucial role in supporting advanced sectors such as quantum computing, fusion energy and semiconductor fabrication. As demand for highly specialized cryogenic and vacuum systems rises globally, Meyer Tool continues to innovate and evolve.

"We've always seen ourselves as more than a fabrication shop," said the author of this article, director of business development at Meyer Tool. "We're problem-solvers and partners to our clients – whether developing a custom cryostat for a national lab or delivering vacuum vessels to a quantum computing startup. The MICRO program empowers us to do even more of what we do best: enable scientific and technological breakthroughs with precision and commitment."

One of the distinguishing aspects of Meyer Tool's success is its dedication to end-to-end excellence. The company handles complex fabrication challenges under one roof – integrating engineering design review, precision machining to ASME- and AWS-certified welding, helium leak detection and final assembly. This comprehensive capability allows Meyer Tool to uphold high standards,

▶ continues on page 14

MTM team members represent the next generation of Illinois' advanced manufacturing workforce. The MICRO agreement supports job creation, training and long-term economic impact in the community. Credit: Meyer Tool & Manufacturing, Inc.

shorten lead times and adapt quickly to evolving project requirements.

In recent years, Meyer Tool has diversified its customer base while remaining focused on its core mission. Its growth reflects increasing investment in both research infrastructure and next-generation commercial technologies, especially in fields that rely on cryogenic and vacuum innovations.

Beyond its technical strengths, Meyer Tool's culture is rooted in people. Many employees have spent decades at the company – a reflection of its supportive workplace, training opportunities and strong sense of shared purpose. The jobs supported through the MICRO agreement demonstrate Meyer Tool's ongoing commitment to inclusive growth and its belief in empowering the communities it serves.

Looking ahead, Meyer Tool is poised to help shape the next generation of scientific discovery and technological advancement. Through its collaboration with DCEO and participation in the MICRO program, the company is reinforcing Illinois' status as a hub for precision manufacturing – and showing how small businesses can make a global impact in building the future. **www.mtm-inc.com**

A high precision accelerator cryomodule produced by Meyer Tool for use in a particle accelerator at Brookhaven National Lab. MTM's fabrication expertise is trusted by national labs and quantum technology firms worldwide. Credit: Meyer Tool & Manufacturing, Inc.

Cryospain's Flat-Bottom Tank Project in Morocco is a Step Forward for LNG

by Cryospain Communications Team

These images show the various stages of the assembly of the flat bottom tank LNG. Credit: Cryospain

As the global energy sector shifts toward more sustainable sources, liquefied natural gas (LNG) has emerged as a key transitional fuel. Its cleaner-burning profile, abundant supply and versatility position it as a bridge between fossil fuels and renewables. In this evolving landscape, Cryospain, a leader in cryogenic engineering, continues to support LNG growth with customized, high-performance storage solutions.

A recent project in northwestern Morocco highlights this role. Cryospain has designed and is now assembling a 6,200 m³ flat-bottomed LNG tank as part of a larger facility dedicated to LNG processing, treatment, liquefaction, storage and export. The site is expected to supply 100 million standard cubic meters of LNG over the next decade, offering a stable and cleaner energy source for both domestic use and international export via the Maghreb-Europe Gas Pipeline (GME).

Cryospain's scope covers the full lifecycle of the tank, including design, manufacturing, transport and on-site assembly. At the time of writing, the team is in the assembly phase at the gas extraction site—a key step in integrating the storage unit into Morocco's natural gas infrastructure. More than just a holding structure, the tank functions as a vital link between raw gas extraction and downstream distribution, both locally and abroad.

Storing LNG requires more than volume; it demands precision engineering and a deep understanding of cryogenic behavior. LNG, composed primarily of methane, must be kept below -160°C. While transparent and non-corrosive, it presents complex technical requirements involving pressure control, thermal stability and boiloff management. Cryospain addressed these challenges with a tank designed to meet international standards for structural integrity, seismic resilience and cryogenic safety. Built to withstand both internal pressure and potential external forces, the tank includes compliant walkways, ladders and platforms for safe inspection and maintenance. Advanced materials and thermal insulation ensure reliable, long-term performance under extreme conditions.

This project fits squarely within Morocco's broader energy goals, which include diversifying the national energy mix and expanding infrastructure for both energy security and international trade. By connecting the facility to a European pipeline network, the tank project strengthens Morocco's role as a regional hub for LNG processing and export. It also positions LNG not only as a cleaner alternative at home but as a driver of economic development and cross-border energy collaboration.

Cryospain's work in Morocco adds to its growing global portfolio. Similar achievements include a flat-bottom LNG tank in Bolivia and a 2,000-meter cryogenic pipeline for a bunkering project in Sweden. The company has also contributed to LNG-powered rail transport. With headquarters in Pinto, Madrid, and an international footprint, Cryospain brings engineering expertise, innovation and a strong commitment to sustainability to every project it undertakes. **www.cryospain.com**

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by Dr. Iqra Azam Ph.D. and Dr. James Benson Ph.D., University of Saskatchewan

The Challenges of Cryobiology: Ice Is (Usually) the Enemy

In our last column, we explored cryobiology's remarkable promise: the ability to "pause" life using extreme cold to preserve cells, tissues and entire organisms. This technology has opened the door to advances in medicine, agriculture and biodiversity conservation. But realizing this promise is far from simple. Putting biological time on hold comes with a set of formidable challenges. In this column, we focus on the first and main challenge encountered during cryopreservation: ice.

The oldest foe in cryobiology is ice. When biological material freezes, the water inside and outside of cells forms ice crystals, which can puncture cell membranes and disrupt delicate cellular structures, causing irreversible damage. In general, it is the ice that forms inside the cells that is considered the most damaging. As one might expect, ice inside the cell can cause severe disruption of intracellular structures like the cytoskeleton and nucleus, and thus the primary objective in cryopreservation has been to avoid intracellular ice. However, ice also causes injury to cells and tissues in a less visible way. When a solution starts to freeze and its water turns to ice, the remaining solution becomes more concentrated, and so, even in the absence of ice physically disrupting a cell, the high concentrations caused by ice formation can cause biological samples to die.

Here is an example: nearly all the cells in your body are happy in a solution that is roughly 0.9% salt. This solution will start to freeze at around -0.5°C (31°F). As the solution cools more, the remaining liquid will become more concentrated. At -5°C (23°F), the solution will be around 8% salt; at -17°C (0°F), the solution will be around 20% salt. This concentration is too high for cells to survive for long. In fact, the relationship between concentration in the

Ice—beautiful but deadly! Credit: I. Azam

presence of ice and temperature is described by the phase diagram on the next page, which is arguably the most important figure in cryobiology. With it, we can understand the equilibrium state of cells and the extracellular concentration as a function of temperature.

The double damage mechanism caused by ice is known as "the two-factor hypothesis," named by influential cryobiologist Peter Mazur, and it has significant ramifications on how to find the best cooling and warming rates for cryopreservation. The two-factor hypothesis states that cells cooled in the presence of ice are injured either by intracellular ice formation or by too-long exposure to high concentrations of solutes.

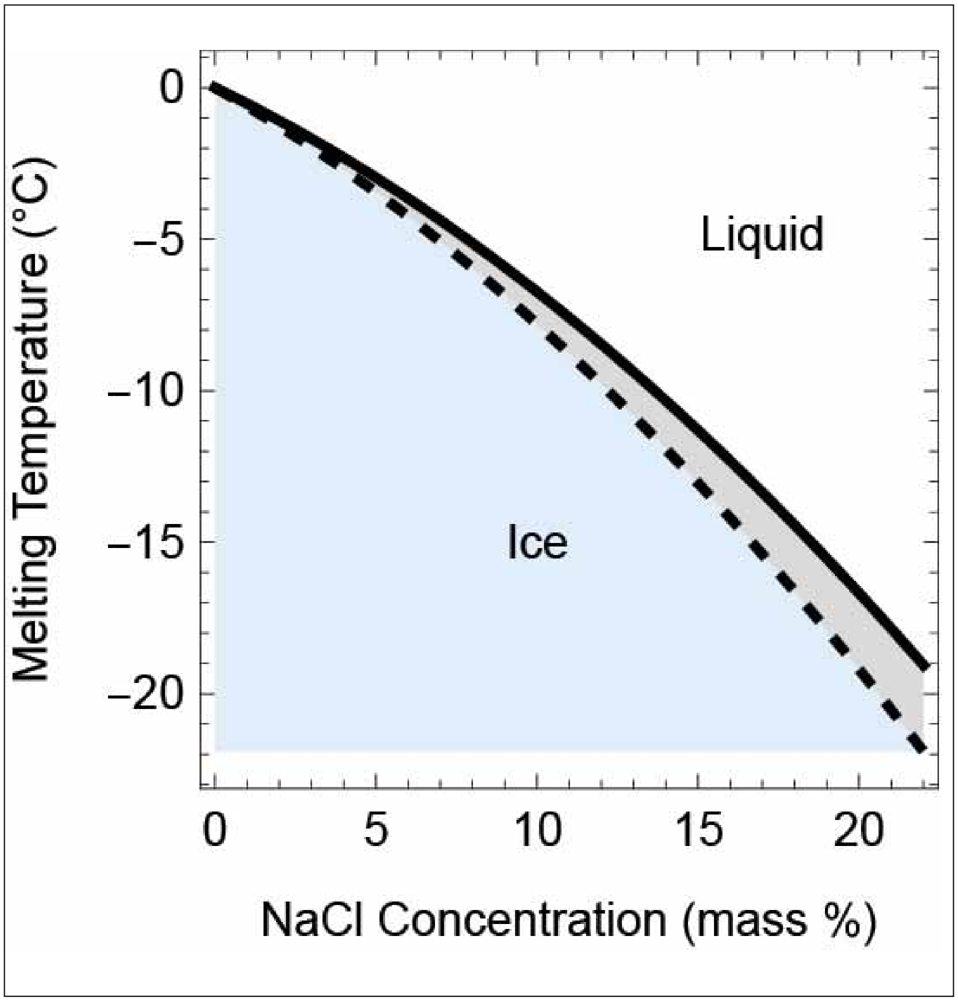
Let's dive a little deeper here. In our above example, we noted that as ice forms outside of cells, the removal of water in the extracellular solution (as ice) concentrates the remaining medium, following the solid curve on the above phase diagram. Cells allow water movement across their membranes to maintain equilibrium with their surroundings via osmosis. Thus, if the sample is cooled slowly enough, cells will lose water in the same ratio that the extracellular environment "loses" the water that becomes ice. This water loss is limited in both cases. In the case of cells, the osmosis may not keep up with the concentration increase. If cells cannot lose water quickly enough, they become less concentrated than their surroundings, and in this case, they are increasingly likely to have intracellular ice form. In the case of water moving to ice, if the system is cooled extremely quickly, the unfrozen water cannot diffuse to existing ice crystals and instead becomes a glass. This is known as vitrification. Pure water vitrifies when samples are cooled at a million degrees per minute. We will discuss this feature in depth in a future column.

To make this concrete, consider the two curves in the phase diagram. The solid curve indicates the temperature and concentration where ice and liquid are in equilibrium. This is known as the liquidus curve, and if cells are cooled slowly enough, they will remain on this curve in equilibrium with their surrounding medium, and the intra-cellular concentration in the cells will mimic the extracellular concentration, and the cells will be less likely to form intracellular ice. If samples are cooled faster than the cells can lose water, the intracellular concentration vs temperature curve will look like the dashed curve. The distance between the dashed and solid curves at any temperature is called supercooling. The larger the supercooling, the more likely it is that ice will form.

Finally, we may return to the two-factor hypothesis of why ice is so challenging. If we want to avoid ice at all costs, we can cool cells extremely slowly, but this exposes cells to high concentrations for long durations. Thus, we must cool a bit faster, but not so fast that we cause there to be too much supercooling in the intracellular space. This relationship between cell water loss and cooling rate is fundamental to the success of cryopreservation. For example, if we cool big embryos quickly, they cannot lose water fast enough, and intracellular ice forms and the embryos die. If we cool sperm too slowly, they are stuck with high concentrations for much longer than needed and the sperm die. In fact, embryos are optimally cooled at less than 1°C/min, and sperm are optimally cooled at more than 10°C/min.

So far, we have tried to convince you that the core challenge of cryopreservation lies in freezing living systems without these ice-caused injuries. Nature offers a possible solution: avoid it altogether. Many fish, insects, and plants produce chemicals known as antifreeze proteins. These proteins bind to growing ice crystals in solution and prevent unfrozen water from reaching the ice until the temperature drops much lower. This way, these organisms can survive mild freezing conditions without dealing with damaging concentration changes or ice formation.

These antifreeze proteins are a great solution for maintaining activity when conditions might get slightly below freezing. You might think, then, that freezing point depression is the way to go, and it is in natural environments where, even in Saskatchewan, Canada, where we live, it doesn't get below -40°C (-40°F).



A phase diagram showing water's state as a function of temperature and concentration. The solid "liquidus curve" marks equilibrium conditions. Slow cooling keeps cells on this curve; faster cooling leads to lower intracellular concentrations (dashed line), increasing the risk of intracellular ice. The grey area shows supercooled states—liquid water that could freeze if nucleation occurs. Credit: Dr. Iqra Azam Ph.D./Dr. James Benson Ph.D., University of Saskatchewan

In the case of cryopreservation, where we must store samples for months or years at -80°C or in liquid nitrogen, there is no way to "freezing point depression" your way out of ice formation. And, in the case of the supercooling offered by antifreeze proteins, there is a significant danger: once ice does form, the solution is in such a disequilibrium state (i.e., far below the liquidus curve on the phase diagram) that ice races through the sample, wreaking havoc and rapidly warming and then rapidly cooling the sample because of something called the latent heat of freezing—the heat release when ice forms. In short, if you placed an antifreeze protein containing fish in your freezer, it would freeze solid (and be dead).

You might think then that ice is always bad, but other organisms embrace the ice: certain frogs, fish, and insects survive freezing conditions by producing different antifreeze-like solutes (yes, like your car) that control ice formation and limit it to harmless regions. If you go into the woods in Ontario in the winter, you might find a frozen frog. In fact, this frog is only mostly frozen, or, to quote The Princess Bride, "mostly dead"—while its extremities are filled with ice, its vital organs are protected from the damaging ice. Should you bring that frog indoors, melting would occur, and the frog would slowly return to its typical frog duties. Should you put this frog in a -20°C (0°F) freezer, the protection would not be sufficient, and the frog would be "entirely dead."

Recent research has even shown that cells may tolerate a little intracellular ice formed during cooling. The theory is that small ice crystals are not dangerous, but when samples warm or are held at "high subzero temperatures," these small crystals combine in a process called annealing, and these large crystals injure cells. There are now exciting lines of research in nature-inspired molecules called ice recrystallization inhibitors, which reduce the extent of annealing and protect cells during warming.

Hopefully, the message is clear: ice is the biggest challenge of cryobiology, and managing it relies on a careful understanding of the balance between the risk of damaging intracellular ice and the injury due to extremely high concentrations of solutes.

Nature provides a few tools like antifreeze proteins and small-molecule antifreeze solutes, and in the next column we will explore how and why these tools are used in nearly all cryopreservation protocols.

Cool Fuel

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

The Resiliency of our Liquid Hydrogen Economy

Back in 2005 as an undergraduate preparing to commit my career to a research topic, my soon-to-be advisor gave me an ultimatum to either develop new property models for natural gas or hydrogen. Although I doubt I fully understood my reasoning at the time, I chose hydrogen because of the plethora of ways it could be produced and used, in a universe that is nearly entirely hydrogen. A couple of graduate courses helped me to understand that the number of ways something can simultaneously exist is known as the thermodynamic property called entropy, which is closely related to the resiliency of systems. As our political winds in the US change, it's time to educate the newcomers while reminding ourselves why liquid hydrogen is here to stay.

Hydrogen is a rare topic that has spanned political and ideological divides through the decades. The US developed industrial-scale hydrogen liquefaction and transport technologies during the race for wet-fusion weapons at the National Bureau of Standards (now National Institute of Standards and Technology) in the 1950s. Although lithium quickly replaced the need for liquid cryogens in weapons, hydrogen has superior rocket fuel properties, and the space race built out a liquid hydrogen economy in North America that enabled us to be first on the Moon. However, the liquid hydrogen industry had little incentive to improve with the US government as the primary user. Hydrogen's first big push outside space launch was in 2003 with Republican President George W. Bush's $1.2 billion hydrogen initiative.[1] This initiative formed the Hydrogen Fuel Technology Office (HFTO) within the Department of Energy to develop zero-emission vehicles. When Plug Power energized the first fulfillment center with liquid hydrogen in 2010, the shipping logistics industry quickly became the largest user of liquid hydrogen, spurring the industry into rapid, commerce-based growth. Few things scream resiliency louder than the combined forces of Amazon, Walmart, Home Depot and Kroger groceries. This success, combined with zero-carbon emission attributes, led Democratic President Joe Biden in 2023 to release a National Hydrogen Strategy and $9 Billion Hydrogen Hub Initiative to align federal agencies behind hydrogen and expand production infrastructure to new regions of the U.S.[2] Whether for national defense or clean shipping logistics, hydrogen still has supporters on both sides of the political aisle and near unanimous support in the Pacific Northwest, where we depleted our fossil-hydrogen reserves in the 1960s. But will the bipartisanship continue?

My first credible indication of the future came last month at the annual Interagency Power Group (IAPG) meeting, where the R&D portfolio managers across the federal government come together to strategize. Hydrogen, with an emphasis on liquid, was one of the four key power thrust topics. The reasons are many. Even when we succeed with nuclear batteries and fusion energy machines, the power-to-weight ratio and resulting portability of these energy sources are not amenable to vehicular use. While lithium-ion batteries continue to improve in charging speed and durability, they fundamentally cannot have better power-to-weight performance than liquid hydrogen, which is key for weight-intensive applications like shipping logistics and aerospace. If the metrics are so clear, what is holding back liquid hydrogen from powering everything from trucks to aircraft while becoming as ubiquitous and resilient as other fuels?

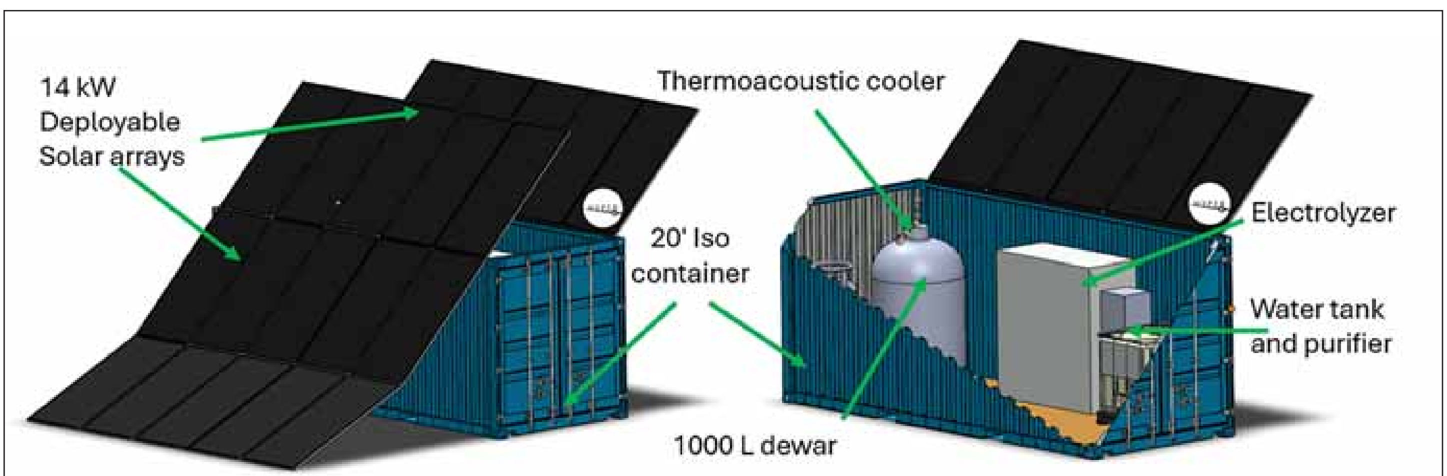


Figure 1: Conceptual rendering for a solar-power driven thermoacoustic cooler for hydrogen liquefaction and zero-boiloff storage. *Credit: J. Leachman*

Liquid hydrogen succeeded in fulfillment centers for two reasons: 1) this large-scale use can afford the steep up-front capital cost, and 2) it guarantees a fleet immediately after installation. Combined, these two reasons reduce the primary problem of liquid hydrogen: boiloff losses. Few other industrial sectors can match fulfillment centers in this way. This brings us to a list of near-term liquid hydrogen technology development needs that could unlock many more industrial sectors and increase resiliency:

1. Liquid hydrogen testing and training facilities – Many companies want to evaluate their technologies developed for other cryogens with liquid hydrogen. Not only do they not know what is needed to bridge the gap, but they also don't have access to facilities that can perform the tests.

2. High-resiliency transfer components – Liquid hydrogen transfer components (like pumps and valves) that never wear out, never need vacuum re-purged and are readily printable from low-mass materials like aluminum, will reduce the primary costs of liquid hydrogen at public refueling stations.

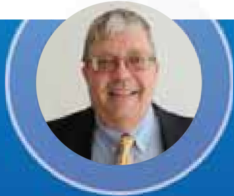
3. High-efficiency cryocoolers – The moment someone realizes a cryocooler with no moving parts, no rare-earth regenerator materials and Second Law efficiencies approaching base-load liquefiers, every liquid hydrogen tank in the country can become a liquefier with no boiloff losses, operable from solar power (see Figure 1 for a conceptual rendering).

This last point, efficiency, is a hot topic these days. Many will immediately refer to the limiting Second Law efficiency of hydrogen systems as prohibiting liquid hydrogen from having competitive efficiencies for some applications. There are also many applications not being electrified at all because hydrogen is the only viable approach, and the infrastructure is lacking. In this, nature teaches us an important point – resiliency beats efficiency because the efficiency of doing nothing, when something must be done, is zero, every time. Let's get the federal hydrogen R&D systems moving again, as the rest of the world isn't waiting.

References:

[1] https://georgewbush-whitehouse.archives.gov/infocus/technology/economic_policy200404/chap2.html

[2] https://bidenwhitehouse.archives.gov/briefing-room/statements-releases/2023/10/13/biden-harris-administration-announces-regional-clean-hydrogen-hubs-to-drive-clean-manufacturing-and-jobs



Cryo Bios

by Dr. John Weisend II, European Spallation Source ERIC, CSA Chairman, john.weisend@esss.se, with Anne DiPaola, *Cold Facts* Editor

T.S. Datta

Professor T.S. Datta began working in cryogenics in the early 1980s after noticing the newly established Cryogenic Engineering Centre near the physics department at the Indian Institute of Technology (IIT) Kharagpur. While completing his Master of Science in nuclear physics, he became interested in the center's focus and explored its applications in air separation, superconductivity and space research. That led him to enroll in IIT's Master of Technology program in cryogenic engineering in 1982, beginning a professional focus that has continued ever since.

Over a career spanning more than 40 years, Datta has contributed to India's cryogenic research and infrastructure development. His early work included helium recovery and purification from monazite sand – an alternative to helium sourced from natural gas. With large monazite deposits in the coastal states of Odisha and Kerala, Datta's efforts provided a new technical approach using cryogenic condensation and high pressure adsorption to isolate high-purity helium.

Later, he joined the Inter-University Accelerator Centre (IUAC) in New Delhi, where he worked on India's superconducting linear accelerator project. His responsibilities included designing helium and nitrogen refrigeration systems, cryogen distribution lines, valve boxes and cryomodules. He prioritized local development and worked closely with Indian industry to design and manufacture custom components. These in-house cryogenic systems have been running reliably for more than two decades, reflecting both practical engineering and operational planning.

T.S. Datta receives the Life Time Achievement Award in 2022 from the chairman of ISRO. Credit: T.S. Datta

T.S. Datta pictured with Dr. Philipe. Lebrun during ICEC26. Credit: T.S. Datta

After completing the accelerator project, Datta focused on superconducting magnet design and development. His group produced a 6-tesla cryo-free solenoid magnet, a superferric quadrupole focusing magnet and a 1.5-tesla MRI magnet and cryostat – all developed domestically.

In his most recent academic role at IIT Kharagpur, Datta worked on high temperature superconducting (HTS) applications. These included superconducting fault current limiters, superconducting magnetic energy storage systems and extremity MRI devices using HTS magnets. His work across cryogenic engineering and applied superconductivity has contributed to both technical understanding and real-world implementation.

Among his key accomplishments was collecting 60 normal cubic meters of helium gas at 99.999 percent purity from monazite sand using cryogenic methods developed with national collaborators. Another significant project was the successful online cavity cooling and liquid collection in cryomodules using indigenously developed cryolines and valve boxes. His team also incorporated techniques such as thermosiphon-based shield cooling and inverse radiation cooling, which later became research topics themselves.

Datta has tracked major developments in the field over the last two decades. He notes a shift from superconducting magnets toward superconducting RF cavities operating at 2 kelvin in particle accelerator systems. He also highlights the improvements in cryocooler technology, especially for zero-loss MRI systems, which have helped make these technologies more efficient and accessible.

He sees the future of cryogenics in several high-demand areas, including particle accelerators, fusion reactors such as tokamaks and hydrogen energy systems. In particular, he expects increased interest in liquid hydrogen as a clean fuel, with ongoing comparison to high pressure gas systems. He also believes HTS could play a larger role in power applications, depending on cost reduction and manufacturing advances.

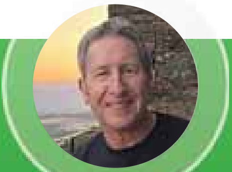
Datta continues to emphasize the need for strong educational foundations in cryogenics. He considers India's academic programs in the field to be robust but points out a gap between education and industry growth. He notes that countries such as China have invested in building cryogenic industries to match their technical education systems. For India to make similar progress, he argues that greater focus should be placed on developing cryogenic products and supporting local industries.

T.S. Datta with colleagues at the 11th Asian Conference on Applied Superconductivity and Cryogenics to promote the industry in Asia. Credit: T.S. Datta

In addition to his technical and academic work, Datta has been active in professional societies and conference planning. He served as secretary and later president of the Indian Cryogenic Council, working to strengthen the organization between 2016 and 2020. He remains engaged with international groups such as the Cryogenic Society of America, the Cryogenics and Superconductivity Society of Japan, the European Cryogenic Society and the British Cryogenic Council.

He currently serves as chief editor of the *Indian Journal of Cryogenics* and has been an editorial board member of Elsevier's *Cryogenics* since 2013. Datta also regularly contributes to international conferences as a member of organizing, program and advisory committees. In 2016, he helped host ICEC26-ICMC2016 in New Delhi, furthering international connections in cryogenics and superconductivity.

After completing his term as visiting Professor from IIT Kharagpur in 2024, Datta remains active in promoting cryogenic technologies through education, technical workshops and international collaboration. His work has supported developments ranging from liquid helium recovery and MRI magnet design to accelerator systems and power-grid technologies. Cryogenics, for Datta, has been a consistent and evolving field of focus – one grounded in both scientific application and national development



Cryotreatment

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

The Science of Deep Cryogenic Treatment (DCT)

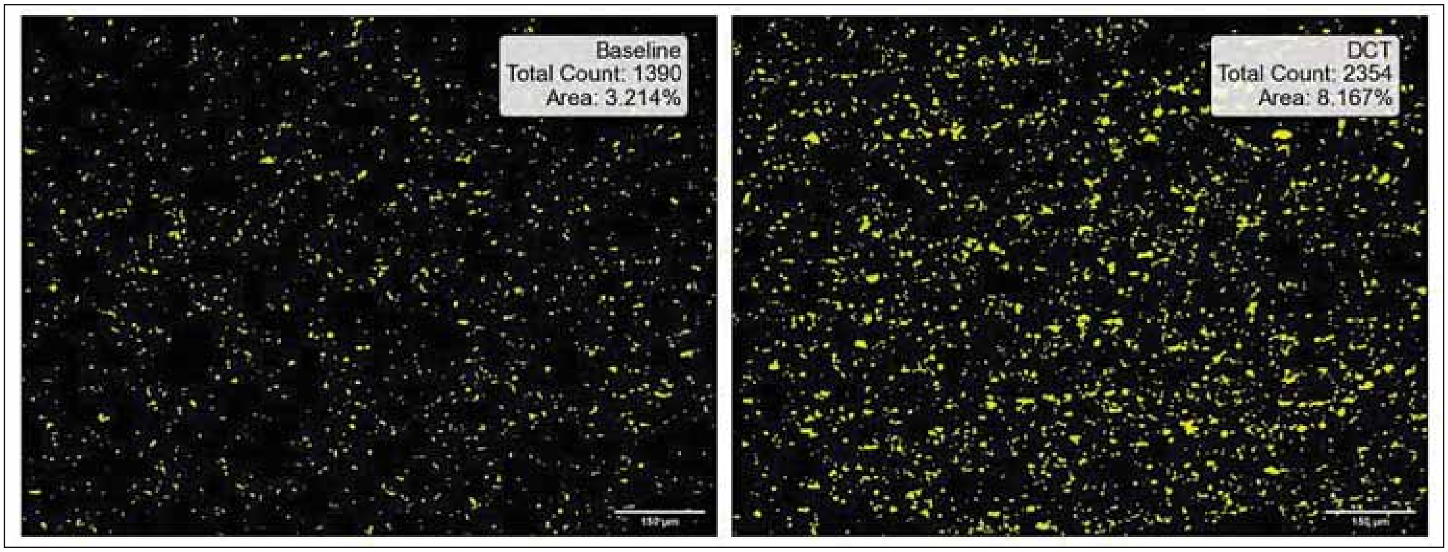


Figure 2: Carbide count in high-carbon steel. Credit: Jack Cahn

Let's dive in and explore the mechanisms and benefits of shallow cryogenic treatment (SCT: -60°F to -190°F) and deep cryogenic treatment (DCT: -190°F to -320°F). A quick refresher: generally, SCT occurs when the foundational heat treatment step of austenitizing is followed by quenching below ambient water or oil temperature, usually by quick exposure to dry ice or cold nitrogen gas vapor. DCT continues this process to even lower temperatures by using liquid nitrogen, a highly insulated chamber and a 24- to 36-hour PLC-controlled cycle. The boundary between SCT and DCT varies by metal and is dependent on material chemistry and prior heat treatment steps.

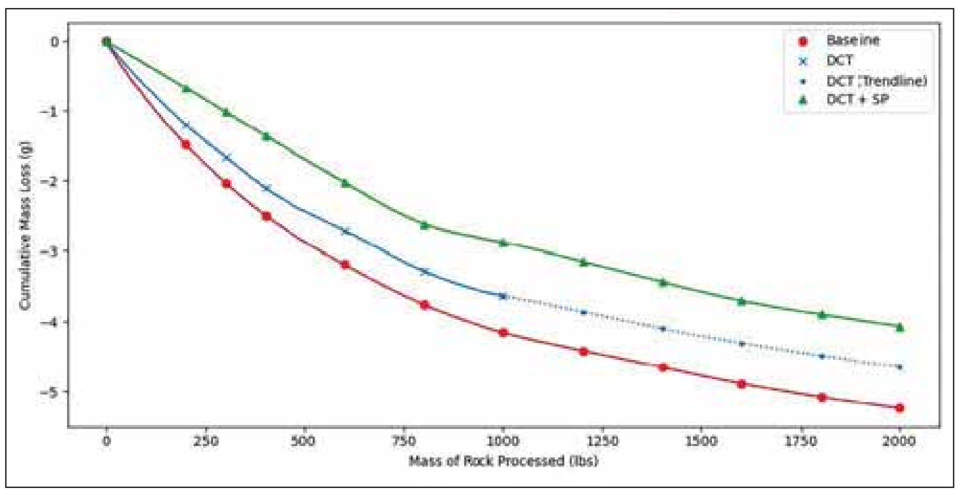


Figure 3: ASTM G81-97(a) wear test of Mn steel after crushing 2,000 lbs. Credit: Jack Cahn

SCT is used to achieve:

Partial transformation of retained austenite. In steels—especially tool and high-carbon steels—SCT converts retained austenite, a softer, unstable phase, into martensite, a harder and more stable phase. Retained austenite forms during quenching and can reduce hardness and dimensional stability. However, because the martensite start temperature (Ms) of 4340 high-carbon steel begins at approximately 314°F and the martensite finish (Mf) is generally below -212°F, SCT does not complete the transformation like DCT does.

Austenite decay begins immediately after newly formed, heat-treated steel begins to cool (the decomposition of austenite from FCC crystal phase into ferrite, bainite, martensite, etc.). Heat treaters often report greater benefit from SCT or DCT conducted immediately on-site, rather than DCT done later at remote facilities, where parts may have cooled for a greater period of time.

Reduced distortion and improvement of dimensional stability. SCT can reduce internal tensile stresses created during machining or heat treatment.

Improved (moderate) wear resistance. Due to the partial phase transformation (retained austenite to martensite) and microstructural refinement, SCT can increase surface hardness and improve wear resistance. SCT is more effective on single-phase rather than dual-phase materials, in less demanding applications when exposed to moderate wear or cyclic loading.

Cost-effectiveness. SCT is more cost-effective and accessible than DCT and predates computer-controlled systems. Unlike DCT, it maintains or slightly improves surface hardness—a key durability metric for most heat treaters.

DCT is used to achieve:

Precipitation of fine carbides. DCT promotes the formation of fine eta-carbides in steels (Figure 2), which strengthen the material via precipitation hardening by pinning dislocations at grain boundaries. Unlike heat treating that requires precise thermal control, these carbides remain stable at ambient temperatures, making DCT especially effective at reducing two- and three-body wear (Figure 3).

Reduction in residual stress. Deep cryogenic temperatures relieve tensile residual stresses caused by machining, fabrication, heat treatment and welding (Figure 4). DCT achieves greater micro-structural stress balance than SCT by reducing atomic-level vacancies. More pronounced than SCT, DCT also induces beneficial compressive stress, helping to heal fatigue cracks that nucleate at grain boundaries, reduce MnS and oxide inclusions and disrupt trans-granular or carbide-precipitated crack initiation or propagation (Figure 5).

Increase in ultimate tensile strength (UTS). DCT's extreme cold reduces grain size in most metals—a phenomenon known as the Hall-Petch effect, which states that as grain size decreases, a material's strength increases. This happens because grain boundaries resist the movement of dislocations

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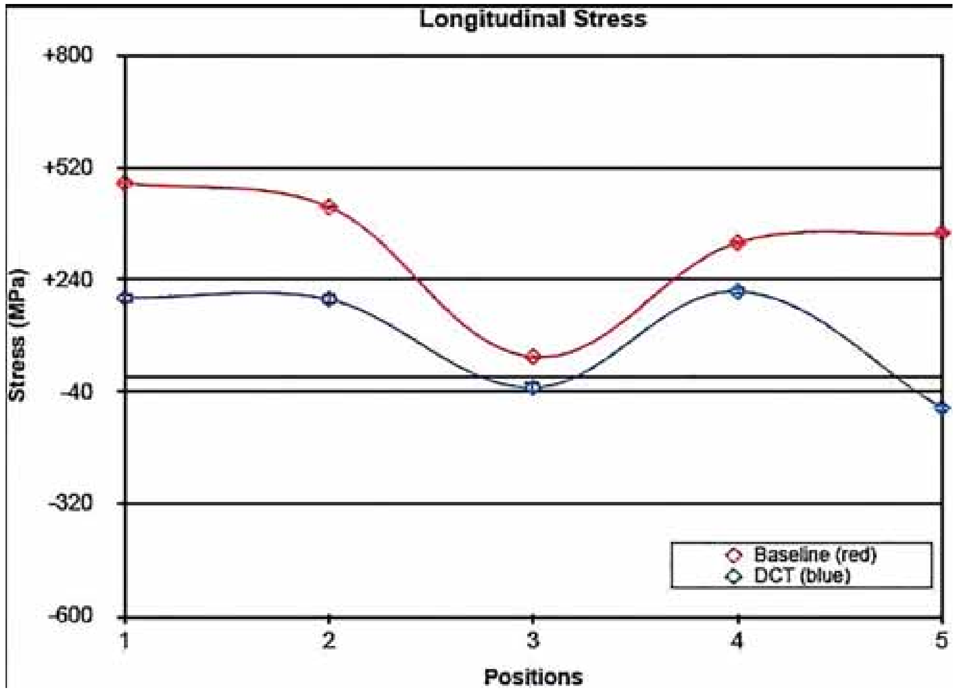

Figure 4: Residual stress test of 13% Mn using XRD. Credit: Jack Cahn

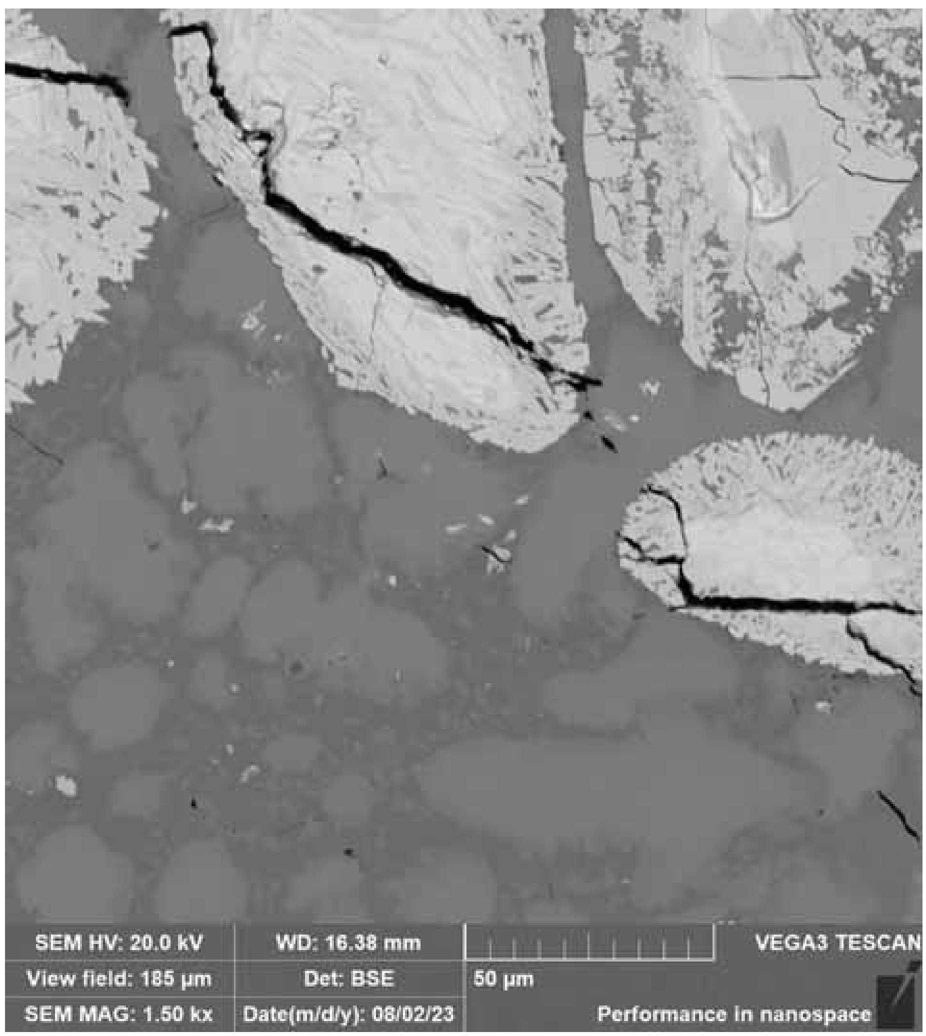

Figure 5: Crack healing between two carbides. Credit: University of Alberta

(the atomic-level defects in a crystal responsible for plastic deformation). More grain boundaries by volume means more resistance to dislocation movement, thus higher strength under stress (Figure 6). Admittedly, this may qualify as "TMI" for non-metallurgists!

Most of the benefits listed above are textbook responses to SCT and DCT on tool steels (440C, H13, S7, D2, M2), carbon steels (4140, 4340, 1018, 1020), and gear steels (52100, 8620, 440C, 1045)—and even titanium, which has a martensitic phase. These materials also demonstrate improved resistance to corrosion after DCT (Figure 7).

Other metals

What about nonferrous materials like aluminum or copper that don't have martensite phases? Most aluminum alloys show added stress relief and fatigue resistance after DCT but no added corrosion protection. Copper, while showing no improvement in wear life, UTS or corrosion, consistently exhibits a 1 to 1.5% increase in permanent conductivity post-DCT—even outside a superconductive state.

Large castings used in mining, energy and transportation—typically gray, ductile, high-chrome white iron or manganese steel—rely on work hardening, where impact or deformation boosts surface hardness and fatigue resistance. DCT is especially valuable to end users of hard rock mining items like shovel teeth and cone crushers because it induces compressive stress (crack healing) deep in the material and accelerates work hardening by forcing increased dislocation density from the reduction in austenite grain size and from the TRIP/TWIP effect.

52100 BEARING AND 4340 HIGH CARBON STEEL

SUMMARY RESULTS:	Yield Strength	Peak	% Stress.	Strain Elong	Reduction @ Break
	KSI	KSI	%	%	%
No Cryo 52100, Baseline	268	359	2.5	3.9	6
Cryo 52100, Cryo then Tempered	317	382	1.6	3.5	1
Cryo 52100, Tempered then Cryo	320	376	1.8	3.8	4.5
No Cryo 4340, Baseline	221	295	15.3	12.5	51.7
Cryo 4340, Cryo then Tempered	240	300	14.2	11.6	51.3
Cryo 4340, Tempered then Cryo	221	287	15.9	12.3	51.6

20% improvement to 52100 yield strength
10% improvement to 4340 yield strength

Figure 6: UTS of 4340 and 52100 steel in baseline and DCT states. Credit: Jack Cahn

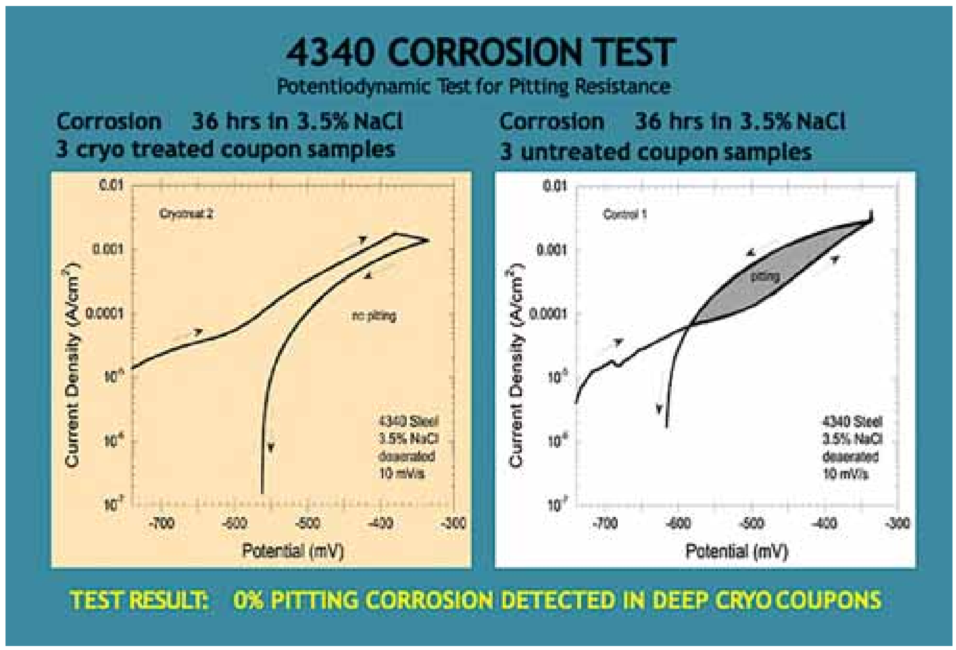

Figure 7: Corrosion in 4340 steel. Credit: Jack Cahn

Weldments benefit from DCT as the heat-affected zone (HAZ) surrounding the weld shrinks significantly following cryogenic treatment. The HAZ is subject to weld-induced residual stresses that often lead to premature cracking and failure. DCT has proven effective across an array of welded items from stainless steel and refractory alloys to additive manufactured items. Because strain at the bond interface is significantly reduced—by up to 70%—additive manufacturing could achieve breakthrough improvements in weight, geometry and tensile strength when dissimilar metals are combined in a monostructure.

Conclusion

Shallow cryogenic treatment offers low-cost and readily available benefits for high and low carbon steels and many nonferrous materials used in low to moderate wear applications. Deep cryogenic treatment is most effective for ferrous alloys, particularly high carbon tool steels, white iron and manganese castings, due to its ability to transform retained austenite and enhance carbide precipitation in high-wear applications—far beyond SCT. Cryogenic treatment of aluminum and titanium is typically limited to stress relief, with minimal gains in hardness or wear resistance. DCT's effectiveness depends on material type, prior heat treatment and application-specific needs.

In the next issue, we'll explore the range of equipment available to perform cryogenic treatment in commercial and industrial settings.

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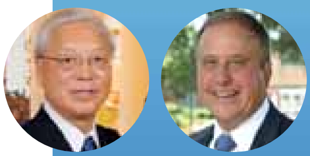


by Quan-Sheng Shu, cryospc.com, and Jonathan Demko, Le Tourneau University

Toward Optimal Cryogenic MLI System (I): Material Evaluation and System Design

Multilayer Insulation (MLI) is essential for minimizing thermal conduction and radiation losses in cryogenic systems, where maintaining ultralow temperatures is critical for system efficiency and performance.[1-2] The selection of MLI materials and the design of the insulation system are pivotal in achieving optimal thermal management. We briefly introduce four specialized calorimeters developed by leading laboratories and used in evaluating MLI performance to assess thermal resistance and conductivity. The importance of intermediate temperature (T) shields is highlighted, as they play a crucial role in mitigating heat transfer between high temperature and low temperature sections, greatly enhancing overall MLI system efficiency. A table summarizing representative MLI test data worldwide is provided, offering empirical insights into material performance across various temperature ranges. Additionally, six distinct MLI system design configurations are explored, with detailed thermal performance results and Carnot efficiencies for each, enabling a comparison of different strategies in terms of the system effectiveness.

Advanced MLI Materials

Currently, MLI systems, also known as superinsulation, are widely used as the most efficient form of thermal insulation minimizing radiation heat for cryostats. Shu, Fesmire, and Demko have systematically introduced the theory, design, and performance data of MLI systems [paper, 1-2]. MLI systems consist of multiple radiation (or reflective) shields separated by low thermal conductivity spacers within an evacuated environment about 1x10^{-5} torr. This design allows for effective thermal insulation by minimizing heat transfer through radiation and conduction. Typical reflector materials for example are 7-micron aluminum foil, single/double aluminized (~400 angstroms

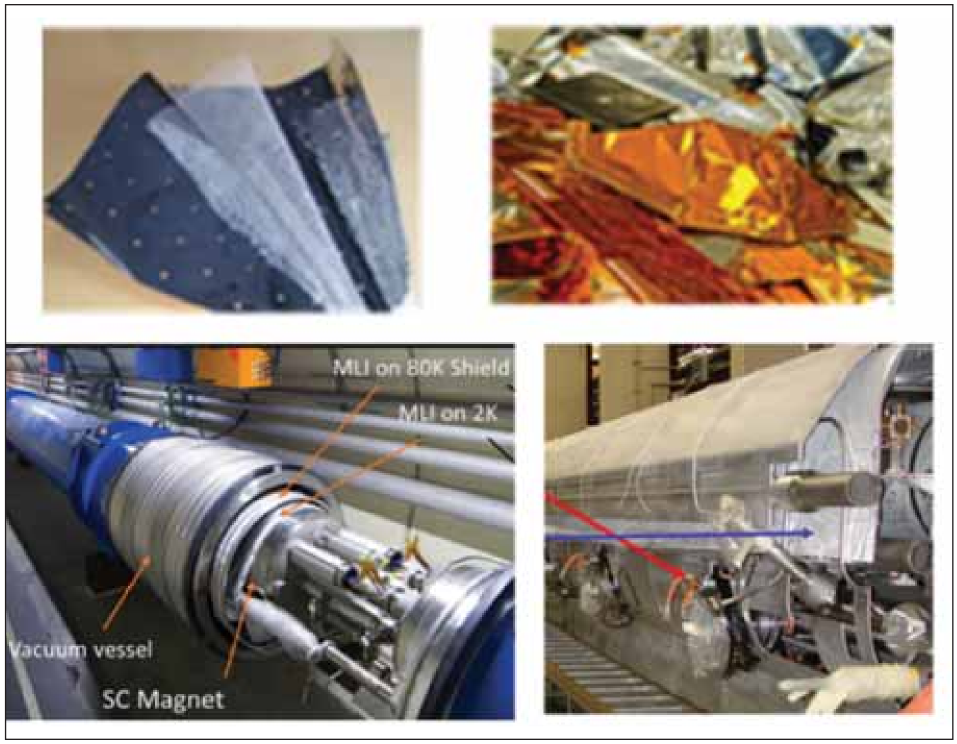


Figure 1. Upper, Various MLI materials. Credit: Fesmire Lower, MLI blankets on cold mass and thermal shield. Credit: CERN and ILC

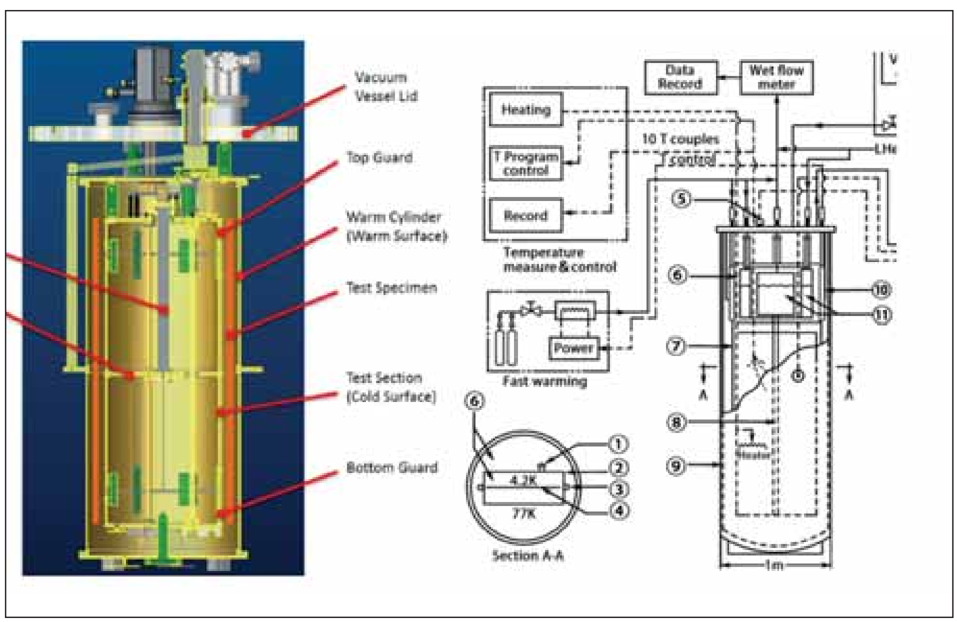


Figure 2. Left, thermal conduct meter calorimeters (TCMC).[4] Credit: Johnson Left, Right, Multifunctional boiloff meter calorimeters (BOMC).[3] Credit: Shu and Fast

Al) Mylar, double gold coated Mylar and crinkled or microporous aluminized Mylar. Spacer materials include micro-fiberglass paper (Lydall Cryotherm-243®, 25 microns thickness), polyester non-woven fabric, silk net, and discrete molded plastic spacers etc.

Specific Calorimeters for Evaluation of Various MLI

There are still less reliable standards for the performance data, workman procedures, design handbooks and constructive guidance, which push many engineers and scientists to develop special calorimeters for testing and obtaining thermal information for applications.[3-6] The dilemmas are typically for MLI, since a 50% aviation of MLI performance is not unusual in some large and complicated applications. It is crucial to have their own calorimeters to test the performance of thermal insulation in various shapes and conditions, like the real cryogenic system for the scaled-up applications. Four representative MLI colorimeters are selected to discuss their design features for further references.

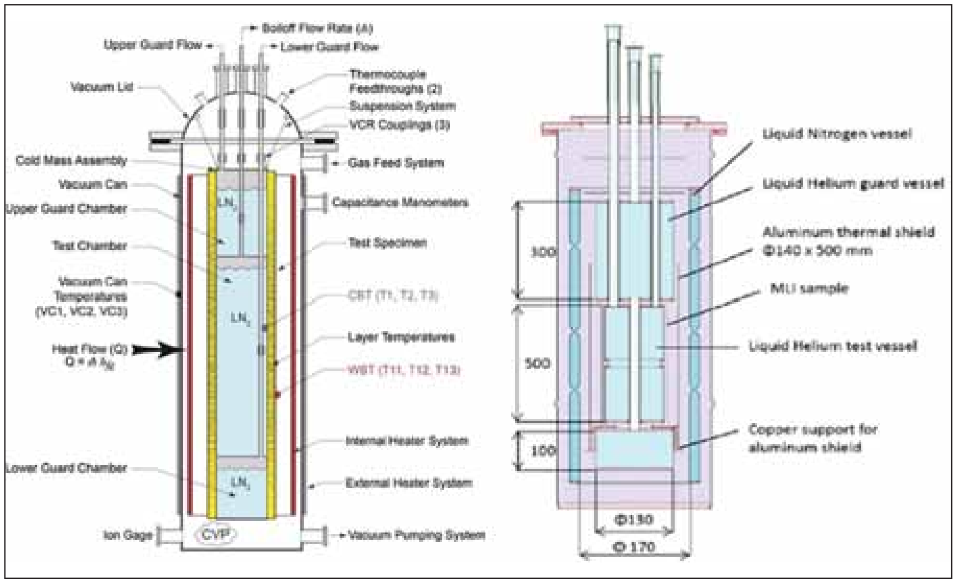


Figure 3 Left, Cryostat-100: basic schematic.[5] Credit: Fesmire. Right, a CBMC between 60 K and 20 K to 4 K.[6] Credit: Venturi

Authors	Th-Tc K	Layers	Heat Flux W/m²	Authors	Th-Tc K	Layers	Heat Flux W/m²
Fesmire [1]	293 - 78	40	0.39 - 0.59	Shu [1]	77 - 4.2	30	$13.2x10^{-3}$
Shu [3]	300 - 77	10 - 30	2.5 - 0.54	Ohmori [7]	64 - 5	20	25 - 34 $x10^{-3}$
Shu [3]	300 - 77	60 - 90	0.47 - 0.38	Nicol [9]	77 - 20	5 - 10	50 - 80 $x10^{-3}$
Ohmori [7]	298 - 70	50	1.5	Johnson [4]	260 - 19	30 - 50	~ 0.67
Mazzone [8]	300 - 80	10--30	2.5 - 0.5	Mazzone [8]	300 - 4	20 - 30	1.44 - 0.51

Table 1. Representative performance data of different MLI blankets. Credit: Shu, Demko, Fesmire and Duckworth

Figure 2 (right) is a multifunctional boiloff meter calorimeter (BOMC), in which various MLI blankets can be tested between 77 K and 4.2 K and 300 K to 77 K, or 300 K to 4.2 K.[3] The existing test configuration was then a rectangle box in higher-T and a plate in lower-T. The shape configuration can be adjustable to a cylindrical box in higher-T and to a desired shape in lower-T. It was utilized by Shu, Fast et al. to study the performance of various MLI combinations, different shapes of various cold surfaces and serious penetration through MLI uncounted in large applications at Fermilab. [3] The calorimeter cryostat is about 3 m high and 1 m diameter. The center LHe boiloff vessel is surrounded by a primary ring-shaped cylindrical LHe guard vessel and then thermally protected by a secondary LN_2 guard vessel. The accuracy of the wet test meter used for the helium gas boiloff is ±0.2%. Thermocouple wires CR-Au/Fe and cooper-constantan were provided with a heat sink by taping them to inside the MLI layers, a LHe temperature surface, and an LN_2 temperature surface. The heaters are also epoxied on the box's outer surface.

At NASA Glenn Research Center, the thermal conduct meter calorimeters (TCMC) for measurement of MLI at low boundary temperatures are reported in detail by Johnson and Chato as shown in Figure 2.[4] The calorimeter consists of cold and warm surfaces, which are a pair of nested cylinders with flat ends inside a cylindrical vacuum vessel. The cold (inner) cylinder has guarded top and bottom ends to minimize the effects of heat transfer at the ends of the test section. The warm cylinder, the test section of the cold cylinder, and a pair of guarded ends on the cold cylinder are each cooled by a cryocooler (the two guards are controlled by a separate cryocooler from the test section). In steady-state conditions, the heat flow through the MLI covering the test section is equal to the heat flow through the CCR. The heat flow through the CCR is calibrated as a function of the temperature readings at two locations along the CCR.

Figure 3 at left shows the Cryostat-100, a fully thermally guarded design, which has tested several hundred specimens for years by Fesmire, Johnson et al. at NASA KSC.[5] It is a primary (absolute) type instrument of thermal transmission measurement. Absolute instruments produce the data by which other instruments, such as the comparative (secondary), can be calibrated. This apparatus is guarded on top and bottom to eliminate end effect for absolute thermal performance measurement. Each of the three chambers is filled and vented separately through a single feedthrough for easy

▶ *continues on page 30*

operation and minimum overall heat leakage. All instrument wires pass other special feedthroughs and are connected from the lid. A novel thermal break design between the liquid chambers (precludes the solid-conduction heat transfer from one liquid volume to another). Figure 3 right is a CBMC between 60 K and 20 K to 4 K.[6] There are serious demands to obtain thermal performance of MLI at 4.2 K with radiation from temperatures of 60 K and down to 20 K, especially in the fields of high energy physics, fusion, airspace, etc. Venturi introduced how a cylindrical boiloff calorimeter used to be for 77–4 K has been successfully redesigned and modified as a calorimeter operated between 60 and 20 K to 4 K through the Al-thermal shield assembly.

Representative Experimental Data on MLI Performance

Table 1 provides a selection of published results on MLI performance from various calorimeters developed for specific applications worldwide. Although these data have been tested from recognized researchers at the well-known laboratories, the data may not be entirely consistent due to differences in MLI materials and workmanship used in different studies. However, it provides a reliable ballpark estimation and design reference.

Energy Saving Systems: MLI with Various Intermediate Shields and MLI Layers

Basic Principles and Typical Configurations

Once the preferred MLI is chosen for an application, from a thermal management point of view, the important task is to search for the configuration using the least works to intercept and remove the heat from ambient to interior. In cryogenics, the Carnot efficiency is the theoretical maximum efficiency, where COPc = Tc/(Th-Tc). So, Qc/Win = Tc/(Th-Tc). Where, Qc is heat moved, Win is external work needed, Th – high T and Tc – low T. Based on Carnot's theorem to remove the same amount of heat, the higher temperature level of the heat being removed, the lower the external work of the cooling device is consumed.

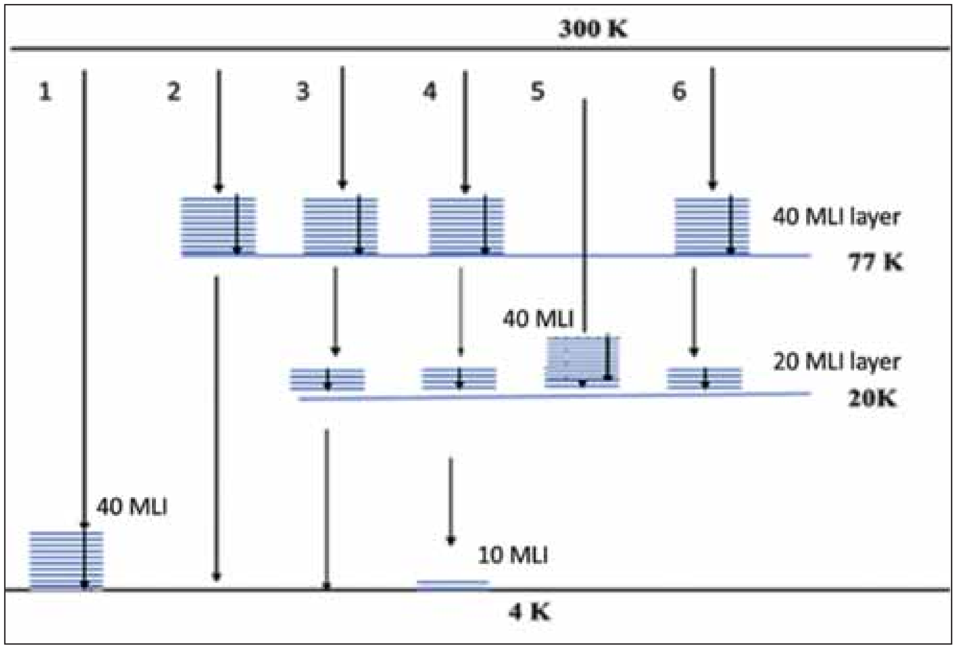


Figure 4. Six typical cases demonstrating MLI systems with various intermediate shields and MLI layers. Credit: Shu, Fesmire, Demko (Technical Note)

Case	Description	Heat Loads, W (in bold) *Min Work, W (in Italic)*						*Total Min Work, W*
		300-4K	300-80K	300-20K	80-20K	80-4K	20-4K	
1	Only 40 MLI layer on 4K	**0.61** *43.6*						*43.6*
2	40-layer on 80K shield		**0.60** *1.67*			**0.195** *13.93*		*15.6*
3	40-layer on 80K, 20-layer on 20K		**0.60** *1.67*		**0.025** *0.35*		**0.00064** *0.046*	*2.066*
4	40-layer on 80K, 20-layer on 20K, 10-layer on 4K		**0.60** *1.67*		**0.025** *0.35*		**0.0002** *0.014*	*2.034*
5	Only 40-layers on 20K			**0.61** *8.7*				*8.7*
6	40-layer on 80K, 20-layer on 20 K		**0.60** *1.67*		**0.025** *0.35*			*2.02*

*The Carlo Coefficient: from 80K to 300K: 0.36, 20K to 300: 0.07, 4K to 300 K; 0.014.

Table 2: The heat loads to 1-Yn² of cold surface (in bold font) and minimum refrigeration works needed to remove the heat loads to ambient (in italic font) for typical six configurations. Credit: Shu, Demko, Fesmire

Therefore, intermediate temperature (T) shields are important for improving thermal efficiency in real MLI systems. The critical question is how many intermediate T shields are needed and at which T levels they should be allocated. To demonstrate basic principles and typical practice, the six typical configurations are chosen and illustrated in Figure 4. The 77 K level can be LN_2 vessels and shields for LHe-LH_2 vessels or SC cold mass. 20 K level can be LH_2 vessels and shields for SC cold mass, special space device, etc. The 4 K level can be LHe vessel, SC mass or space device.

Energy Saving and the Six Typical Cases

Based on the above six cases (configurations), the heat loads per m² from each warm Th surface to the faced cold surfaces Tc are calculated or taken from experimental data. This heat load data is placed in the corresponding cells with bold font in Table 2.[1-2] Then, the minimum work needed to remove this heat load is calculated using the Carnot formula. For easy comparison, the minimum work data are also placed in the same cell (which corresponding heat loads occupied), but using italic font underneath the heat load data.

An example on how to use this table is given as follows: In case 1, the heat load from 300 K through 40 MLI layers and reaching 4.2 K is 0.62 W, and needed is *43.6 W* of refrigeration power to remove that heat. In case 4, the heat load at 77 K is 0.6 W, and to remove it from 77 K level a refrigeration power of *1.67 W* is needed. In another case, heat load from 77 K to 20 K through 20 MLI layers is 0.025 W, and to remove that heat, we need *0.35 W*. Finally, the heat from 20 K to 4 K through 10 MLI layers is only 0.0002 W (0.2 mW) and only *0.014 W* of refrigeration power is needed to remove it. The integrated total minimum power for each case is given in the last column of the table.

References

1. Fesmire, J., Shu, Q.-S., & Demko, J. (2022). Special cryostats for laboratory and space exploration (Chapter 12). In *Cryogenic Heat Management: Technology and Applications*. CRC Press Taylor & Francis Group.

2. Shu, Q.-S., Demko, J., Fesmire, J., & Duckworth, R. (2023). Design, configuration, and thermal optimization of advanced cryostats. *CEC/ICMC-2023 Proceedings*.

3. Shu, Q.-S., Fast, R., & Hart, H. L. (1987). Systematic study to reduce the effects of cracks multilayer insulation. Part 2: Experimental results. *Cryogenics*, 27, 298.

4. Johnson, W., Van Dresar, N., Chato, D., & Demers, J. (2017). Transmissivity testing of multilayer insulation at cryogenic temperatures. *Cryogenics*, 86, 70–79.

5. Fesmire, J., & Johnson, W. (2018). Cylindrical cryogenic calorimeter testing of six types of multilayer insulation systems. *Cryogenics*, 89, 58–75.

6. Venturi, V., et al. (2019). Experimental measurements on MLI performance from 20–60 K to 4.2 K. *IOP Conference Series: Materials Science and Engineering*, 502, 012077. (ICEC/ICMC)

7. Ohmori, T., et al. (2014). Test apparatus utilizing Gifford–McMahon cryocooler to measure the thermal performance of MLI objectives background. *Proceedings of ICEC 2014*.

8. Mazzone, L., et al. (2002). MLI measurement. *CERN LHC/2002–18 (ERC)*.

9. Boroski, W., Nicol, T., et al. (1991). Design of the multilayer insulation system for the superconducting super collider 50mm dipole cryostat. *ITSSC-1991ee*.

by Mark Kimball, Ph.D., Cryogenics and Fluids Branch, NASA Goddard Space Flight Center

Goddard Goings

An insight into past, present and future cryogenic missions where the Cryogenics and Fluids Branch at NASA Goddard Space Flight Center had or has a significant role.

Readers of this column may recall last year's recounting of a past mission, the Superfluid Helium On-Orbit Transfer demonstration, or more succinctly, SHOOT. This year's focus is on a mission in progress and another in formulation: COSI and PRIMA.

COSI

The COmpton Spectrometer and Imager (COSI) is a SMEX (Small Explorers) mission funded through NASA's Explorers Program. Its purpose is to combine direct imaging, spectroscopy and polarization measurements of soft gamma rays emanating from various entities in the universe. All this is required to meet ambitious primary science goals: uncover the origin of galactic positrons, reveal galactic element formation, gain insight into extreme environments with polarization and probe the physics of multi-messenger events. Major science indeed.

To achieve these goals, the main COSI instrument uses an array of 16 germanium detectors that date back to the Lawrence Berkeley National Laboratory in California in the early 1990s. This technology has matured over the intervening decades, starting in the laboratory and then progressing through a series of stratospheric balloon missions to where we are today: a ticketed ride on a SpaceX Falcon 9.

To operate, the detectors must be cooled below 90 kelvins. I'll let Howard Tseng from Goddard's Cryogenics and Fluids Branch explain the cooling chain:

"GSFC is contributing the Cryostat Heat Removal Subsystem (CHRS). The CHRS uses radiators with a constant conductance heat pipe (CCHP) from the cryocooler to the radiator. The cryocooler is the Sunpower CryoTel CT-S, and the control electronics are provided by

Figure 1: An artist's rendering of the COSI satellite. Credit: Northrop Grumman Systems Corporation

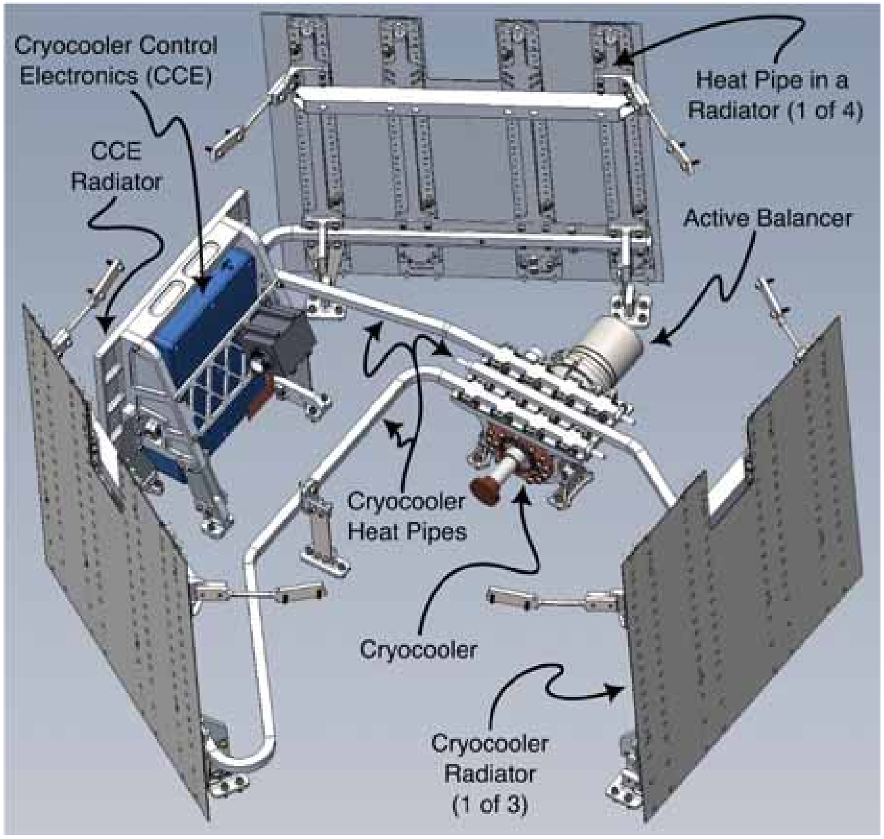


Figure 2: A drawing of the cryogenic system on COSI. Credit: NASA

IRIS Technology. The heat pipes and radiator are provided by Advanced Cooling Technology (ACT), but the radiators are painted here at GSFC. Our system is providing the cooling to the cryostat, which is being developed by Berkeley. The cold head is kept optimally at 80 K and absorbing 7 W (current best estimate) from dissipation in the detector and parasitic heat flowing down wires from higher temperature."

He goes a bit deeper into the ongoing technology development:

"The cryocooler has an active damper that is being controlled by a 'new' Cryocooler Control Electronics. 'New' being that this CCE has not been designed to do this, and the CCE has not been paired with this cryocooler before. So, there is a non-insignificant development effort needed to make sure the CCE algorithms work and that the CCE hardware can support driving both the cryocooler and the active balancer on the cryocooler."

Never a dull moment around here. Anyhow, if you wish to learn more about COSI, I would start at https://cosi.ssl.berkeley.edu and go from there.

PRIMA

Another satellite being proposed now with cryogenic instruments at its core is PRIMA. That's not a misprint. Instruments is correct, since there are two unique instruments cooled by a single sub-kelvin cooler on this 1.8-meter telescope. Oh, and the telescope itself is also cooled to cryogenic temperatures. Fun.

The PRobe far-Infrared Mission for Astrophysics is a collaboration between GSFC, JPL, SRON, CNES and Cardiff University. It's currently in Phase A of the NASA lifecycle. If you are not well versed in NASA-speak, this means the project is in the concept and technology development phase. Here, top-level requirements drive designs that rely on calculations, simulations and models to prove feasibility. This process usually devolves into a tug-of-war between structural concerns, thermodynamic realities and mass constraints reminiscent of a freshman-level physics force diagram – but I digress.

Figure 3: A rendering of the five-stage continuous adiabatic demagnetization refrigerator (CADR) being developed for PRIMA. A thin outer magnetic shield has been removed to show the ADR stages and heat switches inside. Credit: NASA

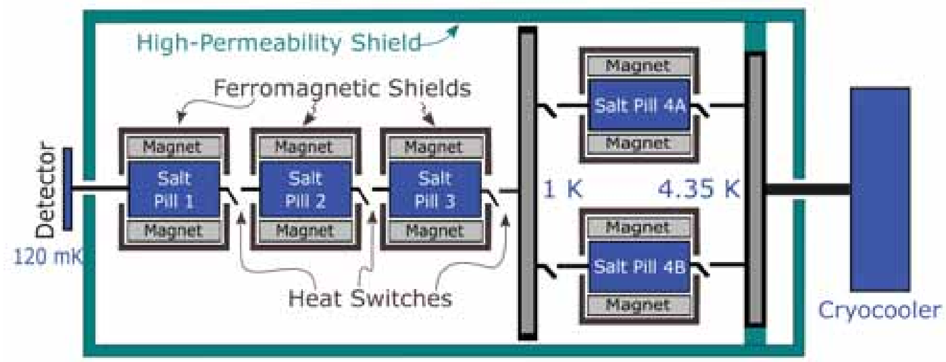


Figure 4: A drawing of the five-stage CADR. The three stages on the left operate synchronously to remove heat from 0.120 K and reject it at 1 K. The two stages on the right alternate pulling heat from the 1 K plate and rejecting it to the 4 K cryocooler. Credit: NASA

The cryogenic system starts with a three-stage pulse tube cooler. This precools helium gas before it reaches the impedance within the separate Joule-Thomson cooler. Ultimately, the combination of these two coolers generates a temperature near 4.5 K with a heat lift of 50 mW. An interesting historic note: The particular cryocooler earmarked for use is the spare unit developed for the MIRI instrument that is performing flawlessly aboard the James Webb Space Telescope. This cools the infrared telescope to near 4.5 K and is also the heat sink for the multistage continuous adiabatic demagnetization refrigerator (CADR) being developed by the Cryogenics and Fluids Branch. Of the total available heat lift of 50 mW at 4.5 K, the CADR is allocated a mere 10 mW for its heat rejection. This becomes important later.

Both PRIMA instruments, PRIMAGER and FIRESS, require two stable temperatures to operate: 1 K and 0.120 K. The CADR provides these by linking together what is essentially two ADR systems running asynchronously (see Figure 4). The three stages left of the 1 K plate in Figure 4 work together to lift heat at 0.120 K from the detector and wiring transcending from higher temperature and pass it to the 1 K

▶ *continues on page 35*

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

Making Liquid Hydrogen Flow Like Water Part 2 – Reliquefaction

The end-use applications of liquid hydrogen (LH_2) are expanding, and the need for putting LH_2 to use at the points of use is arising. In this series we are looking at the life cycle of the hydrogen molecule from point A, its production, to point Z, its consumption. From the point of liquefaction, there are many points along the liquid hydrogen pathway. How do we make the liquid hydrogen flow like water from point to point in the middle? Or how can we at least not lose the hydrogen to the atmosphere?

In Part 1, we examined the utilization of "boiloff" gas for electrical power or other uses. In part 2, we'll look at the benefits and limitations of reliquefaction. Rather than venting the hydrogen boiloff gas to the atmosphere, it may be better to direct the gas back to a refrigerator and have it recondensed (re-liquefied) and put back into the LH_2 storage tank. If there is refrigeration available, such as in the case of a large liquefaction plant, it certainly makes sense. If there is no refrigeration available, but the LH_2 is deployed to a remote region, Antarctica for an extreme example, then it may make sense to add that refrigerator to include the reliquefaction capability. The sense here is the economics of the delivery of the molecule to point Z (the end use) for the power generation.

Where does the hydrogen boiloff gas come from? Heat is always coming into the liquid from the environment; this ongoing heat ingress causes the pressure to build inside the tank; eventually, when the tank pressure reaches the maximum allowed, it must be vented. The heat buildup and resulting venting process are shown in Figure 1. In nature, with liquid water and localized heat under Earth's surface, the same process applies as for liquid hydrogen.

Figure 1. Old Faithful venting in Yellowstone National Park. Credit: J. Frank, Public Domain, National Park Service

The hydrogen "boiloff" gas comes mainly from the transient on/off operations in moving LH_2 from point to point where tanks build pressure; piping, valves, and pumps are periodically cooled down (and warmed up); where dispensing operations add more heat and incur more vaporization in pumps and components; and where the tanks must be vented from the pressure buildup that comes naturally and with all these pressure-driven transfer operations. Note that a just-emptied (except the ~10% heel left inside) vehicle tank full of cryogenic gas at full tank pressure will always represent a significant mass of hydrogen that must be blown-down to the lower starting pressure to facilitate the next filling operation. The daily pressure build into the storage tank is commonly called the boiloff rate (BOR) and receives a lot of focus. However, in most instances, with a properly built tank, these losses are relatively small. But it all adds up. The mass of hydrogen vented through the entire LH_2 pathway can be half of the hydrogen mass consumed at point Z.

But technologies and methodologies are now available to cut these losses to 0%, 5%, 10%, or any number that meets the economic breakpoint. The use cases here are centered around the variable on/off operations typical in transportation applications. In priority order, these technologies are summarized as follows: 1) Condition the liquid so that it can absorb heat (create enthalpy margin by active refrigeration); 2) Re-liquefy the vapor from the vehicle tank blow-down and transfer operations; and 3) Utilization of the hydrogen gas to provide electricity (base load or auxiliary power to charge a battery bank).

Although system architectures do not often include reliquefaction by design, the future is showing an advent of simplified, practical refrigeration equipment for the 20 K range. However, the phase change from gas to liquid is a significant divide in terms of the energy and thus the electricity required to make that happen. For example, the enthalpy change of cold gas at 30 K to saturated gas at 20 K (at one atmosphere pressure) is only about 108 J/g (ideally). But to go across the divide from gas to liquid is 449 J/g, a much bigger price to pay. For balance-of-plant, there are the additional costs of process piping to route the cold gas, a tank to collect the condensate (the reliquefied liquid), and a transfer system to put the liquid back into the main storage tank.

Hydrogen venting operation in Titusville, FL. Credit: J. Fesmire, GenH2 Corp

In Part 3, we'll cover the much more energy-efficient way to prevent losses and provide the means for LH_2 to flow like water. A liquid, even liquid hydrogen, will not boil if it can absorb heat. The active refrigeration system integral with the storage tank system provides the capability for controlled storage and transfer of liquid hydrogen, thus making the LH_2 pathway practical and effective for end-use applications.

Goddard Goings... Continued from page 33

plate. The two remaining stages periodically swap roles, with one absorbing heat at 1 K and the other rejecting it to the cryocooler. This "second" ADR is not unprecedented. A system that operated in a similar fashion was presented in the April 2015 edition of *Cold Facts.*

ADRs providing continuous cooling at sub-kelvin temperatures have been demonstrated in the laboratories of the Cryogenics and Fluids Branch at GSFC for nearly three decades. Also, a pair of ADR stages that provide cooling near 1 K is not something "new," as stated before. What is new here is the linking of these two CADR systems together to create a single cooler with two stable temperature platforms, ruggedized to survive a spaceflight launch. If this isn't enough "newness" to keep your interest, remember that I mentioned earlier the total heat rejection from the CADR to the cryocooler may be no more than 10 mW. That's right – not only must this ADR provide up to 9 µW of cooling at 0.120 K and roughly 1 mW of cooling at 1 K, but it has a ceiling on the heat rejection to the cryocooler. Talk about being confined inside a tight box. I'm feeling a bit claustrophobic.

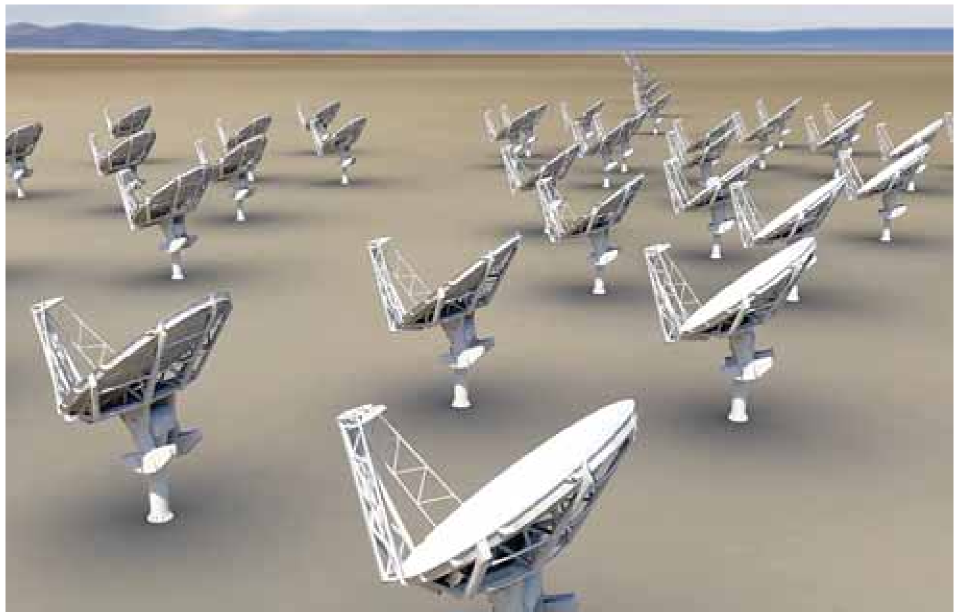
Now, I realize I've spent half this article outlining the cryogenic system on PRIMA. This is *Cold Facts*, after all. However, if you want to learn more about the science, instruments or team associated with PRIMA, a good place to start is https://prima.ipac.caltech.edu. The CADR is described in more detail in the proceedings of the SPIE Astronomical Telescopes + Instrumentation Conference, 2024, Yokohama, Japan (https://doi.org/10.1117/12.3020300) or in a manuscript accepted for publication in the *Journal of Astronomical Telescopes, Instruments, and Systems* (JATIS) titled "The Continuous Adiabatic Demagnetization Refrigerator for the PRobe far-Infrared Mission for Astrophysics (PRIMA)."

NSF National Radio Astronomy Observatory and RIX Industries Join Forces to Revolutionize Cryogenic Cooling for the ngVLA Project

by RIX Industries Communications Team

In a groundbreaking collaboration that could change the landscape of both scientific discovery and cryogenic technology, the U.S. National Science Foundation's National Radio Astronomy Observatory (NSF NRAO) has teamed up with RIX Industries to develop cutting-edge cryogenic cooling solutions for the Next Generation Very Large Array (ngVLA). The ngVLA, designed to push the boundaries of radio astronomy, will see up to 263 antennas across North America, expanding the capabilities of its predecessor, the NSF Very Large Array (VLA), almost tenfold.

One of the biggest challenges in building such a massive system lies in the cryogenic cooling required to maintain the optimal performance of the sensitive radio receivers. With current cooling systems contributing significantly to operational costs, the ngVLA project needed an innovative solution that would drastically reduce energy consumption and improve reliability. That's where RIX Industries' Thermoacoustic Stirling-cycle Cryocooler (TASC) technology comes into play.



The National Radio Astronomy Observatory (NRAO) and Associated Universities, Inc. (AUI) are launching a two-year initiative to design a next-generation radio telescope with capabilities far beyond existing observatories. Building on the success of the NSF's Karl G. Jansky Very Large Array (VLA), the proposed array—called the next-generation Very Large Array (ngVLA)—will feature over 200 antennas spanning the US desert southwest and northern Mexico. This facility aims to advance our understanding of planets, galaxies, black holes, and fundamental physics. Credit: Bill Saxton, NRAO/AUI/NSF

Overcoming the Technical Hurdles

RIX's TASC technology, which uses thermoacoustic principles to achieve efficient cryogenic cooling, had to be adapted to meet the specific needs of the ngVLA. The primary technical challenge was ensuring that the dual-stage cryocooler could be packaged into the ngVLA's antenna enclosures while adhering to strict mass and energy requirements. The cooler had to operate efficiently at two different temperature stages – one at 20 K and another at 80 K – while using less than 2,700 watts of power per unit.

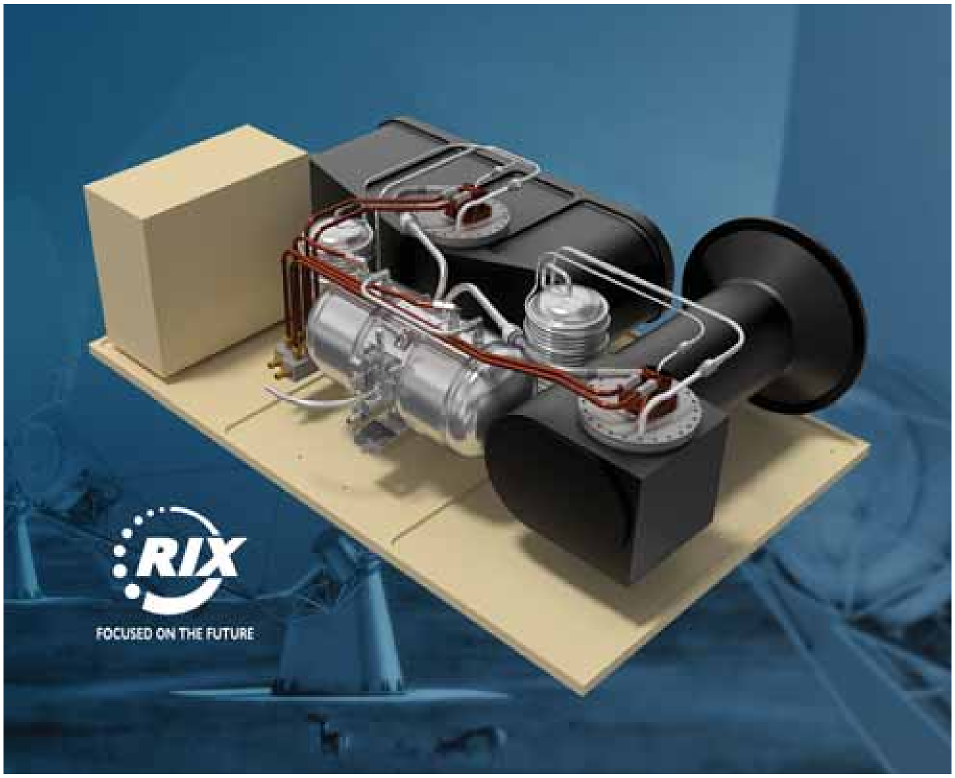
RIX Industries, with its deep expertise in thermoacoustic cooling, took on the task through a feasibility study funded by NSF NRAO. The results were promising, confirming that their TASC technology could be adapted to the ngVLA's unique cooling requirements. Following this success, further design studies involving detailed simulations and mechanical design confirmed that the TASC cryocoolers not only met performance benchmarks but also offered several operational advantages, including a significant reduction in maintenance and power consumption compared to the traditional Gifford-McMahon (GM) cryocooler systems currently in use by NRAO.

Improving Reliability and Efficiency

The ngVLA's long operational life posed another critical challenge. Traditional GM cryocoolers have many moving parts, use oil that needs regular filtering and maintenance and are prone to helium leaks, all of which add up to significant downtime and higher operational costs. By contrast, the RIX TASC cryocooler has fewer moving parts, requires no oil and has a welded construction that eliminates many helium leak paths. This makes it far more reliable, especially for a system as large and geographically dispersed as the ngVLA.

"Where traditional systems demand frequent maintenance, the RIX TASC technology offers significant reliability benefits. By eliminating oil and reducing moving parts, we're addressing long-term operational concerns while cutting down on overall system maintenance," said Rob Selina, ngVLA project engineer.

The use of RIX TASC technology also offers considerable environmental advantages. One of the key benefits is reduced helium consumption. As a nonrenewable resource, helium is becoming increasingly



Artist's interpretation and full rendering of the RIX Industries TASC System cryocooler. Credit: J. Hellerman U.S. National Science Foundation/NSF National Radio Astronomy Observatory, RIX Industries

scarce, and the RIX cryocooler's efficiency directly translates to lower helium use – a crucial factor for the sustainability of the ngVLA project.

Broader Implications Beyond Astronomy

While the ngVLA project is the immediate beneficiary, the broader implications of this technology stretch far beyond astronomy. The dual-stage cryocooler is now capable of reaching temperatures as low as 20 K, making it suitable for a range of commercial and scientific applications. These include high temperature superconductor (HTS) cooling, hydrogen and argon liquefaction and the cooling of scientific instrumentation for both terrestrial and space-based applications.

RIX Industries' commitment to advancing this technology, even in the face of funding limitations for prototype fabrication, underscores the transformative potential of this collaboration. Their decades of experience in cryogenics, including work in aerospace and medical sectors, positions RIX as a key player in providing sustainable and efficient cooling solutions for the future.

Looking Ahead

As NSF NRAO continues to seek funding for the full-scale prototype development of this technology, the partnership with RIX Industries serves as an exemplary model of how collaboration between scientific institutions and industry can lead to groundbreaking technological innovations. The ngVLA promises to set new standards for efficiency, sustainability and scientific discovery, and the integration of advanced cryogenic systems will be a critical part of that legacy.

Rob Selina concluded, "This collaboration with RIX Industries is a prime example of how industry partnerships can drive innovation and solve real-world challenges. We are confident that the success of the ngVLA, with its advanced cryogenic technology, will pave the way for similar advancements in large-scale scientific infrastructure across other disciplines."

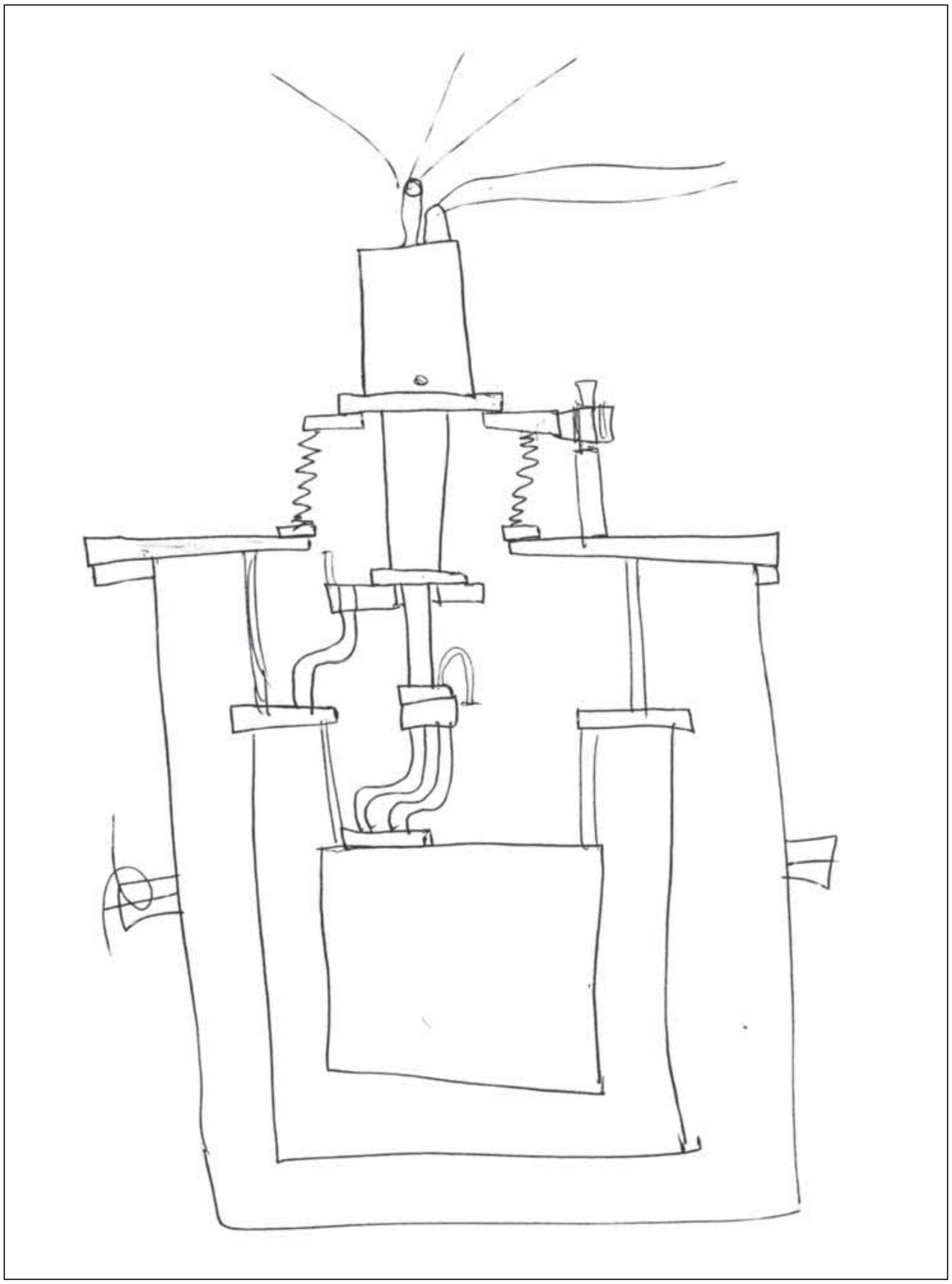
By combining the expertise of NSF NRAO and RIX Industries, the ngVLA project is not just redefining the future of radio astronomy but also shaping the future of cryogenic technology for years to come. **www.rixindustries.com**

Danaher's Acquisition of ADR Cryostat Line Pioneers the Future of Cryogenic Technology

by Charlie Danaher, Danaher Cryogenics, President

In December, Danaher Cryogenics marked a significant milestone by completing the acquisition of the adiabatic demagnetization refrigerator (ADR) Cryostat product line from FormFactor. Originally developed by FormFactor's subsidiary, High Precision Devices (HPD), the ADR product line has garnered a strong reputation among researchers and experimentalists worldwide. These advanced cryostats, many of which are still in service at leading institutions, represent a critical tool for cutting-edge research in a variety of fields.

Danaher Cryogenics is both honored and excited to continue the legacy of HPD, making this exceptional family of cryostats available to scientists working in quantum, astronomy, nuclear forensics, material science and other specialized domains that require sub-kelvin cooling platforms. With cooling capabilities as low as 50 mK, these cryostats provide the precision and reliability needed for the most demanding experimental environments.



A cleaned-up sketch from 2004 that spawned the design of the Model 102 ADR Cryostat. Credit: Danaher Cryogenics

The Story Behind the ADR Product Line

The history of the ADR cryostat family begins in 2004 when Dr. Joel Ullom of NIST Boulder approached HPD with a request for a compact ADR cryostat design. During their initial phone conversation, Charlie Danaher and Bill Hollander sketched out what they understood was needed. This sketch manifested as the Model 102 Denali ADR Cryostat. This collaboration laid the foundation for the ADR series, which grew to include several models, each improving upon the last in terms of cooling architecture, size and functionality. Models 102, 103, 104, 106 and 107 were developed over the years, each iteration offering unique features to meet the evolving needs of the scientific community.

The development of the ADR product line was greatly supported by NIST Boulder, a partnership that played a key role in advancing the capabilities of the ADR systems. These cryostats have since become integral to research in areas such as quantum computing, low temperature physics and materials science, where ultralow temperatures are essential for precise measurements and experiments.

Complementing Danaher's Existing Product Line

Before acquiring the ADR family, Danaher Cryogenics had already offered a diverse portfolio of cryogenic systems, including large dilution refrigerator cryostats and sorption cooler-based systems, featuring Chase Research Cryogenics (CSA CSM) sorption coolers.

By integrating the ADR product line into its offerings, Danaher Cryogenics now boasts a comprehensive portfolio that spans the full sub-kelvin temperature range, from 1 K clear down to 10 mK.

A Critical Mass of Expertise and Capabilities

Danaher Cryogenics has carefully assembled a team of engineers and scientists with over 50 years of combined experience in sub-kelvin cryogenics. This deep expertise underpins the company's ability to develop highly specialized cryogenic systems that are at the forefront of technology. The integration of the ADR product line enhances this capability, positioning Danaher Cryogenics as a leader in the sub-kelvin cryogenics space.

Beyond just providing products, Danaher Cryogenics is committed to engaging with customers to fully understand their unique challenges. Often, the solution to a problem is not immediately apparent, and it requires a collaborative approach to define the right solution. By working closely with research teams, Danaher Cryogenics can not only deliver off-the-shelf products but also develop tailored systems that address complex, project-specific requirements.

Transcending the Customer-Vendor Relationship

Danaher Cryogenics views its relationship with customers not merely as a transaction but as a partnership. The company understands that in the world of scientific research, particularly in cryogenics, the ultimate solution may be a product that has yet to be fully conceptualized. The company's

A line-up of product family members, showing the different chassis sizes, as well as illustrating the modular integration of multiple cooling stages for ultralow temperature applications. Credit: Danaher Cryogenics

A consolidated overview of the DC cryogenic product line, displaying the full suite of offerings from compact inserts to high performance systems used across scientific and industrial research. Credit: Danaher Cryogenics

approach involves not just delivering existing products but also guiding customers through the design and implementation phases to help develop bespoke solutions that best meet their specific needs. This customer-centric philosophy is what sets Danaher Cryogenics apart as a trusted partner in the field.

Optimism for the Future

The future of cryogenics is exceptionally bright. New applications and discoveries are being made every day, expanding the need for advanced cryogenic systems capable of meeting the evolving demands of science and technology. From quantum computing to deep space exploration, Danaher Cryogenics is poised to lead the way in providing the solutions that will enable the next generation of scientific breakthroughs.

With the acquisition of the ADR cryostat product line, Danaher Cryogenics is more committed than ever to supporting the global research community. By leveraging decades of expertise, a growing portfolio of products and a deep understanding of the evolving needs of researchers, Danaher is well equipped to meet the future challenges of cryogenic technology and continue its legacy as a leader in the sub-kelvin cryogenics industry. **www.danahercryo.com**

SPOTLIGHT ON A CORPORATE SUSTAINING MEMBER (CSA CSM): Eta Space

Eta Space Progresses Cryogenic Fluid Management Technology in Space, Energy and Beyond

by Leah Sudhir, Eta Space

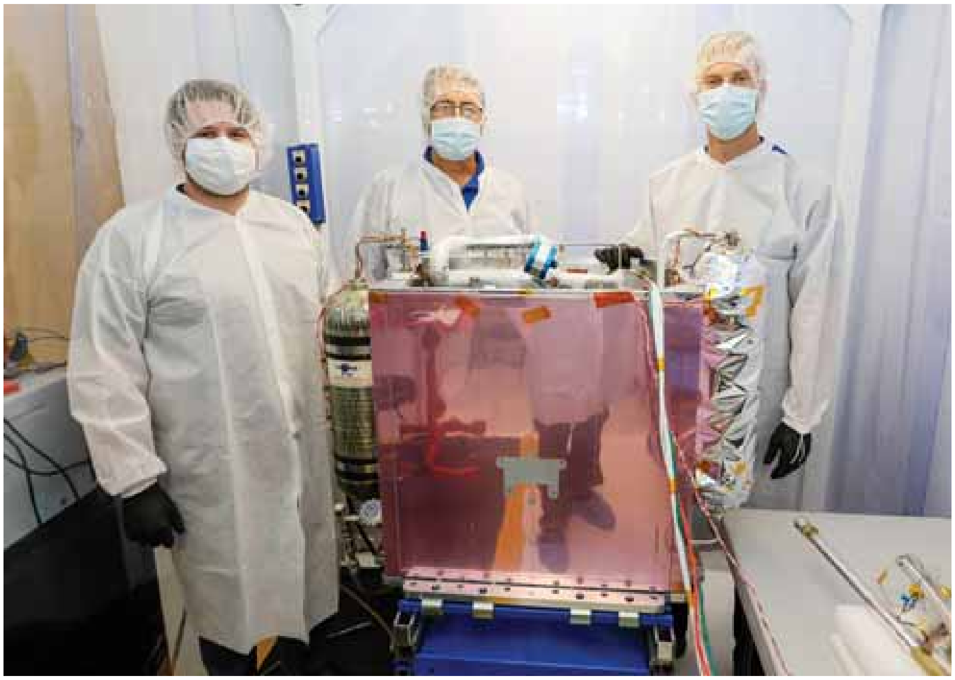
Eta Space is at the forefront of cryogenic fluid management (CFM) technology for the aerospace industry, continuously pushing the boundaries of innovation and expanding its customer base. Founded by Dr. William "Bill" Notardonato, who brings over 30 years of experience from NASA, the company has assembled a team of industry experts dedicated to ensuring sustainable space exploration for the future.

LOXSAT goes through testing, payload nears completion

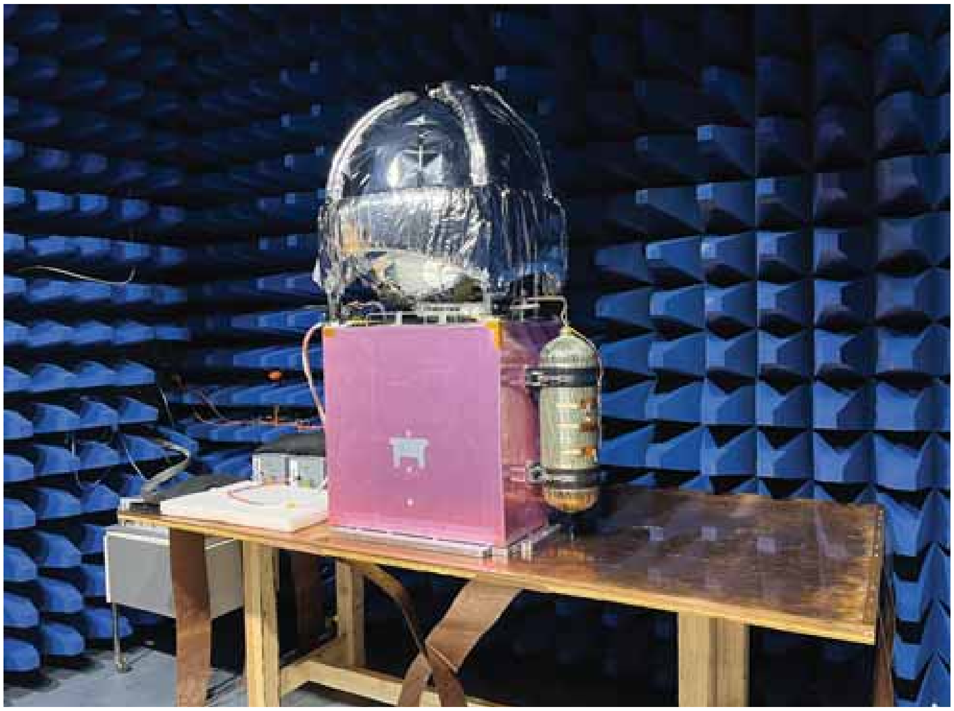
The company is close to the completion of its leading project, LOXSAT, its long-form liquid oxygen satellite. LOXSAT is a NASA-funded CFM demonstration that aims to prove long-term cryogenic storage and transfer in low Earth orbit (LEO). The team at Eta Space has achieved a laundry list of milestones for LOXSAT: in-house manufacturing and qualification of our flight tanks, completion of payload assembly and integration, vibrational testing at Kennedy Space Center's Vibration Test Lab and EMI testing at Kennedy Space Center's EMI Lab. The LOXSAT team is now wrapping up the assembly integration and testing with thermal vacuum chamber (TVAC) testing. This test provides a further understanding of exactly how LOXSAT systems will function in space.

Once the payload is completed, it will be shipped to Long Beach, Calif. where it will integrate with Rocket Lab's Photon Bus and go through its own series of integrated testing before ultimately being sent to the launch complex at the Rocket Lab launch facility in Mahia, New Zealand. LOXSAT is scheduled for launch in early March 2026.

"The breadth of knowledge required to put LOXSAT together more than proves our abilities here at Eta Space and we are very proud of what we have accomplished so far," said Jeff Bone, LOXSAT Project Manager.



(From left to right) Co-Investigator Daniel Hollibaugh, CEO Dr. William Notardonato and LOXSAT Project Manager Jeff Bone stand with the LOXSAT payload nearing its completion. Credit: Glenn Beil Photo



The LOXSAT payload undergoes environmental control testing at the Kennedy Space Center's EMI Lab in November 2024. Credit: Eta Space

"Eta Space as a company has gained critical expertise not only in the cryogenics world, but in the welding and fabrication of space flight-rated tanks, which is a bottleneck in the space industry, and we are continuously looking to improve our processes and technologies."

The payload's nine-month mission will provide critical, ground-breaking data that will serve to platform larger, full-scale cryogenic depots to fuel future missions. Specifically, LOXSAT will perform multiple zero-boiloff storage and transfer tests of liquid oxygen, a key component in cryogenic propulsion systems. This vision is currently in the works with Cryo-Dock™, a large-scale propellant depot in LEO that can service any compatible vehicle with a mating umbilical. It will likely store liquid oxygen and liquid methane, a combination highly utilized in most rockets today. The temperature differences between the two are similar enough that the storage of both propellants is proved by the success of LOXSAT since liquid methane is stored at a slightly higher temperature than liquid oxygen. Eta Space is currently looking to fund this project and collaborate with future customers of Cryo-Dock to make this vision happen.

Eta Space offers custom welding services, including the welding and fabrication of flight-rated tanks, shown by lead welder Jerry Goudy. Credit: Leah Sudhir

Eta Space introduces new divisions and its products and capabilities

Along with the development of LOXSAT and Cryo-Dock, Eta Space also offers several in-house capabilities: cryogenic propellant tanks, spacecraft electronics including data acquisition and control, cryocooler power electronics, integrated refrigeration and storage (IRAS), liquid hydrogen (LH_2) testing for small scale components and systems and hydrogen consulting and design services.

Eta Space has also spread its work into three divisions: Eta Space houses most of the work for LOXSAT, Cryo-Dock and other lunar pursuits. Eta Energy was introduced at the beginning of 2024, focusing on hydrogen energy applications for both transportation and superconductivity. The Energy division's work involves developing and testing designs for hydrogen aircraft applications aimed at major commercial aircraft suppliers and manufacturing major airline components. Through its work, Eta Energy seeks to facilitate the transition of companies from carbon-intensive fuel sources to more environmentally sustainable alternatives like LH_2.

Eta Energy also has its own liquid hydrogen testing facility (LHTF), first announced in December 2022, which is continuously in operation. The facility has successfully conducted tests of LH_2 process equipment, composite materials, hydrogen energy storage devices and superconductivity applications for government and industry clients.

A third division, Eta Defense, will be introduced this year as Eta Space works with the Department of Defense (DoD) to apply advanced cryogenic technologies to defense applications on Earth and in space. Stay tuned for further information on these capabilities in a future article.
www.etaspace.com

Omniseal is Sealing the Future of Space Travel with Cryogenic Innovation

by Kha Le

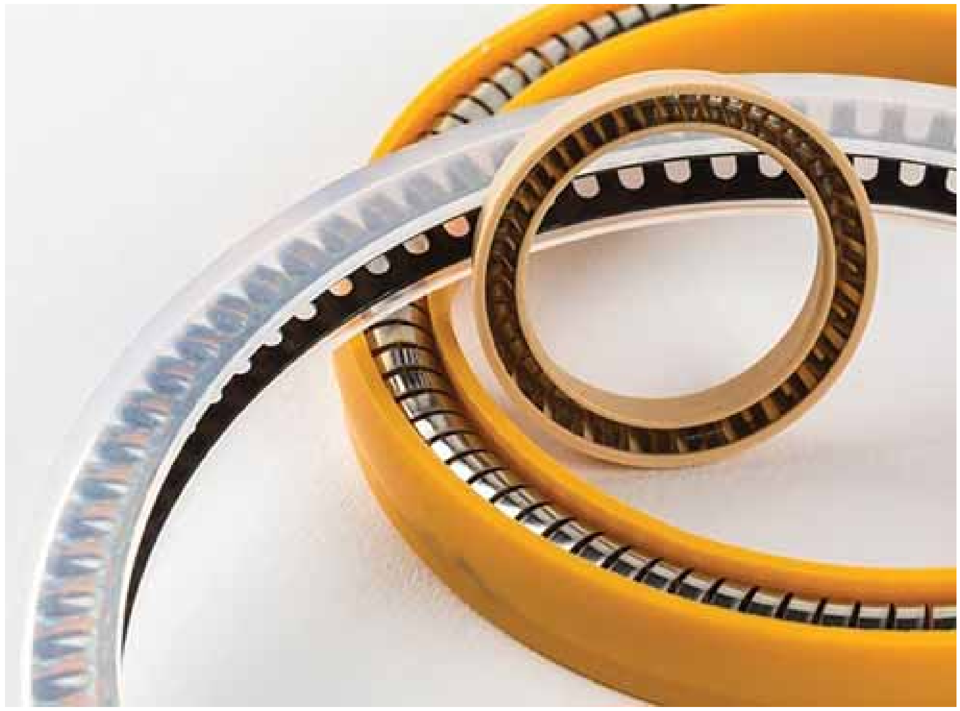
In the high stakes world of space exploration, success can hinge on something as seemingly simple as a seal. Yet in the harsh, unforgiving conditions of space – from cryogenic temperatures to violent mechanical shocks – nothing is simple. That's where advanced sealing technology, like the cryogenic solutions engineered by Omniseal Solutions, becomes not just a component, but a mission-critical asset.

Cryogenic environments present some of the most extreme engineering challenges in the aerospace sector. Fuel tanks, valves and other vital components in launch vehicles must operate reliably under immense pressure, rapid thermal cycling and exposure to aggressive propellants. A failure in any one of these systems due to leakage can jeopardize entire missions, wasting not only millions of dollars but years of work.

The nature of cryogenics pushes materials to their limits. At extremely low temperatures, many materials lose their elasticity and become brittle, compromising sealing performance. Rapid shifts between these frigid temperatures and the extreme heat of re-entry cause additional strain through thermal cycling. The result is a volatile environment where conventional sealing materials – metals or elastomers – often fall short.

To tackle these conditions, our teams at Omniseal Solutions have developed and refined polymer-based, spring-energized sealing systems. These high performance seals combine low-friction materials such as PTFE with internally energized springs – engineered in a variety of designs including V-springs, canted coils and helical coils – to provide continuous, reliable contact against sealing surfaces. These designs allow the seals to adapt to the dimensional instability and pressure fluctuations that are common in launch environments.

One of our most trusted solutions in this field is the Omniseal® RACO® spring-energized seal. Engineered specifically for cryogenic static face seal applications, this robust sealing system features a heavy-duty, corrosion-resistant spring housed within a U-shaped polymer jacket. This configuration delivers exceptional sealing force even at ultralow temperatures, resisting shrinkage and maintaining a tight seal against leakage. Whether it's a spacecraft, a satellite propulsion system or ground support infrastructure, the RACO® seal ensures structural integrity from pre-launch preparations through the final mission stages.



Omniseal® spring-energized seals. Credit: Omniseal Solutions

Omniseal Solutions' legacy in this field dates back to the space race of the 1950s and 1960s. At a time when launch vehicle failures due to seal leakage plagued the aerospace industry, we provided the breakthrough: custom-engineered spring-energized seals capable of performing under the combined stresses of cryogenic conditions and high pressures. Aerospace pioneers like Aerojet General and Rocketdyne integrated our solutions to improve reliability and prevent catastrophic failure – turning setbacks into launchpad success.

A major turning point came with the innovation of the RACO® spring design by Roy Creath, a trailblazing engineer from Southern California. His work laid the foundation for a new generation of high-integrity seals that have stood the test of time, remaining in use in today's modern launch vehicles and space technologies. These seals helped transform leakage control from a persistent problem into a solvable challenge, reshaping how the industry views performance under extreme conditions.

The space industry today continues to evolve rapidly and with it, the demand for even more advanced sealing solutions. Launch systems are getting lighter, propulsion methods are pushing new limits, and components are expected to perform across a wider range of mechanical and chemical stresses. Our engineers and R&D experts are constantly refining materials and geometries to meet these emerging needs, ensuring that our seals not only withstand but excel under increasing performance pressures.


Omniseal® RACO® spring-energized seals. Credit: Omniseal Solutions

What makes this work especially rewarding is its direct connection to mission success. A reliable seal may be unseen by the public, but its impact is unmistakable. It allows engineers to fuel rockets with confidence, pilots to fly at the edge of the atmosphere and scientists to gather data from distant planets – all without worrying about failure at the seams.

The spirit that drove Omniseal Solutions to contribute to the original space race still propels our innovations today. From helically wound springs to PTFE jackets, every advancement is part of a larger effort to help our space partners push further, faster and more safely than ever before.

To those in the space sector – or any field where performance under extreme conditions is essential – our message is simple: your mission is our mission. And we'll keep sealing the future, one breakthrough at a time. **www.omniseal-solutions.com**

Product Showcase

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

DZS 600 VSD+ and DZS 1200 VSD+ Pumps

Atlas Copco

Atlas Copco has introduced the DZS 600 VSD+ and DZS 1200 VSD+, two compact, dry claw vacuum pumps designed for long-lasting, energy-efficient performance in clean, oil-free environments. Ideal for applications such as CNC routing, pneumatic conveying, and hospital vacuum systems, these pumps operate quietly and reliably with minimal maintenance. Their modular design includes features like a non-return valve, a silencer, and PEEKCOAT-coated rotors for durability, while the integrated VSD+ inverter ensures efficient speed control based on process load. Users can monitor and manage pump performance in real time via the Atlas Copco VSD+ app, which simplifies setup and operation. **www.atlascopco.com**

SKL-E Pack Screw Compressor

CVS Engineering GmbH

CVS Engineering GmbH has introduced the SKL-E Pack, a stationary, electric unloading system for silo vehicles that offers a low-noise, low-emission alternative to traditional truck-mounted compressors. Designed for industries such as food, construction and recycling, the SKL-E Pack enables efficient unloading without requiring the truck engine to run, reducing fuel use, maintenance and noise. It allows greater operational flexibility for fleet operators, ensures consistent unloading quality for receivers and supports sustainable, energy-efficient processes – making it a cost-effective and environmentally friendly solution for bulk material handling. **www.cvs-eng.de**

L-Type Rapid Cryostat

kiutra

The L-Type Rapid is the fastest cryostat on the market, designed to speed up development cycles with fast cooldown, warmup, and sample exchange. It offers fully automatic, cryogen-free operation without helium-3, simplifying everyday use and making it ideal for device manufacturers, research labs, educational and shared facilities. Its modular design supports flexible configurations and delivers excellent temperature stability from sub-kelvin to room temperature. Suitable for measurements such as-electrical resistivity and magnetotransport properties of thin-film and bulk samples, Josephson junction characterization, superconducting resonator and qubit spectroscopy and CMOS and cryo-electronic device testing. See full specifications, application notes, options, components and more at **www.kiutra.com**.

CNA-11R Compressor

SHI Cryogenics Group

SHI Cryogenics Group's new CNA-11R is a rack-mountable evolution of the proven CNA-11 Compressor, reimagined for space-conscious, low-interference environments. Designed to fit a standard 19" rack enclosure, it features air cooling, single-phase power input (100–240 V, 50/60 Hz), and a low power draw of just 1.2–1.5 kW. Its compact design reduces vibration and noise, making it ideal for sensitive applications such as superconducting single-photon detectors (SSPDs), quantum technologies and other applications where space and low interference are critical. The CNA-11R's low-profile build allows for seamless integration into laboratory and industrial systems where every inch counts. Fully compatible with SHI's RDK-101D(L) (0.1W@4K) Gifford-McMahon cryocoolers, it delivers reliable performance in environments where space, quiet operation and flexibility are essential. **www.shicryogenics.com**

People & Companies in Cryogenics

OPW Clean Energy Solutions has unveiled updated logos for its sub-brands – Superior Products, Rockwood Swendeman, Special Gas Systems (SGS) B.V. and Cryogenic

New brand images. *Credit: OPW*

Experts, Inc. (CEXI) – to reflect its growing portfolio of cryogenic and flow control technologies. These rebranded divisions enhance OPW CES's ability to deliver end-to-end solutions across hydrogen, LNG, helium and industrial gas markets. The update supports OPW's ongoing commitment to innovation, customer-focused service and global clean energy leadership, building on recent acquisitions and the technical strengths of its hero brands like ACME Cryogenics, RegO and Demaco (all three CSA CSMs).

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Ratermann Manufacturing (CSA CSM) has been certified as a Great Place to Work®, recognizing its strong commitment to a positive, supportive workplace culture. Based on anonymous employee feedback, the certifi-

Mary Ratermann Carter. *Credit: Ratermann*

cation highlights Ratermann's dedication to trust, collaboration, and professional growth, reinforcing its reputation as an employer of choice in the industry.

Ratermann is also proud to announce that **Mary Ratermann Carter** has joined its Cryogenics Division, where she will lead Cryogenic Business Development initiatives. In this role, Mary will collaborate with customers across emerging industries – including aerospace, semiconductor, pharmaceutical, and more – to support and connect them with the best cryogenic solutions.

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Alberta-based **Deep Cryogenics International** (DCI) launched its first U.S. deep cryogenic treatment (DCT) operation in Longmont, Colorado, just north of Denver. The facility serves the mining, road construc-

Linda Williams, president of DCI, and Jack Cahn, DCI's chief technologist. *Credit: DCI*

tion, energy, and aerospace industries across the American West. In addition to housing the only deep cryogenic applied research lab focused on the mining industry, the site features the world's largest DCT chamber – measuring 8' x 8' x 20' and capable of processing payloads up to 45,000 pounds.

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Alice & Bob, a leading developer of fault-tolerant quantum computing technology, has announced plans to build a $50 million, 4,000 m² quantum computing

Alice & Bob founders Théau Peronnin and Raphaël Lescanne. *Credit: Alice & Bob*

laboratory in Paris, supported by **Quantum Machines** and **Bluefors** (CSA CSM). Funded by its recent $103 million Series B round, the facility will serve as a hub for developing Alice & Bob's next-generation cat qubit-based quantum chips – lithium, beryllium and graphene – and will include a nanofabrication cleanroom and a cryostat farm with 20 Bluefors dilution refrigerators. The lab will feature Quantum Machines' hybrid control systems and will reserve space for graphene, Alice & Bob's planned 100-logical-qubit quantum computer. Aimed at accelerating the shift from research to commercialization, the lab represents a major investment in French and European quantum infrastructure and is expected to significantly advance the development of scalable, hardware-efficient quantum systems.

Meetings & Events

CRYOCO Cryogenic Engineering and Safety Course
July 14-18, 2025
Golden, Colorado
www.cryocourses.com

CSA Short Course: Cool Fuel - The Science and Engineering of Cryogenic Hydrogen
July 22, 2025
Virtual
2csa.org/short-course

30th International Conference on Low Temperature Physics
August 7-13, 2025
Bilbao, Spain
www.lt30.es

European Conference on Applied Superconductivity (EUCAS)
September 21, 2025
Porto, Portugal
https://eucas2025.esas.org

European Cryogenic Days & Cryogenic Heat and Mass Transfer Workshop 2025
October 27-30, 2025
Twente, Netherlands
https://www.ecd-chmt.com

24th International Cryocooler Conference
June 2026
Syracuse, NY
https://cryocooler.org

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