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The Magazine of the Cryogenic Society of America, Inc.

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A monumental program centered on ovarian tissue cryopreservation is offering hope to women and girls across Canada. This medical procedure safeguards healthy ovarian tissue before cancer treatments can harm it, ultimately enabling female patients to have biological children in the future.
Credit: Royal University Hospital Foundation

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

From the Executive Director

As the autumn leaves turn vibrant shades of red and gold and the air takes on a crisp chill, I am delighted to welcome you to the November issue of *Cold Facts*. With the holiday season on the horizon, this month is a time of reflection and gratitude. With that being said, I'd like to express our thanks to all of you – our readers, contributors and advertisers – who make this magazine possible. THANK YOU!

In this month's issue of *Cold Facts*, we are excited to introduce a brand-new column titled "Quantum Corner." This recurring column will feature anything and everything quantum related, especially as it pertains to cryogenics and superconductivity. We are happy to welcome Ioana Craiciu as the author of this column. Ioana is a Postdoctoral Scholar in the Microdevices and Sensor Systems Section at NASA's Jet Propulsion Laboratory. She obtained an undergraduate degree in Nanotechnology Engineering from the University of Waterloo, followed by a Ph.D. in Applied Physics from Caltech. Her research interests lie at the interface of engineering and physics. In her Ph.D. thesis work, she built quantum memories for light using nanostructured resonators coupled to ensembles of rare earth ions. At JPL, she is part of the superconducting devices group, where she is working on designing, testing and optimizing superconducting nanowire single photon detectors.

In more brand-new news, CSA recently launched its new Online Learning & Publications portal. This portal provides valuable reference materials authored by world-leading cryogenic experts. From detailed course notes on major topics to recordings of past short courses, these valuable resources provide necessary tools for researchers, students, scientists and industry professionals. The Online Learning & Publications portal will be updated regularly with new content, so make sure to check back often! To access the portal, visit **http://2csa.us/lms**. We hope you find this new online tool to be useful and user friendly! If you have any content you'd like to add to the portal, please let us know.

I also want to remind you that CSA offers a variety of other online resources for the cryogenics community. One of the more popular resources is the CSA Job Center. This job center is your clearinghouse for cryogenic jobs, whether you are an employer looking for an employee or an individual seeking employment. CSA members receive free job postings, while non-members can post at a nominal fee. All job seekers can utilize the job center free of charge. Visit the following link to check out the CSA job center: **http://2csa.us/jobs**.

As always, we hope you find this issue of *Cold Facts* enjoyable and informative!

Dr. Atefeh Najafi, Ph.D., gives a tour of the Benson Cryobiology Lab to a group of high school students. *Credit: Royal University Hospital Foundation*

Ovarian Tissue Cryopreservation Offers Hope in Canada

by Matt Olson, University of Saskatchewan

A monumental program centered on ovarian tissue cryopreservation is offering hope to women and girls across Canada. Dr. James Benson, a world-renowned cryobiology expert, leads this transformative initiative. This medical procedure safeguards healthy ovarian tissue before cancer treatments can harm it, ultimately enabling female patients to have biological children in the future. Dr. Benson's innovative approach involves extracting and preserving unaffected ovarian tissue, preventing its damage from the harsh effects of chemotherapy, radiation and surgery. Remarkably, Dr. Benson is one of the few pioneering research in reproductive cryobiology in Canada. He holds the position of associate professor in the Department of Biology at the University of Saskatchewan's (USask) College of Arts and Science, playing a pivotal role in the concerted effort to establish an outstanding cryobiology research program at USask.

"I think it hits on a lot of different levels," Benson says. "We're really providing a service for women, but especially girls in need at a particularly vulnerable time. And the fact that we've got the infrastructure in place means that USask can be a beacon of hope."

In the aftermath of cancer remission, the preserved ovarian tissue can be re-implanted, paving the way for the birth of a biological child. Benson emphasizes that this process has demonstrated significant success rates in helping children, adolescents and women of reproductive age achieve healthy pregnancies.

Ovarian tissue cryopreservation has transitioned from an experimental phase to mainstream practice in recent times. While Europe and the United States boast established clinical and research programs for this procedure, its availability in Canada remains limited.

"There is no option in Saskatchewan for some women and most girls with cancer that want to have fertility preservation," Benson explains. "Some women can preserve their egg cells before treatment, but girls don't have any mature egg cells. The only option they have is to freeze this tissue. There have been a number of successes around the world. It's a great program that just needs to be offered [in more places]."

Dr. Laura Hopkins, MD, a professor in the Division of Oncology at USask's College of Medicine and the provincial lead for gynecologic oncology, underscores the potential of this service to restore choice to women whose options have been curtailed by cancer. According to Hopkins, pediatric ovarian tissue is especially susceptible to the adverse effects of cancer treatments, and the sole recourse for girls under 13 is ovarian tissue cryopreservation technology.

"Being treated for cancer, whether it's surgery, chemo or radiation, is isolating for everyone, and I think there's a real loss of confidence and hope for the future," she elaborates. "These kids also face a loss of

fertility and a loss of potential to have normal hormone production for sustaining health. Fortunately, most children nowadays are cured of their cancer. They are cancer survivors, and we need this program to give them their lives back."

Hopkins also points out that instituting a cryopreservation program would align Saskatchewan with the care and fertility preservation guidelines of the Canadian Fertility and Andrology Society, an esteemed nonprofit organization dedicated to advancing reproductive sciences in Canada. Both Benson and Hopkins are optimistic about USask's potential to pioneer such a program in Western Canada, thanks to the unique expertise of the faculty and the existing university facilities.

In 2021, Hopkins secured funding to advance research in ovarian cancer pharmaceuticals and diagnostics, along with establishing a tumor bank at USask for the safe storage and study of excised cancerous tissue. Additionally, Benson highlights the presence of numerous cryobiology-experienced researchers at USask, including those at the Western College of Veterinary Medicine (WCVM).

"By building this program, we could be modeling what the future state of a program in ovarian cryopreservation should look like," Hopkins continues. "We happen to have James Benson here, and I feel like all of us should do everything to support unique talent within the institution."

Krysta Hawryluk, a patient of Dr. Hopkins, serves as a living testament to the urgency of establishing a fertility preservation program. In early 2020, Hawryluk, initially believing she had endometriosis, received a devastating ovarian cancer diagnosis. Within weeks, she underwent surgery to remove her ovaries. When diagnosed in Saskatchewan, the option of cryopreservation was never on the table. Hawryluk, at the age of 28, had to undergo surgery to combat her cancer, leaving her without the ability to have biological children.

"During that time, I would have taken any chance; I would have taken a two percent chance to have a baby," Hawryluk says. "Any kind of hope is just enough when you're dealing with something as serious as your health." Hawryluk has since become a vocal advocate for making this service available throughout Canada, having learned from Hopkins that such treatment exists but wasn't accessible in her home province. "I think that everyone should have that opportunity to make the choice to have their own children. Having that choice taken away from me was the hardest because whether you can have a child or not shouldn't be fate's decision," she concludes.

Both Hopkins and Benson harbor hope that, with institutional and healthcare professional support, a program can be established to offer optimal care to patients like Hawryluk. "This is an evolving science where the success rates are going up every year as technology advances," Hopkins says. "We've got the scientific expertise, and we also have the need to make this ovarian tissue cryopreservation available to patients in Saskatchewan." **www.usask.ca**

Advancing Prostate Cancer Treatment: Focal Cryoablation's Efficacy Explored

by Anwar Khan and Ansar U. Khan, Fremont Urology Health Center, and Larry Siref and Michael Feloney, Creighton University School of Medicine

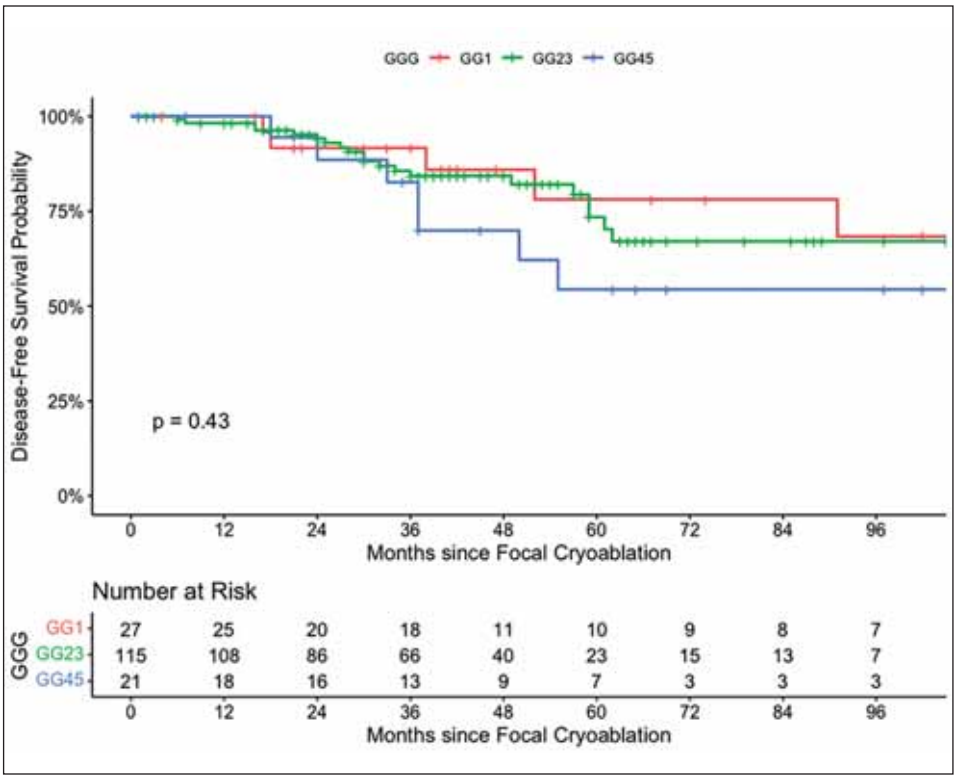
Introduction

Prostate cancer ranks among the most prevalent malignancies afflicting men today, standing as a prominent concern in both urology and oncology. The historical use of cryoablation, a technique involving freezing of the prostate tissue, dates back to the 1960s. This early approach was fraught with significant morbidity. However, a resurgence of interest emerged in 1993 with the introduction of transrectal ultrasound guidance for real-time monitoring of the procedure. Contemporary guidelines offered by the American Urology Association (AUA) present various treatment options for localized prostate cancer (PCa), encompassing surveillance, prostatectomy, radiation therapy, cryosurgery, and high intensity focused ultrasound therapy (HIFU). While treating the entire prostate gland has demonstrated efficacy, it often incurs severe side effects such as erectile dysfunction and urinary incontinence, thus undermining patients' quality of life. To mitigate these drawbacks, focal ablative therapies like focal cryoablation (FC) have emerged as a promising alternative. This article delves into the nuances of FC's effectiveness and outcomes, particularly in addressing intermediate and high-risk prostate cancer.

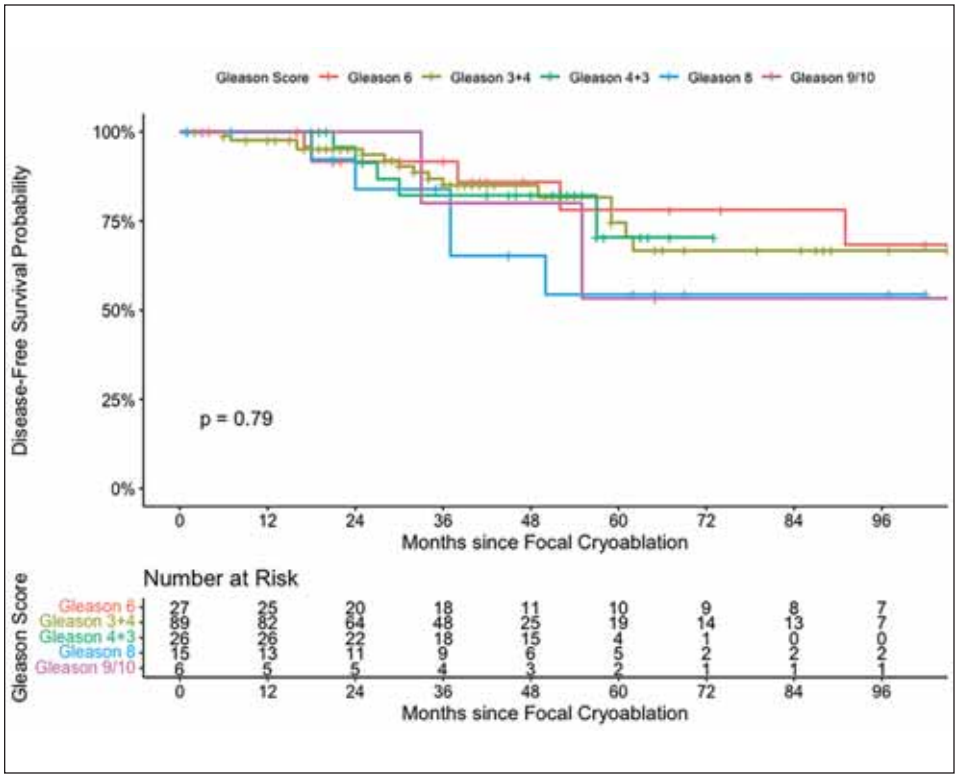
Focal Cryoablation: A Promising Approach

Focal cryoablation has garnered attention as a potential solution to the limitations associated with whole gland treatments. The technique aims to arrest tumor progression while preserving erectile and urinary functions, an important consideration for patients' well-being. While studies in 2002 documented the use of focal therapy for prostate cancer, it's with the advent of multiparametric MRI that interest in this modality regained momentum. However, the suitability of focal therapy for intermediate and high-risk prostate cancer remains a subject of debate. Recent research suggests that only a subset of patients,

▶ *continues on page 12*



Focal cryoablation using Kaplan-Meier and Log-rank by Gleason Grade Group (2008-2020). *Credit: Gleason Grade*



Focal cryoablation using Kaplan-Meier and Log-rank by Gleason Score (2008-2020). *Credit: Gleason Grade*

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typically those with a maximum Gleason Score of 4+3 (or Gleason Grade Group 3) and specific histologic profiles, are suitable candidates for focal therapy. Notably, focal therapy had primarily been considered for low or intermediate-grade cancers in the past. This study seeks to contribute to the growing body of literature by examining 163 patients with varying grades of prostate cancer who underwent FC between November 2008 and December 2020, with a median follow-up of 39 months.

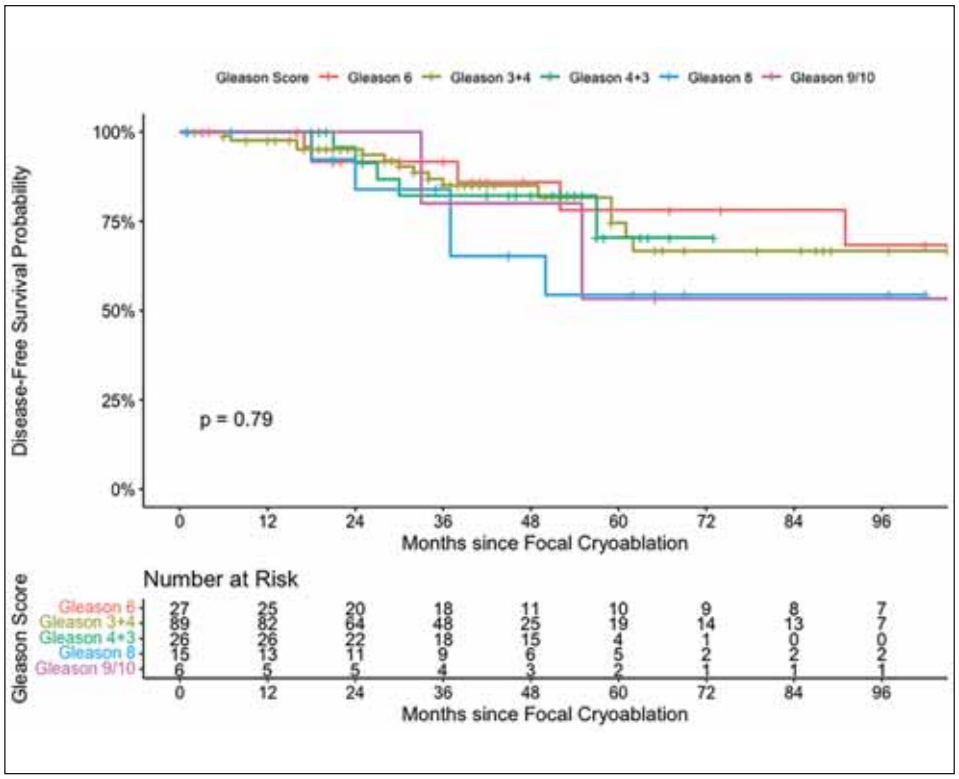
Unpacking the Study: Methods and Results

The retrospective cohort of 163 patients underwent FC, and their progress was meticulously monitored for biochemical recurrence (BCR), an important oncologic outcome. Biochemical recurrence was defined according to the American Society for Radiation Oncology (ASTRO) guidelines, encompassing either three consecutive PSA increases exceeding 0.5 ng/mL or a PSA level surpassing the nadir by 2 ng/mL. After undergoing FC, patients demonstrated a substantial reduction in PSA levels, with a median post-operative PSA of 1.39 ng/mL. The study's pivotal findings shed light on biochemical disease-free survival rates at the five-year mark, with percentages of 78%, 74%, and 55% for low, intermediate, and high grade cancers respectively.

Importantly, genetic risk stratification, through the Decipher score, revealed comparable BCR rates to patients who did not undergo genomic testing. This underscores the potential utility of genomic testing in prognostication. Despite not yielding statistically significant results, univariate hazard ratios (HRs) were employed to assess factors such as pre-operative PSA, Decipher score, and Gleason Grade Groups for their impact on BCR.

Balancing Efficacy and Quality of Life

The study's discussion emphasizes the broader context surrounding focal ablative therapies. A comparative overview highlights the efficacy of different modalities, such as high intensity focused ultrasound therapy (HIFU) and photodynamic therapy, in attaining disease-free survival and reducing the need for radical therapy. Although limitations within the study, such as its single-center, single-physician design and possible underreporting of side effects by patients, are acknowledged, the overall picture is one of progress.



Focal cryoablation using Kaplan-Meier and Log-rank by Decipher score. *Credit: Gleason Grade*

Conclusion

The study's results contribute to our understanding of focal cryoablation's efficacy in contrast to traditional whole gland treatment. The delicate balance between cancer control and preservation of quality of life, particularly concerning erectile function and urinary continence, underscores the value of focal therapy. While this study doesn't definitively establish FC's complete effectiveness, it does shed light on favorable PSA kinetics at the five-year mark, an encouraging indicator of progress. As further investigations unfold and accumulate, the viability of focal cryoablation as an efficacious treatment option for prostate cancer, particularly for high-risk cases, continues to gain credence.

The Gleason grading system is used to help evaluate the prognosis of men with prostate cancer using samples from a prostate biopsy. Together with other parameters, it is incorporated into a strategy of prostate cancer staging which predicts prognosis and helps guide therapy.

SCIENTIFIC INSTRUMENTS

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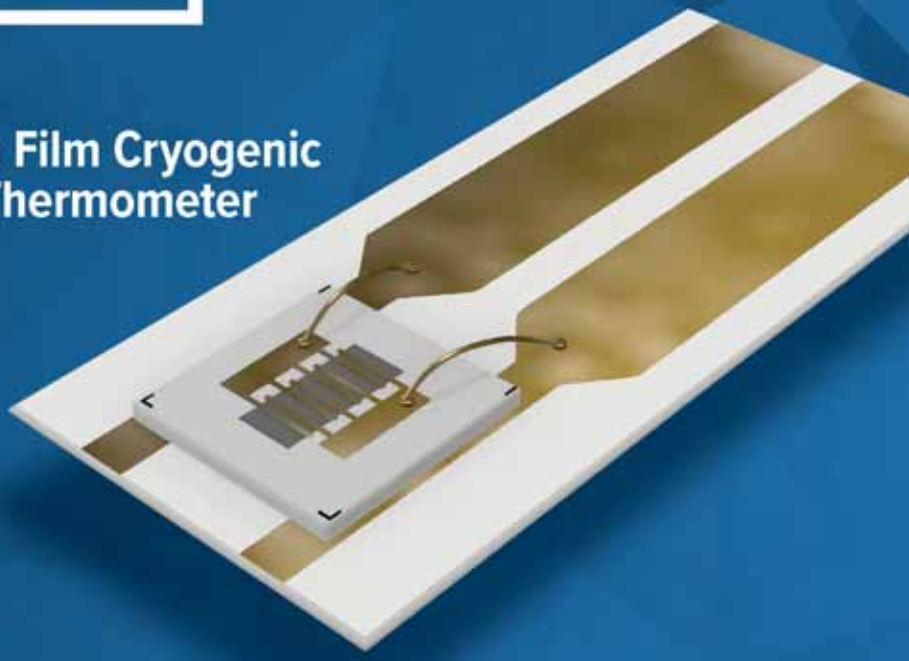

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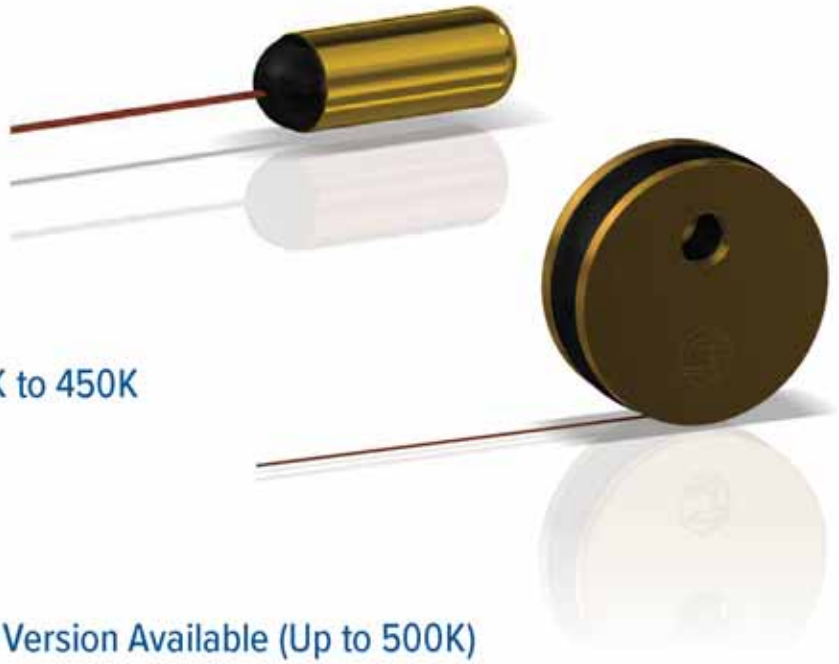

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Cryogenic Equipment Impacts Life Sciences

by Greg Parra, AVCO Vice President

"It's too hot, it's too cold." We have all heard those famous words from family, friends, coworkers or feedback from instrumentation. Whether it is to control temperature in a confined environment, rotating equipment, or bioprocessing, cryogens are utilized throughout industries.

At times, valves are overlooked as an integral part of the equipment's performance and reliability. Not all ball valves are created equal. Valves are designed to stop/start and control the flow rate of cryogens. Failure to meet these fundamentals results in higher operating costs, equipment failure and bio process failures.

There are different types of equipment and processes for controlling cryogens in bioprocessing, pharmaceuticals, life sciences, medical devices, semiconductors, military and space. In this article, we will review the use of ball valves in life sciences, pharma, and medical devices.

AVCO 2500 Series ball valve with manual operator. *Credit: Greg Parra*

AVCO 2500 Series vee-port ball valve with pneumatic actuator. *Credit: Greg Parra*

The industry standard for the design of valves, tubing, and fittings is included in ASME BPE-2022. This standard specifies the requirements for the design of bioprocessing equipment in the aforementioned industries. The particular applications and equipment include water for injection (WFI), pure water (PW), point of use (POU), integrated heat dissipation module (IHDM), heat exchange module (HEM) and magnetic resonance imaging (MRI). Providing cryogenic valves that meet or exceed industry standards is the challenge.

The performance of the valve should be based on the ability to prevent external and internal leakage with temperature swings from -320 °F to 250 °F. The inherent problems with differential temperature are the thermal expansion and contractions of valve material. In addition, there are varying degrees of expansion rates for all materials as well as the rotational force between the ball and seat.

AVCO has engineered the 2500 series to account for thermal expansion and rotational forces to provide a proven performer. The design features provide for positive sealing both internally and externally. The benefit to the end user is a lower cost of ownership. AVCO's ability to deliver is based on commercially off-the-shelf (COTS) interchangeable components. This includes, but is not limited to valve body, ends, ball, seats and seals.

AVCO valves and components are designed to meet the following industry standards: ASME B16.34, BS 6364 and ASME BPE 2022. These standards, also ensure the safety of plant personnel. Additionally, Alloy Valves & Control practices safety procedures within our facility and in the design of our products. Our motto is "Safety: first, last and always."

As with all AVCO 1000 and 2000 series valves, there are options for various vee-port balls for the rate of flow. Operators include pneumatic and electric actuators. The pneumatic actuators can be supplied double-acting or spring return with analog or digital positioners. The digital positioners are available with HART, Foundation Fieldbus, or Profibus communication. For open-close feedback, we have available both mechanical and proximity switches. Electric actuators are provided in open/close or with 4-20 mA input/output signal. The supply voltage is 120VAC to 12/24VDC.

Increasing the reliability of processing equipment is the goal of machine operators, plant engineers and plant managers. This will correlate to increasing the quality of the end product and data points from the test lab – whether the test lab is an environmental arena or a test article. For the purchasing manager, a product that is competitively priced and delivered in a timely manner will improve the efficiency of the facility and ensures the client receives the product they requested. Back to the original question, "Are all ball valves created equal?" The simple answer is no. **www.avcovalve.com**

Iktos and Curreio Forge Alliance for AI-Driven Drug Discovery

Cryo-electron microscopy (cryo-EM) is a powerful imaging technique used in structural biology to visualize biological macromolecules and complexes at the atomic or near-atomic level. It has revolutionized the field of life sciences by allowing scientists to obtain high-resolution three-dimensional structures of biomolecules, such as proteins, nucleic acids, and viruses, in their native, hydrated state. Now, a new alliance is accelerating structure-based drug discovery using AI and advanced microscopy techniques.

Iktos, a pioneering Artificial Intelligence (AI) entity focused on innovative drug design, has joined forces with Curreio, Inc., a Japanese trailblazer in cryo-electron microscopy-based bio-molecule structural analysis, to announce a dynamic collaboration in the realm of AI-powered drug innovation. This partnership pairs Iktos' groundbreaking generative design technology, Makya™, with Curreio's cutting-edge cryo-EM platform, in a concerted effort to expedite the cost-efficient creation of groundbreaking preclinical drug candidates targeting an undisclosed objective.

Iktos' Makya™ generative AI technology ushers in a new era of molecular exploration by autonomously crafting virtual novel molecules aligned with desired disease-treating attributes. This approach radically enhances chemical space exploration, yielding innovative molecule blueprints endowed with optimized predicted properties, operational latitude, and intrinsic synthetic accessibility. The integration of Iktos' Spaya™ retrosynthesis AI technology further empowers the process, addressing the multifaceted challenge of identifying molecules that fulfill a gamut of criteria – potency, selectivity, safety, and project-specific requisites.

The synergy between Iktos' generative AI and Curreio's cryo-EM-generated insights will channel a structure-based modeling approach, maximizing protein-ligand interactions while harmonizing with the project's Target Product Profile (TPP).

Cryo-EM-based structural analysis stands at the forefront of biomolecular structural elucidation, achieving the prestigious Nobel Prize in Chemistry in 2017. Curreio's mastery of this analytical technique, particularly in single-particle structure analysis, eliminates the need for crystallization and enables analysis in aqueous solutions. Their prowess in protein sample production, purification, grid preparation, and 3D structural analysis expands horizons in drug discovery for challenging protein and protein-supra-molecular complex targets.

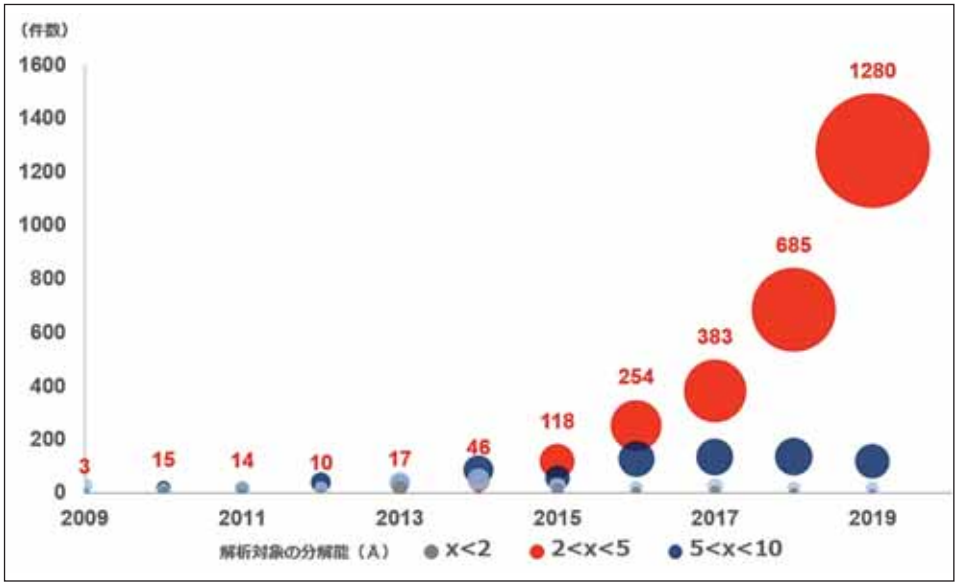

Figure 1: Changes in the number of protein analyzes by cryo-EM. *Credit: Protein Data Bank, Japan*

Yann Gaston-Mathé, co-founder and CEO of Iktos, remarked, "We are thrilled to collaborate with Curreio, a specialist in biomolecular structural analysis, to accelerate structure-based drug discovery. Our innovative technology platforms will synergize to usher in new frontiers in drug innovation."

Motoki Nakai, founder and CEO of Curreio, Inc., expressed enthusiasm, stating, "We have high hopes that this joint research, utilizing our cryo-electron microscopy (cryo-EM) technology, will greatly accelerate our unique structure-based drug design efforts."

Founded in 2016, Iktos is a French AI-driven chemical research start-up pioneering solutions for medicinal chemistry and drug design. Utilizing deep learning generative models, Iktos optimizes molecules in silico, streamlining small molecule discovery projects and enhancing pharmaceutical R&D productivity. The company offers its innovative technology through professional services and the Makya™ SaaS software platform, while also developing Spaya™, an AI-based synthesis planning software for retrosynthesis.

On the other hand, established in 2019, Curreio is a drug discovery startup specializing in cryo-EM structural analysis technology. With expertise in protein production, purification, grid preparation, and 3D structural analysis, Curreio enables top-tier cryo-EM-based structural analyses. The company's initiatives span internal/collaborative drug discovery projects and support services for pharmaceutical firms, aiming to expand the horizons of drug discovery for challenging protein and protein-supramolecular complex targets. **www.iktos.ai** and **www.curreio.com**. *Source: Curreio.*

Unleashing Hydrogen—a Paradigm Shift in Energy Storage and a Sustainable Future

by Jason Few, President and CEO, and Tony Leo, FuelCell Energy, Inc.

As the wheels of innovation propel society forward, some elements of our technological landscape remain entrenched in the past, seemingly impervious to the tides of change. The heating oil tank, a relic from a different era, stands as a testament to this phenomenon. In a time when the urgency of sustainable energy solutions has never been greater, the persistence of this inefficient and high carbon intensity component raises concerns and challenges us to rethink the status quo.

At its core, the heating oil tank functions as a reservoir of potential energy, converting stored oil into heat as needed. Parallels can be drawn to the batteries within our devices—holding energy in anticipation of its eventual demand. However, this concept of energy storage is far from mundane; rather, it is a cornerstone in the journey towards achieving clean electricity capable of powering our lives sustainably. Yet this critical piece of the puzzle calls for a revolutionary transformation, a shift of focus towards a resource that holds immense promise: hydrogen.

Hydrogen, the universe's simplest and most abundant element, harbors within its atomic structure unparalleled energy potential. While we encounter hydrogen in compounds like water (H_2O), pure hydrogen's lightweight nature causes it to escape Earth's gravitational pull, making it a rare sight. However, through the process of electrolysis, which marries renewable electricity and water, we have the means to unlock zero-carbon hydrogen—an ideal medium for energy storage.

Step onto the stage FuelCell Energy, a pioneer in fuel cell solutions, spearheading the integration of hydrogen into the landscape of clean energy storage. Our cutting-edge solid oxide electrolysis system leads the efficiency charge, employing electrolysis to convert water into its elemental forms: hydrogen and oxygen. This stored hydrogen emerges as a powerful resource, ready to fuel electricity generation through fuel cells, all the while leaving no detrimental emissions in its wake.

Solid oxide nuclear applications. *Credit: FuelCell Energy, Inc.*

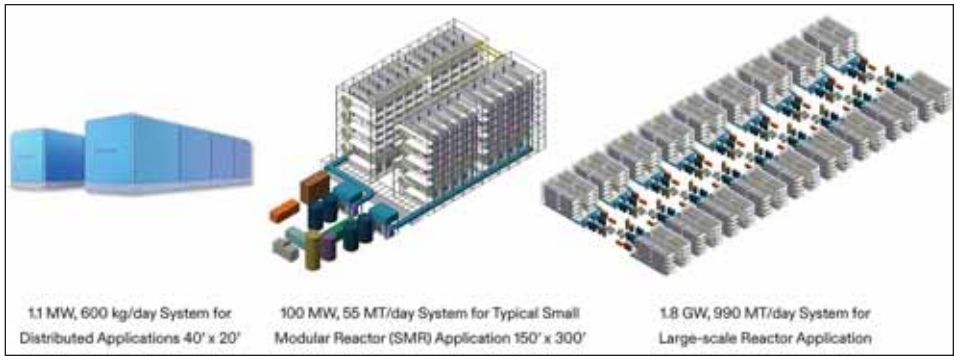

Diagram of hydrogen production from nuclear energy. *Credit: FuelCell Energy, Inc.*

The implications of hydrogen's potential stretch well beyond its role as a cleaner energy alternative. Its superior energy density compared to traditional fossil fuels highlights its inherent efficiency, effectively curtailing our dependence on ecologically harmful resources. Beyond this, hydrogen can address the volatile nature of renewable energy sources, providing stability by mitigating fluctuations and guaranteeing an unwavering power supply.

This transition towards hydrogen-based energy storage has gained substantial momentum, with governments and corporations alike investing in research and infrastructure. As the global drive towards sustainability and carbon neutrality accelerates, the imperative to embrace innovative energy solutions like hydrogen becomes all the more compelling.

Hydrogen's impact spans a broad spectrum, presenting an eco-friendly footprint that positions it as a transformative force for a clean and resilient energy ecosystem. The paradigm shift it can trigger echoes the transformative influence of inventions such as the telephone and the incandescent lightbulb

▶ *continues on page 18*

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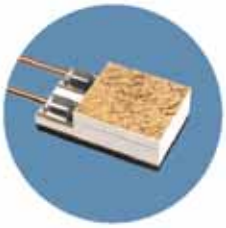

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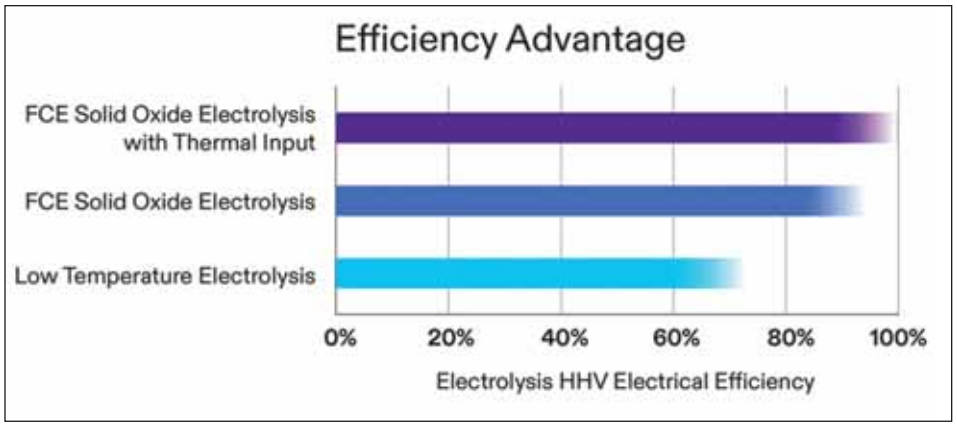
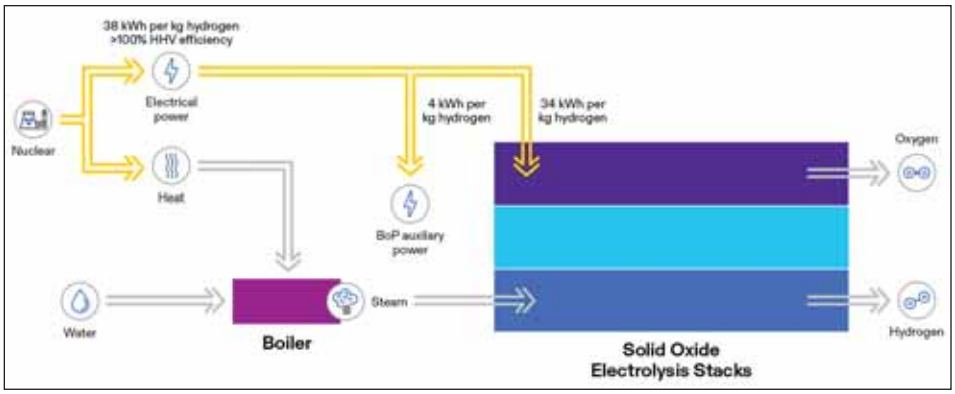
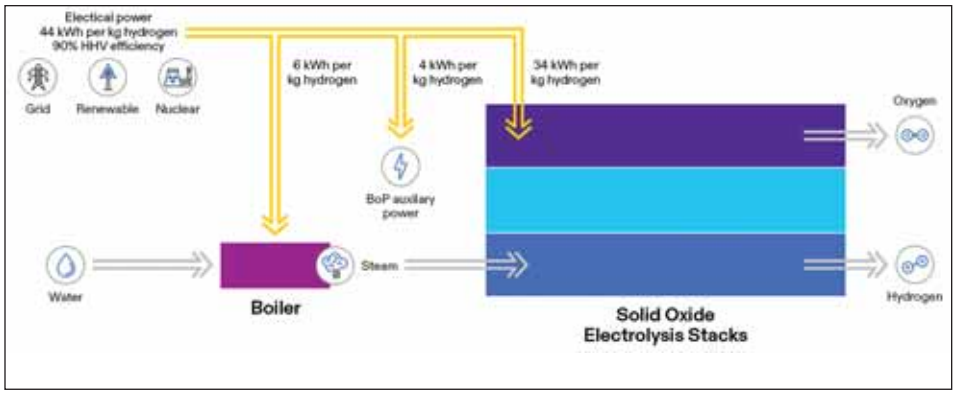


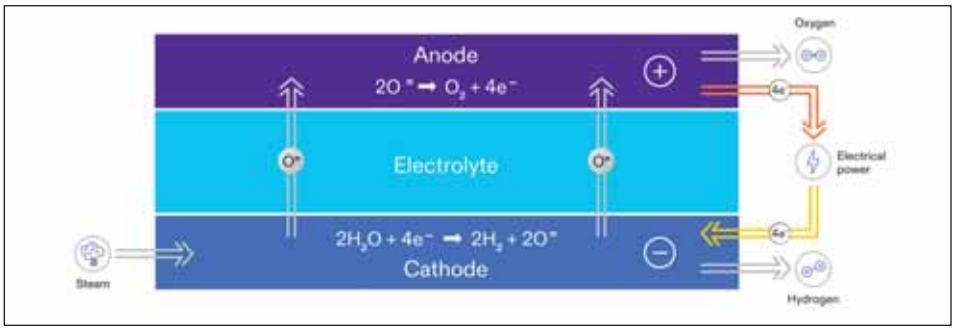
Solid oxide electrolysis schematic. *Credit: FuelCell Energy, Inc.*



Solid oxide electrolysis efficiency graph. *Credit: FuelCell Energy, Inc.*



Solid oxide electrolysis energy use. *Credit: FuelCell Energy, Inc.*



Solid oxide electrolysis efficiency benefits. *Credit: FuelCell Energy, Inc.*

Hydrogen Dominates CEC/ICMC'23 as Engineers Advocate Small-Scale Liquefaction, Storage

by Greg Gosnell, CEO, GenH2

Interest in hydrogen is skyrocketing, but this new "hype cycle" is dramatically different. As the energy world turns its attention to viable hydrogen solutions, it's increasingly clear that small-scale hydrogen infrastructure is a critical component to accelerate adoption. Why does small-scale matter? The current focus in hydrogen infrastructure revolves around large centralized hubs, but there's an urgent need for smaller, modular solutions that are more flexible and quicker to deploy, meeting the surging market demand. This is especially vital for research, development and testing of new hydrogen products, where small quantities of hydrogen must be readily available for experimentation in various settings. Large-scale systems fall short in fulfilling this demand, underscoring the necessity of smaller systems to propel the hydrogen economy forward.

Furthermore, commercial markets will require hydrogen at the point of end use, particularly in areas where geographical constraints limit the feasibility of large-scale systems. Distributed liquid hydrogen infrastructure will play a pivotal role in catering to the needs of long-haul trucks, aviation, ships, trains and more. Industrial-scale liquefaction and storage systems offer space efficiency and the necessary flexibility to support the expansion of commercial hydrogen applications. The heightened demand for liquid hydrogen infrastructure has also given rise to innovative cryogenic solutions aimed at mitigating hydrogen loss during transfer and storage. Cutting-edge technology, combining advanced insulation systems with active refrigeration, has nearly eradicated these losses, rendering hydrogen more economically viable at the pump.

The recently concluded Cryogenic Engineering Conference and International Cryogenic Materials Conference (CEC/ICMC'23) in Honolulu, Hawaii, served as a testament to the escalating interest in hydrogen and the growing need for small-scale and distributed solutions. The $GenH_2$ team, composed of leading experts in hydrogen infrastructure and cryogenics research, including Executive Vice President and Chief Architect James Fesmire, Chief Technology Officer Dr. Jong Baik, Product Development Engineer Marco Guerrero, and Lead Mechanical/Fluid Systems Engineer Peter Higgins, actively participated in the event. The presentations delivered by Fesmire, Guerrero, and Higgins emphasized the significance of small-scale equipment, garnering significant attention from an audience more accustomed to large-scale hydrogen solutions. Their presentations elucidated how $GenH_2$ has developed small-scale liquefaction capabilities to support the testing of new hydrogen technologies for storage and transfer. These small-scale solutions will play a pivotal role in expediting the expansion of hydrogen infrastructure.

GenH2's unique system efficiently liquefies hydrogen without the need for liquid nitrogen pre-cooling. *Credit: GenH2*

Small-Scale Liquefaction and Storage

Guerrero's presentation, titled "Mobile Hydrogen Liquefaction and Storage System," provided a comprehensive overview of the current status of this technology, discussing system design, fabrication, operational methodology, and test performance results. A mobile hydrogen liquefaction and storage unit has been meticulously crafted to demonstrate the entire liquid hydrogen (LH_2) value chain, encompassing hydrogen production, liquefaction, storage, transfer, and recovery. The LS20 mobile system, a unique LH_2 technology demonstrator, serves as a primary component of a multipurpose LH_2 test platform, designed to test liquefaction, controlled storage, and zero-loss transfer methodologies.

The LS20 system, meticulously designed, fabricated, and tested at $GenH_2$, incorporates several primary subsystems, including an electrolyzer, gas precooler, Ortho-Para hydrogen converter, cryocooler-based hydrogen liquefier, portable LH_2 storage tank, ultralight LH_2 fuel tank for aviation applications, safety devices, sensors, an

▶ *continues on page 20*

GenH2's controlled refrigerated storage guarantees zero hydrogen loss through its advanced insulation and refrigeration techniques. *Credit: GenH2*

The GenH2 LS20 offers compact, on-demand liquid hydrogen for various applications, including backup power, emergency response, and clean energy storage. *Credit: GenH2*

automated venting system, and associated instrumentation and control systems. The system successfully demonstrated continuous hydrogen liquefaction in accordance with design specifications, facilitated by an automated control system that maintains the liquid at the desired level, minimizing boiloff loss.

Additionally, the system showcased the functions of zero-loss transfer, boiloff gas recovery, and re-liquefaction. These results provide proof-of-concept data critical for future LH_2 infrastructure design and the essential LH_2 refilling and servicing methodology for various hydrogen mobility applications.

Distributed Hydrogen Liquefaction

Higgins' presentation, "Small-scale Industrial Hydrogen Liquefaction," divulged details about a small-scale industrial 1,000 kg/day hydrogen liquefaction plant (HLP), known as LS1000, currently in detailed design and scheduled for operation in 2024. This plant is set to achieve localized, efficient on-demand hydrogen production in remote or strategically advantageous locations for transportation, minimizing or eliminating the complications, costs, and evaporative losses associated with LH_2 transportation logistics.

The LS1000's chief advantages include safety, reliability, modularity, cost-effectiveness, freedom in site selection, and the ability to harness renewable energy sources. At its core, the LS1000 employs a closed-loop helium Brayton cycle to achieve temperatures well below the liquefaction threshold, followed by storage and maintenance of LH_2 with zero losses or densification via a helium side stream from the refrigeration cycle. The system's use of low pressure helium enhances safety compared to other hydrogen liquefaction cycles. The compact liquefier design with minimal major components inside the vacuum vessel simplifies the system, increasing reliability, enabling a high degree of automation, and simplifying maintenance to reduce downtime. The LS1000 is also scalable to accommodate varying production capacities per unit or to cool mega-scale LH_2 storage tanks, without the need for LN_2 pre-cooling, making it suitable for remote areas with available electricity or where local electricity production capacity exists, such as in natural gas fields.

LH_2-Controlled Storage/ Transfer

Fesmire's presentation, "Simulation Test Platform for LH_2 Controlled Storage/ Transfer," underscored the growing necessity for clean energy propulsion machines, such as trucks, tractors, ships, and aircraft, to transition to onboard liquid hydrogen (LH_2). However, the established methods of storage and transfer pose challenges due to losses, especially for sporadic or on/off duty-cycle applications.

Integral servicing system methodology is imperative for safety and cost-effectiveness, driven by time savings, product preservation, and minimized venting exposures. Modern controlled storage technology facilitates quick and effective vehicle servicing at the point of use. Simulations of controlled storage/transfer (CS/T) methodologies were conducted using a multipurpose LH_2 simulation test platform featuring two primary systems: the Cryostat CS900 tank and transfer system and the LS20 liquefaction/refrigeration and storage system.

Testing covered both steady-state and transient operation modes, demonstrating zero boiloff (ZBO) and zero-loss transfer (ZLT) modes. These tests served diverse technical purposes, including product development for tanks, refrigeration, transfer systems (lines, dispensers, pumps, valves), experimental validation of analytical models and thermofluidic properties, thermal insulation performance testing under relevant conditions, thermophysical characterization of materials and structures, instrumentation and sensor development, and tank boiloff and heat flux engineering design data. The comprehensive paper provided detailed descriptions and preliminary test results, along with thermal performance analyses derived from real-world testing and experimentation.

Small-scale hydrogen liquefaction and storage solutions stand as the linchpin for propelling the widespread adoption of hydrogen and propelling the ongoing "hype cycle" to new heights. The recent CEC/ICMC'23 event served as a vivid testament to the escalating enthusiasm surrounding hydrogen and underscored the urgent demand for small-scale, distributed solutions. These innovations hold the key to shaping a sustainable future powered by hydrogen. **www.genh2hydrogen.com**

Bi-Directional Floating Ball Valve Technology Revolutionizes Cryo Systems

by Ido Navon, Habonim

In the realm of cryogenic applications, Habonim has pushed the boundaries of innovation with the latest addition to its product lineup: the Cryogenic Bi-Directional Floating Ball Valve. Over the past 30 years, Habonim has pioneered high-end cryogenic ball valves for a diverse range of applications and industries. With the surge in popularity of cryogenic technologies driven by the widespread adoption of liquefied natural gas (LNG), the demand for advanced, cost-effective solutions has become paramount.

The rise of Small-Scale LNG (SSLNG) and the global trading of LNG have set the stage for an unprecedented market expansion. Collaborating closely with industry leaders in cryogenic systems and equipment, Habonim identified the superiority of floating ball valve technology over traditional valve designs. Enhanced flow rates, simplified automation, improved durability and reduced costs established floating ball valves as a clear frontrunner in cryogenic applications.

Overcoming Limitations

Historically, cryogenic floating ball valves suffered from a unidirectional limitation due to an inner-ball pressure relief hole. However, Habonim has defied this constraint with the development and successful implementation of its patented bi-directional cryogenic floating ball valves. By incorporating this breakthrough technology across the majority of their cryogenic floating ball valve series, Habonim has ushered in a new era of bi-directional cryogenic systems.

The innovative bi-directional valves introduced by Habonim offer a transformative solution. By enabling a single pipeline to perform both loading and offloading functions, the need for dual pipelines is eliminated, resulting in significantly reduced installation costs and timelines. Moreover, these valves double as shutoff valves, allowing upstream pipe offloading without the risk of excessive pressure buildup.

Habonim's latest innovation is advancing cryogenic systems with improved technology, efficiency and cost-effectiveness. *Credit: Habonim*

Evolution of Cryogenic Valve Technology

The historical unidirectional nature of cryogenic floating ball valves stems from their design. In the open position, the media flows around the ball, filling the valve cavity. As the valve closes, pressure from the upstream side increases, pressing the ball against the seat to form a sealing surface. Although the flow is cut off, the trapped media inside the valve cavity can transition from liquid to gas due to temperature fluctuations, leading to volume expansion. This trapped gas, in turn, elevates the inner pressure within the cavity, resulting in undesirable overpressure buildup.

While ball valves inherently offer superior flow rates compared to globe valves, their legacy use necessitated upscaling of both valves and piping to accommodate the required flow rate. This drawback prompted the shift towards floating ball valves, which provide higher flow rates without the need for larger valves. The outcome: more compact, lightweight and cost-efficient systems with equivalent flow capacities.

Ball valves offer higher flow rates than globe valves, allowing smaller size without flow loss. Replacing globe valves with floating ball valves reduces system cost up to 60% and simplifies automation. *Credit: Habonim*

Habonim's endeavors in redefining cryogenic systems have borne remarkable results. Several systems originally reliant on globe valve technology were revamped with floating ball valve solutions, leading to up to 60% reductions in overall system costs,

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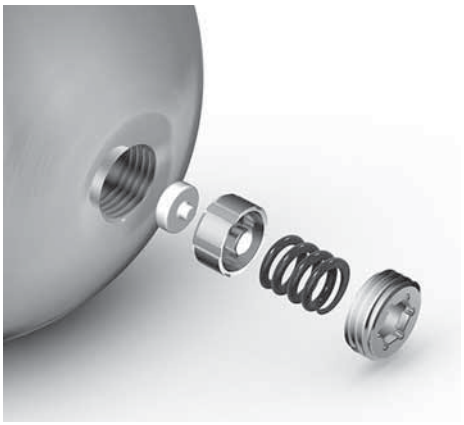
As industry evolves, Habonim merges floating ball valve benefits with bi-directional sealing, optimizing performance-to-cost ratio for cryogenic systems. *Credit: Habonim*



Innovative spring-loaded seat design releases cavity pressure through slight deformation, enhancing valve performance in Habonim's C47 series. *Credit: Habonim*

The integral pressure relief valve prevents excess pressure by allowing media flow from the cavity at preset levels. Habonim's unique PRV design is embedded inside the ball, enabling bi-directional cryogenic functionality in all valve series 2.5 inches and above. *Credit: Habonim*

reduced footprints, and enhanced automation feasibility. Adapting to an evolving industry landscape, Habonim has engineered solutions that merge the benefits of bi-directional sealing and floating ball valves. These solutions ensure cryogenic bi-directional sealing while preventing overpressure buildup within the valve's inner cavity, thereby offering optimized performance-to-cost ratios.

Solution No. 1: Self-Releasing Spring-Loaded Seats Design

Habonim introduces a patented solution via the C47 three-piece valve series. This design incorporates spring-loaded seats with an integrated seal that, under elevated pressure, undergoes slight deformation against the spring, releasing cavity pressure to the pipe. Subsequently, the spring restores the seat to its original shape, preparing the valve for a new cycle. This unique approach offers pressure relief from both upstream and downstream directions.

Solution No. 2: In-Ball Embedded Pressure Relief Valve (PRV) Device

By replacing the ball's pressure relief hole with an integral PRV device ball, virtually any cryogenic floating ball valve can be transformed into a bi-directional counterpart. The PRV device, acting as a check valve, permits media flow from the upstream cavity at preset pressures, averting excessive pressure accumulation. This innovative approach provides bi-directional cryogenic design and is available across all cryogenic floating ball valve series 2.5 inches and above.

A New Horizon for Cryogenic Systems

Marked by innovation, Habonim's bi-directional floating ball valve technology stands as a testament to the fusion of pioneering engineering and industry foresight. As the cryogenic landscape continues to evolve, these advancements are poised to revolutionize the efficiency, cost-effectiveness and reliability of cryogenic systems. **www.habonim.com**

Cool Fuel

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

'Three Pillars' and Clean Hydrogen Production

A national debate is currently raging around the so-called '45V' modification to the Inflation Reduction Act (IRA) tax incentives designed to support clean hydrogen production. The concept for 45V was originated by Jesse Jenkins, an assistant professor of mechanical engineering at Princeton University,[1] and supported in a follow-up study commissioned by the Natural Resources Defense Council (NRDC).[2] Cause for the change centers around 'Three Pillars' for clean hydrogen production, including:

1. **Additionality**: All clean hydrogen produced must be from new renewable energy installations, not those currently connected to the power grid.

2. **Hourly Matching**: All clean hydrogen produced must be from renewable energy generated during the same hour.

3. **Deliverability**: The renewable energy to produce clean hydrogen must be from the same power grid region as the generated hydrogen.

The pillars seem fair on the surface and garnered enough support to enable a vote that will take place in October. This is a huge vote with ramifications affecting both the future of the clean hydrogen and power grid sectors. Since my expertise is clean hydrogen, not the power grid, I sat down for a Q&A session with my friend Mani Venkatsubramanian, who runs WSU's Energy Systems Innovation Center (ESIC), to gain the broadest perspective I could before jumping to a conclusion. Mani is the Boeing Distinguished Professor of Electrical Engineering who created the power grid software helping France manage oscillations in the European interconnection.

The Wells Dam on the Columbia River. *Credit: Cummins*

Our discussion started with Additionality. Since the western power grid is already mostly renewable energy, with many clean hydrogen projects coming online, we're well on our way as a representative case study for a future with clean hydrogen production. Our problem is regulating the renewable energy supply already on the grid. Curtailment, renewable energy supplies removed from the power grid for regulation, is a big problem out west. So far this year, California has curtailed 2.27 Terawatt-hours of renewable energy, enough to produce 150 tonnes of clean hydrogen per day, comparable to the current total North American liquid hydrogen production capacity.[3] As another example, Douglas County Public Utility in Washington was ramping hydroelectric dam turbines to balance power supplied from a wind farm.[4] They anticipate being able to pay for the entire cost of the 5MW Cummins electrolyzer they are installing just through reduced maintenance costs to the dam turbines. The excess power that would otherwise be curtailed can now be converted to hydrogen, enabling long-term storage and sale to new markets. This will help both the hydrogen and power grid sectors. The Additionality requirement would prohibit existing renewable energy providers from using IRA tax incentives to address current curtailment issues with clean hydrogen production.

We discussed Hourly Matching next. Energy storage is a major problem for the electric grid that leads to the previously mentioned curtailment issues. The market cannot currently respond quickly enough to adjust prices to account for the variability in energy supply. However, this could change with technological advances such that the "hourly" requirement for the timescale is arbitrary. Smart technologies, like smart electric vehicle charging, could eventually adapt in real time to pricing variation and mitigate

the need for this pillar altogether. Many sectors, like data centers, can already opt out of hourly pricing requirements once a limit is reached. However, until we improve energy storage, potentially once the regional hydrogen hubs are established, hourly matching may be the best we can do.

Mani coughed when I brought up the third pillar of Deliverability. "This pillar ignores the existence of the power transmission grid," he said. The power grid is one of the largest and most efficient machines ever built by humanity. The 6% or so losses in power transmission between regions is small relative to the 20-40% losses of electrolysis.

While some transmission connections are congested, if there is a constraint on the transmission system, the transmission system operator will not approve the transaction between the power producer and the electrolyzer. In other words, the transmission system can already account for this pillar in situations where deliverability becomes a problem between regions. This pillar could even make it harder for full utilization of renewable power and hydrogen across regions.

Do we want the inevitable transmission of nonrenewable power between regions to result in dirty hydrogen production from fossil energy? No, we don't. Clean hydrogen producers should future-proof their investments by building production facilities in regions likely to have access to substantial renewable energy supplies much farther into the future than the IRA is subsidizing. This could occur within power grid regions or between regions with sufficient transmission support.

Constraining these installations with the three pillars will result in unnecessary delays. Just this month, the International Energy Agency released their annual Global Hydrogen Review recommending to "quickly address regulatory barriers, particularly for project licensing and permitting."[5]

Although '45V' may have some merit in specific situations where power grids have little curtailment, no storage capabilities, and congested transmission lines, it will immediately exacerbate the regulatory issues for the entire hydrogen and power grid sectors. With the nationwide trends towards increased renewables, storage research, and upgrades to power grid infrastructure, it seems to us that '45V' will hurt the NRDC's ostensible mission by limiting adoption of clean hydrogen, while further restricting power grid operators, through these requirements.

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by J.R. Feller and A. Kashani, NASA Ames Research Center

A Chill in Paradise: The 30th CSA Space Cryogenics Workshop

The CSA's Space Cryogenics Workshop (SCW) made a triumphant return in person after a pandemic-induced hiatus. It was held July 16-18, 2023, at the Outrigger Kona Resort and Spa in Kailua-Kona, Hawaii.

The workshop commenced with a grand welcome reception at the picturesque Pa'akai Point. This event was not only a celebration of the workshop's return but also a showcase of Hawaiian culture. Guests were treated to a buffet of local cuisine, tropical drinks and entertainment that beautifully captured the aloha spirit, setting the tone for the days to come.

30th SCW Group Photo showing some of the participants at the event. *Credit: CSA*

The first full day of the workshop began with an engaging and informative oral session, "Cryogenic Fluid Management" (CFM) I, chaired by Michael Meyer and Alok Majumdar. This session featured a range of papers covering a variety of topics related to cryogenic fluid management, including innovative approaches to cryocooling, control system development for hydrogen storage, liquefaction testing for lunar and Martian environments, leak-tight liquid hydrogen origami bladder actuation, cryogenic spray characterization under varying chamber pressures and thermo-fluid modeling of the LOXSAT Payload.

In the CFM Modeling I session, chaired by Mohammed Kassemi and Wesley Johnson, papers explored diverse aspects of cryogenic fluid management, including the mathematical modeling of submerged helium injection for tank pressurization, two-dimensional network flow modeling for filling cryogenic tanks without vents using a dynamic vent system, the impact of non-condensable gases on the thermodynamics of perfluoro-n-pentane and computational fluid dynamics modeling of a cryogenic methane drainage test, considering the presence or absence of induced sloshing.

After lunch, a session titled "Sub-Kelvin Refrigerators" highlighted advancements in sub-Kelvin cooling methods for space instrumentation. Topics covered various refrigeration technologies designed for space applications. During the afternoon break, a series of posters were presented, addressing a range of topics including the applicability of mechanical test standards for composites in cryogenic conditions and the robustness of sensors used in aerospace applications. The final session of the day, titled "Cryocoolers," discussed different cryocooler technologies and their applications in space instrumentation and future technology development.

The evening was dedicated to awards and recognition. The CSA T.H.K Frederking Space Cryogenics Workshop Student Scholarship was awarded to two outstanding researchers, Hannah Rana of the Harvard-Smithsonian Center for Astrophysics and Stella Ristic of the Illinois Mathematics & Science Academy. Additionally, the Best Paper Award was presented to Scott Courts of Lakeshore Cryotronics for his remarkable work on the stability of Cernox temperature sensors stored at room temperature over an astonishing 29-year period.

The second and final day of the workshop began with CFM II, chaired by Daniel Hauser and William Notardonato. The papers presented in this session covered a wide range of cryogenic topics, from "The Flow Boiling and Condensation-Transfer Line ISS Experiment" to "Investigating the Explosive Hazard of Liquid Oxygen-Liquefied Natural Gas Rocket Propellant." The fourth and final session focused on multilayer insulation (MLI) and was chaired by Weibo Chen and Franklin Miller. Three papers were presented, covering topics such as the evaluation of thermal insulation performance and vapor cooling methods for MLI and foam insulations.

As the sun set on the Hawaiian horizon, the 30th SCW came to a close. It was a gathering of brilliant minds, innovative ideas, and a passion for pushing the boundaries of cryogenics. The workshop left attendees with a profound sense of awe and inspiration, reminding us of the boundless possibilities that space cryogenics holds for the future.

SCW 2023 Welcome Reception. *Credit: CSA*

SCW 2023 Oral Session. *Credit: CSA*

SCW 2023 Poster Session. *Credit: CSA*

Amir Jahromi and Mark Kimball, the co-chairs of the 29th SCW in 2021, presenting the Best Paper Award for that workshop to Scott Courts of Lake Shore Cryotronics. *Credit: CSA*

The CSA T.H.K. Frederking Space Cryogenics Workshop Student Scholarship awarded to Stella Ristic by Dr. Jeff Feller. *Credit: CSA*

SCW 2023 Awards Dinner. *Credit: CSA*

SCW attendees enjoying the manta ray viewing deck overlooking Keauhou Bay. *Credit: CSA*

Cool Cryo Guests

by Nils Tellier, PE, EPSIM Corporation (www.epsim.us), nils@epsim.us

Our Cool Cryo Guests feature highlights articles submitted by industry experts. We encourage you to send in your work for possible inclusion in a future issue. For consideration, please contact Anne DiPaola at editor@cryogenicsociety.org.

Tips for Cryogenic Air Separation Units: Thermal Cycle and Turboexpanders

This series of articles aims to provide tips for cryogenic air separation units, particularly in the context of increasing energy costs. Cryogenic Air Separation Units (ASUs) operation relies on the simultaneous balance of material and thermal equilibrium. The following discussion presents the heat exchangers commonly used in Air Separation Units (ASUs).

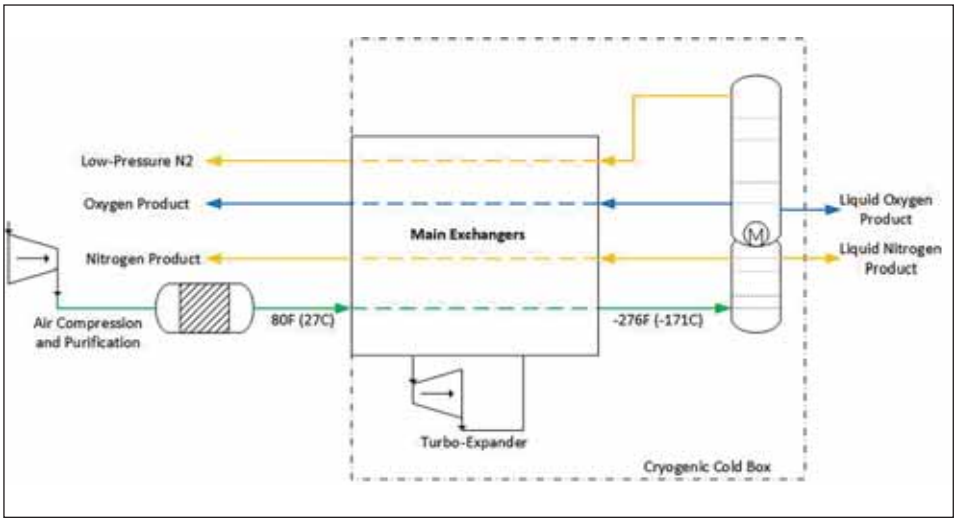


Figure 1: Cryogenic air separation basic diagram. *Credit: EPSIM Corp.*

Process Overview

In a cryogenic air separation plant, compressed air at near-ambient temperature is cleaned of moisture and CO_2 and cooled to its condensing point before entering the distillation columns, where it is separated into its elements (oxygen, nitrogen and argon). As an order of magnitude, compressed air at 80 °F (27 °C) is cooled to nearly -276 °F (-171 °C), where it turns into a mist.

The air cooling is not achieved by brute force from some gigantic chiller. Instead, it is reached gradually by warming the returning product gases from the separation. A turboexpander adds the refrigeration necessary to compensate for the heat losses through cryogenic insulation and liquid production.

Large heat exchangers maintain the steady-state thermal balance of the ASU, as illustrated in Figure 1.

Cryogenic Heat Exchangers

Cooling a constant flow of compressed air by 360 °F (198 °C), counterflowing against low pressure gases, poses several challenges. The heat exchange duty is massive, gigantesque and dwarfs the air compressor's power in comparison. Extracting the cold from the outgoing gas products, which are typically at very low pressure, requires a relatively huge heat exchange area. Balancing the heat exchange between four or more streams, each with its own heat capacity and mass flow, involves many passages stacked in optimum sequence. Containing gases at vastly different pressures without losing mechanical integrity necessitates structural strength, both internal and external. Finally, maintaining the plant's thermal efficiency entails minimal temperature difference at the pinch. This gargantuan bill is achieved with brazed aluminum heat exchangers (BAHX).

BAHX exchangers are constructed by stacking layers of finned aluminum plates with alternated streams and separated by parting sheets. The alternating stream passages are connected to headers at each end of the exchanger core for the inlet and outlet of the gases. BAHX exchangers offer significant advantages over shell and tube: 80% size reduction, 6 to 10 times greater heat transfer surface area and 10 to 20 times more UA per volume and up to 95% less weight.

The concept of BAHX is so advantageous over other types of exchangers that it is used all over the cryogenic equipment, including subcoolers, condenser/reboilers and vaporizers as illustrated in Figure 2.

Additional Exchanger Applications

Two variants of the typical ASU main exchanger applications include:

Reversing heat exchangers, or REVEX: Moisture and CO_2 are removed from the high pressure air by freezing inside reversing passages in the exchangers. When fouled, the passages are cleaned by counterflowing waste nitrogen. The incoming air is routed through a clean set

of passages. The reversing passages are switched every 10 to 15 minutes. Oxygen and nitrogen products flow through fixed passages. ASUs with reversing exchangers do not need front-end adsorber purification, but trace hydrocarbons must be captured by guard adsorbers inside the cold box.

REVEX plants are relatively simple to start and operate but do not perform at the efficiency level of some ASUs with front-end purification because of the higher air loss due to the frequent switching.

High pressure vaporization of liquid oxygen: Since the early 2000s, ASU manufacturers have gradually opted to draw liquid instead of gaseous oxygen. The liquid is pumped to pipeline pressure and vaporized inside the main exchangers against the incoming air. There are two significant benefits: first, the oxygen compressor is eliminated, along with the energy losses associated with gas compression; second, the air cooling leverages the oxygen phase change resulting in significantly higher heat exchange. The design challenges include fabricating an exchanger that can handle large pressure differences between passages and ensuring that trace hydrocarbons do not accumulate from localized dry vaporization inside the exchanger's oxygen passages.

Thermal Balance and Efficiency

The ASU's performance can be measured by the temperature difference at the endpoints of the main exchangers. A small temperature difference at the warm end indicates good plant thermal efficiency with minimal refrigeration losses. Likewise, a small temperature difference at the cold end is a sign of good oxygen recovery with minimal losses in the waste nitrogen stream.

The challenge is that each gas has a different mass flow and heat capacity. With a single main exchanger, closing the warm end ΔT opens the cold end temperature difference and vice versa. To simultaneously close the ΔT at both ends, high pressure gas (air or nitrogen) is extracted at the midpoint of the exchanger to supply the turboexpander. According to the modified Claude Cycle, the side stream feeding the turbine bypasses the main exchanger's cold section. This allows achieving as little as 5 °F (3 °C) ΔT at both ends by increasing the temperature difference at the midpoint.

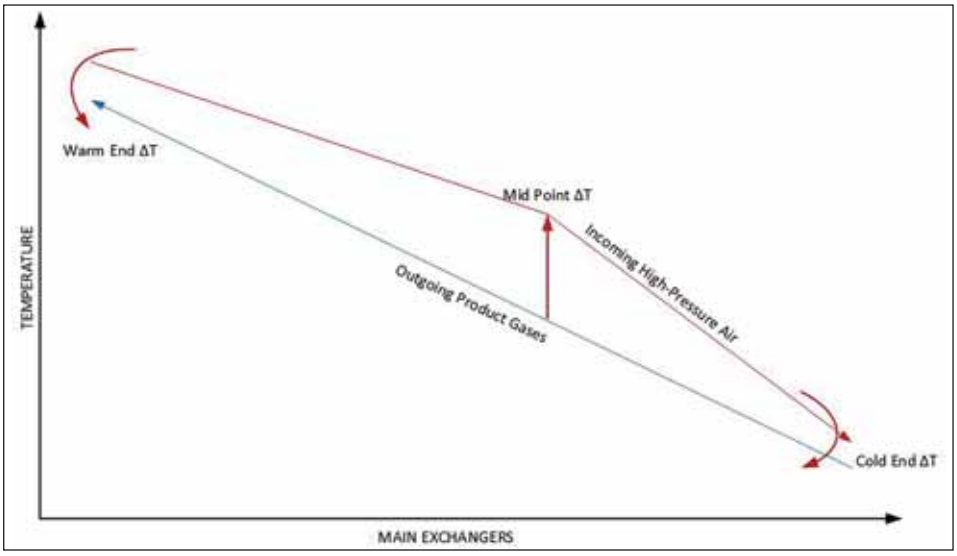


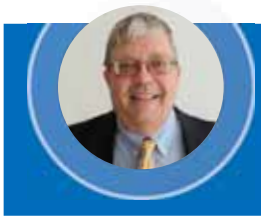
Figure 2: Influence of the midpoint stream on endpoint temperatures. *Credit: EPSIM Corp.*

BAHX heat exchangers. *Credit: Chart Industries*

Operations Tips

ASU deriming: Removing traces of moisture and CO_2 that would otherwise obstruct and damage the exchangers is important before cooling down the cold box. This is done by flowing dry gas (air or nitrogen) at very low pressure. The BAHX exchangers' passages are narrow and finned and subject to preferential gas path if a passage is obstructed. Heating the derime gas above ambient can improve moisture removal; however, it will slow down the plant cooling. The author prefers to limit the use of heated derime gas to the condenser/reboiler, where flow paths may be difficult to establish. Aluminum exchangers can be catastrophically damaged if the derime gas is too warm, and it is critical to follow the plant manufacturer's guidelines and temperature limitations.

▶ ***continues on page 31***



Cryo Bios

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

Russell J. Donnelly

Russell J. Donnelly

Born April 16, 1930

Died June 13, 2015

Eugene, Oregon

Russell James Donnelly was an expert in both classical and quantum fluid dynamics and made major advances in the area of superfluid helium and quantum turbulence. He was also a strong advocate of science education and scientific publication.

Donnelly was born in Hamilton, Ontario, Canada, and earned his bachelor's and master's degrees in physics from McMaster University. He moved to Yale University for his doctoral studies where he graduated with a Ph.D. in 1956. His thesis, titled "On the Hydrodynamics of Liquid Helium," captures two of Professor Donnelly's primary scientific interests: fluid mechanics and helium cryogenics. After graduating, Professor Donnelly joined the physics department at the University of Chicago where he continued to work on classical fluid dynamics and liquid helium. In 1966, he moved to the University of Oregon as the chair of the physics department. He remained there for the rest of his career, acting as department chair twice.

One of his first tasks as department chair was the establishment of an astronomical observatory. His successful efforts in bringing together scientists, funding agencies and community members, demonstrated Donnelly's ability and interest in collaboration and public outreach. This was a consistent theme of Donnelly's career.

Donnelly's research at Oregon included experimental studies of quantized vortices, second sound and turbulence in superfluid helium, and how this might be related to classical turbulence. He also continued work on classical fluid dynamics, particularly on Taylor-Couette flow. He was a highly skilled experimental scientist and in 1967 wrote, along with P. Parks and W. Glaberson, *Experimental Superfluidity*, which acted as a primer and reference text for experimenters working with He II. His interest in vortices and turbulence was such that he named his cat Vortex. His work with quantized vortices was summarized in another book, *Quantized Vortices in He II,* published in 1991.

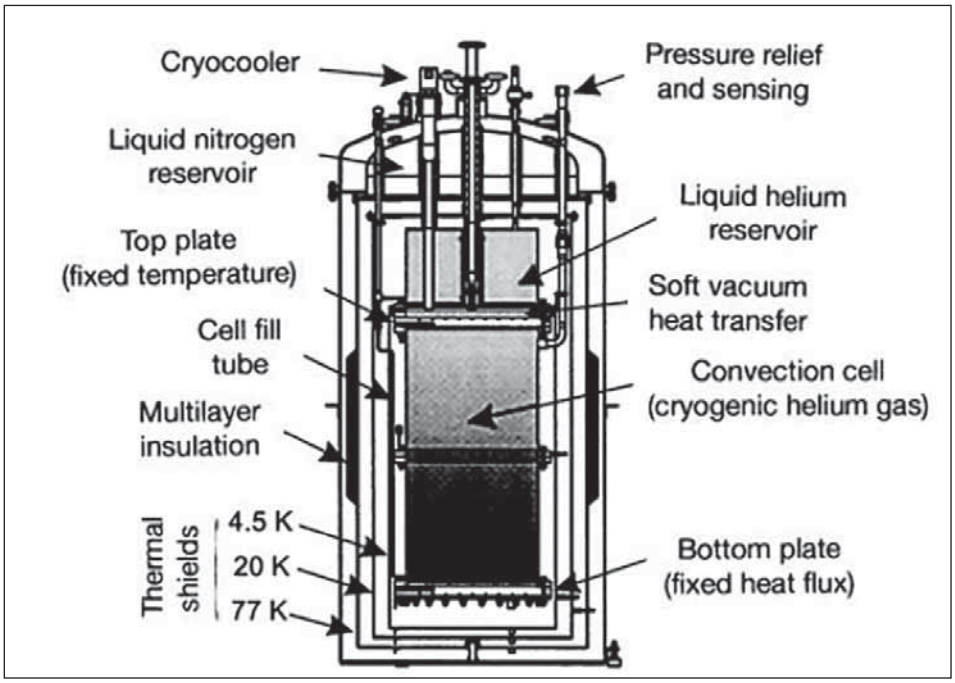


Figure 1: Convection Cell Facility built by Donnelly and his collaborators. The convection cell is 0.5 m in diameter and 1 m tall. *Credit: "Turbulent Convection at Very High Rayleigh Numbers." J. J. Niemela, L. Skrbek, K. R. Sreenivasan & R. J. Donnelly. Nature 404 (2000).*

Donnelly and his collaborators proposed two ambitious experimental facilities. One was a wind tunnel using liquid helium as the working fluid which would take advantage of the low viscosity of helium (and He II) to produce very large Reynolds number flows. Funding could not be found for this facility. The second proposed facility was built and consisted of a large convection cell using helium at 5 K to make fundamental measurements of thermally driven fluid convection (Rayleigh–Bénard convection, see Figure 1). The facility allowed measurements of turbulent convective flows.

Collaboration and service to the scientific community was important for Donnelly. He knew and collaborated with many scientists worldwide, including Joe Vinen (*Cold Facts,* Vol. 39 #3). He served on the editorial boards of a number of

Cryo Bios... Continued from page 30

journals including: *Physical Review A, Physics of Fluids* and *Physica B*. He served as a book editor for CRC Press and contributed significantly to the Division of Fluid Dynamics of the American Physical Society, serving twice as its chair. He also organized numerous conferences and workshops on fluid mechanics, quantum turbulence and low temperature physics. He mentored 25 Ph.D. students, many of whom went on to become leading scientists in their own rights.

Professor Donnelly's contributions were not limited to the scientific community; he was heavily involved with and supported the Oregon Bach Festival and the Oregon Mozart Players in Eugene, Oregon. He was the driving force behind the PBS Nova special "Absolute Zero" (https://www.pbs.org/wgbh/nova/zero) and was its principal scientific consultant.

Russell Donnelly earned many honors over his life, including being made a Fellow of the American Physical Society and of the Institute of Physics in the United Kingdom. He was awarded the Fritz London Prize for his contributions to low temperature physics.

Cool Cryo Guests: Air Separation... Continued from page 29

ASU cool down: After deriming the plant, the cold box is gradually cooled to its operating temperature. The turboexpander provides refrigeration, and introducing a small amount of liquid nitrogen at the top of the upper column at the end of the cooldown can help build the initial liquid inventory. The columns and main exchangers will shrink noticeably due to thermal contraction, and localized temperature imbalance can induce large amounts of stress on the piping and aluminum exchangers. To avoid catastrophic damage, controlling the cooldown rate and monitoring and remedying excessive temperature differences at both ends of the main exchangers are important. Running the upper column at a higher pressure can prevent the air compressor from surging during the reboiler's initial operation. Once the liquid level is well established around the reboiler, the upper column pressure can be gradually reduced to design and the plant brought to full production capacity.

ASU operation: In some plant designs, an expander trip will immediately create a large temperature imbalance and stress the main exchangers to the point of rupture. It is advisable to configure an alarm on the temperature difference at the warm end of the exchangers, such that on excessive ΔT, the ASU trips and the air compressor unloads (but does not shut down) to prevent damaging the main exchangers.

Conclusion

Brazed aluminum heat exchangers have transformed the air separation industry. Small temperature pinches in the 5 °F (3 °C) order result in high thermal efficiencies. Compact design reduces the plant footprint, pressure drops and energy consumption. These exchangers represent an important part of the plant equipment and capital. They must be monitored and protected against plugging and excessive temperature gradients to avoid catastrophic damage. Exchanger manufacturers have changed over the last 20 years but remain few. BAHX exchangers are long lead items, and ASU owners should track which manufacturers can provide a replacement exchanger, particularly for older plants and those with reversing exchangers.

Clean Energy Future

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

Liquid Hydrogen for Backup Electrical Power in Data Centers

Large industrial backup electrical power mainly comes from burning a fuel, spinning a wheel and rotating machinery to generate electricity. If you want to store any excess electrical power for later – you cannot (batteries are only for small things). So, fire up your furnace, start those wheels spinning and hope that you planned well to balance demand with supply. And keep trucking in that diesel fuel from a refinery connected to some hole in the ground somewhere in the world. Also remember that it takes a barrel of crude oil (42 gallons) to produce 11 or 12 gallons of diesel.[1]

Microsoft's 3-MW hydrogen electric cell system in Latham NY, includes two 40-foot containers, each holding 18 proton exchange membrane (PEM) cells by Plug. A gaseous hydrogen tube trailer is seen at left. *Credit: John Brecher, microsoft.com[3]*

But the situation is beginning to change. Imagine if you could skip all those steps – no fuel burning, no spinning wheels, no rotating machinery – and make clean, quiet electrical power, on demand, when and where needed, directly from an electrochemical reaction. This dream system – the hydrogen electric cell (aka "Fuel Cell" – terribly inappropriate name choice) – has been around, at least conceptually, since 1842.[2] The hydrogen electric cell (HEC) is coming of age with performance coming up and prices going down. The technology infusion called for in data centers is a good example of the possibilities for making these facilities work more reliably and with less carbon emission.

Hydrogen can be made from water from abundant renewable energy at any place on Earth and liquefied with energy leveraged by renewable energy, thus storing up renewable energy, at-scale, in the form of liquid hydrogen (LH_2) for use where and when needed. The tie-in to data centers involves improvements in areas of both performance and environment. In terms of performance, Microsoft strives to provide datacenter customers with facilities that are operational 99.999% (five nines) of the time. In case of a power outage, batteries kick on to provide instant power while the backup generators are fired up.[3] The backup generators typically burn diesel fuel which Microsoft has committed to eliminate by 2030.

Previously, in 2021, Microsoft partnered with Caterpillar and Ballard to test a megawatt-scale hydrogen electric cell backup generator that provided 3 MW of power for 48 hours supported by an 18,000-gallon LH_2 tank.[4] The test was successful and demonstrated the feasibility and reliability of using hydrogen fuel cells for data center backup power.

Hyperscale data centers can be 100 MW and up. In 2021 there were 540 hyperscale centers in the world with dozens more being added each year. The facility sizes are greatly increasing as well. For example, the Citadel in northern Nevada occupies 670,000 m^2 and requires up to 650 MW to operate. The Amazon data centers in Ashburn, Virginia, use about 1 GW (spread over multiple facilities) and the US-Norwegian company Kolos is building a massive facility near the Arctic circle with plans to expand to 1 GW.

The corresponding LH_2 needs for backup power for data centers are likewise staggering. A small 10 MW datacenter would require 14.4 tonnes for 24-hour backup. The latest hyperscale facilities like Citadel and Kolos would require 936 tonnes and 1,440 tonnes of hydrogen for a 24-hour backup period.[5] Clearly, the storage and supply infrastructure should be LH_2-based even if the demand was 1/100th less. A reliance on diesel generators for backup power would make an enormously big carbon footprint. As hydrogen-based energy storage is now seen as a viable option to meet the large-scale, long-duration requirements of data centers, LH_2 is the only viable option for putting these amounts of hydrogen to work at these scales.

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[3] Hydrogen fuel cells could provide emission-free backup power at data centers, news.microsoft.com, Oct. 2023.

[4] Microsoft partners with Caterpillar and Ballard to test megawatt-scale hydrogen fuel cell backup generator, www.datacenterdynamics.com, Nov. 22, 2021.

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Quantum Corner

by Ioana Craiciu, Jet Propulsion Lab

Why Are Quantum Technologies So Cool?

Efforts to build a useful quantum computer are underway, with startup companies competing alongside the big leaders in information technology. Other quantum technologies are already part of our everyday lives, from MRI scanners in hospitals to atomic clocks, which are used to keep precise track of time on GPS satellites and inform Coordinated Universal Time. The word "quantum" itself has become almost synonymous with cutting-edge technological advancement.

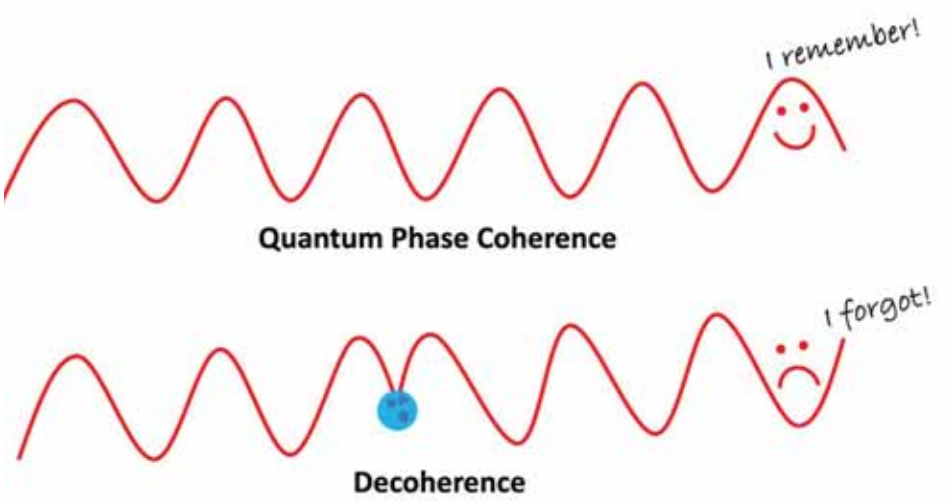
Many, but not all, quantum technologies require cryogenic cooling to operate. Take the examples above. The magnets in MRI machines are cooled to 4 K, but atomic clocks run at room temperature. Quantum computers based on superconducting qubits use dilution refrigerators to reach temperatures of 10 mK, but quantum computers based on atoms or photons don't need to be in a cryostat or refrigerator. Why is that? Let's first look at quantum technologies and what unifies them.

What is quantum technology?

The outlines of what is and isn't a quantum technology are fuzzy, but broadly, a quantum technology is one that leverages the aspects of quantum mechanics that do not usually manifest themselves in our daily lives. These aspects include quantum phase coherence, superposition, entanglement, quantum tunneling and quantum measurement. The fact that we don't usually experience these phenomena is already hinting at the reason why many quantum technologies require cryogenic cooling: in order to observe effects not often encountered in our daily lives, we might need to subject a system to more extreme conditions.

Why do quantum computers need cryogenics?

There are a number of reasons why some quantum computers need cryogenics. The most fundamental reason is the need to preserve quantum phase coherence. Phase coherence is a prerequisite for other useful quantum behaviors such as superposition and entanglement.



When a photon interacts with something in its environment, like an atom, it can lose its phase coherence.
Credit: Ioana Craiciu, Jet Propulsion Lab

One example of a quantum object is a photon, or a single particle of light. If you think of a photon as a wriggling electromagnetic field moving through space, preserving phase coherence means that the photon remembers to wiggle on beat, so that the field traces a neat sinusoidal wave over time. This remembering is key for quantum computing because the phase coherence is used to store information, and computers don't work if they forget the information they're processing. Maintaining coherence in any quantum object is largely achieved by making sure the system doesn't interact with any other object. For photons, this is pretty easy, since they don't interact very much. They almost never interact with other photons (although they can be made to interact through a nonlinear intermediary), and they can maintain their coherence when traveling through glass or when reflecting off metal surfaces. Quantum computers that use photons as their fundamental components don't need any cooling to maintain coherence. However, single-photon quantum computers may use cryogenic cooling for other reasons. Detecting single photons reliably requires exquisitely sensitive and low-noise detectors, and the highest-performing detectors are based on superconductors that need to be cryogenically cooled.

When a photon interacts with something in its environment, like an atom, it can lose its phase coherence.

A single atom is another type of quantum object. An atom can undergo its own kind of periodic transformation of a property called spin, and coherence means remembering to transform on beat. Atoms, however, easily interact with other nearby atoms through electric or magnetic fields, leading to a loss of coherence. To mitigate this, quantum computers based on neutral atoms or ions use electric fields, magnetic fields and lasers to isolate and cool individual atoms and to keep them trapped in a vacuum, far away from other atoms. The atoms in these computers are quite cold, with temperatures on the order of 1 mK. However, the techniques used to cool the atoms involve slowing down their vibrations

using lasers, so cryogenics are not needed to cool the atoms. However, cryogenic cooling might still be useful in atomic/ionic quantum computers. For example, the atoms comprising a quantum computer might be housed in a cryogenic chamber in order to create a better vacuum. A better vacuum means fewer stray atoms around, which is important since stray atoms can lead to collisions that knock a computing atom out of its trap.

Perhaps the most well-known quantum computing effort uses superconducting qubits. Superconducting qubits are electronic circuits made of superconducting metals. These qubits need to be cryogenically cooled for two reasons. The first is that they are made of superconducting metals. Superconductivity is a special kind of electrical conductivity, where charge carriers are not constantly colliding with phonons or nuclei in the conductor's atomic lattice. If the circuit were not superconducting, such collisions would lead to almost instant phase decoherence. Superconductivity only occurs at temperatures below the critical temperatures of the superconducting metal, which for aluminum, a common material for this application, is around 1 K. The reason temperatures as low as 10 mK are needed is that, unlike trapped atoms, it is impossible to completely isolate a superconducting qubit from its environment. Superconducting qubits are built on semiconductor wafers using nanofabrication techniques. They are quite large by quantum standards, usually several tens of micrometers across. The quantum circuits are therefore surrounded by many atoms. Atoms with thermal energy vibrate, creating variable electric and magnetic fields. The extremely low temperatures keep the atoms in the environment frozen in place and thereby quiet the electric and magnetic field fluctuations that would otherwise lead to decoherence in the qubit.

There are other notable quantum computer platforms in the solid state, such as quantum dots or defects in silicon and Majorana fermions for topological quantum computing, and these also require cryogenic cooling to the sub-100 mK level.

What other quantum technologies need cryogenics?

There are many other quantum technologies that require cryogenics, such as superconducting magnets, which are used in MRI scanners and the Large Hadron Collider, single-photon detectors for quantum information and astrophysics, quantum memories and transducers for quantum networks, and fundamental science inquiries such as searching for dark matter.

In this series, I plan to explore the intersection of quantum technologies and cryogenics, focusing on the developments in quantum technologies at cold temperatures and the progress in cryogenic technologies enabling them.

The views expressed are the author's own and do not necessarily reflect those of NASA or JPL.

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

Absolut System

Absolut System is a French SME that designs, optimizes and qualifies innovative solutions ranging from components such as cryogenic coolers, heat exchangers or thermal links, to integrated systems such as vacuum test chambers.

Energy Flux

At the forefront of sustainable energy solutions, Energy Flux's cutting-edge technologies harness the power of nature to drive innovation. Its green hydrogen production integrates cryogenic storage, ensuring efficient energy utilization and distribution.

NanoMagnetics Instruments Ltd.

NMI specializes in NV-Center microscopy, high-res confocal microscopy, HEMS, AC & DC measurements, VSM, and sub-nanometer nanopositioners. Their cryostat systems enable low temperature research, advancing quantum sciences and material characterization.

Princeton CryoTech*

Design, sales, startup and service of cryogenic distribution and storage systems, including vacuum insulated storage equipment, piping, manifolds and bulk tanks. Secure on-site cryogenic storage of biological materials and cryogenic shipping services.

Signal Microwave*

Field replaceable nonmagnetic SMA and 2.92 mm connectors for quantum computing, with a bandwidth of 27 GHz for SMA and 40 GHz for 2.92 mm versions. Materials used are phosphor bronze, beryllium copper, Teflon (PTFE), and Ultem.

Tech4Imaging LLC*

Cryogenic mass flow meters, two-phase mass flow meters, cryogenic mass gauging, flow loop testing and level sensing.

***CSA CSM**

Pioneering High-Performance Valve Solutions

by Leire Colomo, Ampo Poyam Valves

Ampo Poyam Valves (AMPO), with a history spanning nearly six decades, has established itself as a significant player in the realm of highly engineered valves and fluid handling solutions tailored for demanding applications and services. Drawing from its extensive experience, the company has earned a reputation for handling international projects with precise technical specifications, providing dependable solutions with minimal maintenance costs. Core principles at AMPO encompass effective supply chain management, including an integrated foundry and robust field support through its service division.

Cryogenic valve testing.
Credit: AMPO

Cryogenic top entry ball valve.
Credit: AMPO

Established in 1964, the company has cultivated expertise in critical applications, including cryogenic temperatures, high temperatures, corrosive media and erosive and abrasive environments, both on the surface and underwater, always meeting rigorous conditions with unwavering reliability.

Cryo and Low Temp Expertise

A pivotal strength of the company lies in its proficiency in cryogenic applications and low temperature solutions. Millions of cryogenic valves have been installed at facilities operated by major energy contractors worldwide. These valves play a vital role in liquefied natural gas (LNG) and liquefied petroleum gas (LPG) terminals and transportation vessels. AMPO manufactures valves covering the entire LNG and LPG supply chain, from gas retrieval to transportation pipelines, liquefaction, carrier vessels and storage tanks. These valves are also suitable for low temperature applications such as ethylene, oxygen, nitrogen, petrochemical plants and refineries.

AMPO employs skilled engineers who employ modern design tools like 3D CAD and FEM analysis, advanced multibody and fluid-structure interaction modeling, and rigorous quality assurance practices throughout the development, fabrication and qualification processes. With more than 60 years of experience in manufacturing cryogenic valves, AMPO is recognized as a leading manufacturer of highly engineered valves for the LNG market, including various types of cryogenic valves.

Applications

AMPO excels in virtual prototyping, design and manufacturing of critical cryogenic valves across the temperature spectrum, suitable for LNG or liquefied air gases, as well as liquefied hydrogen or helium. The valve portfolio includes microflow control and shut-off valves, axial check valves and top-load ball valves. Testing is pivotal for quality validation, covering valve sizes from DN_2 to $DN_2$500. The company's testing facilities encompass hydrostatic and gas pressure test benches, LN_2 baths and clean rooms for cryogenic and oxygen service valve assembly. Mass spectrometers are employed for helium leak detection.

Cryogenic helium leak and pressure tests at 77 K are standard procedures, essential for valves operating in extreme conditions above 80 K. Tailor-made solutions are integral to AMPO's engineering activities, with a focus on delivering integrated smart solutions as turnkey projects. AMPO's testing technician staff holds certification for leak testing level 2 using the trace gas method per ISO 9712. Test procedures adhere to International Standard ISO 27895 for leak testing of vacuum valves, commonly used for gas flow or vacuum pressure control. Key parameters for verification include:

- Sniffing leak detection ≤ 5x10^-10 Pa·m^3/s
- Vacuum leak detection ≤ 5x10^-13 Pa·m^3/s

These capabilities and extensive facilities empower AMPO to validate product quality, assess valve performance under various conditions and develop highly engineered solutions. The company is positioned to provide clients with reliable valve solutions tailored to project requirements.

Recent Developments

AMPO has recently introduced liquid hydrogen and helium on/off and control valves with flexible designs. Additionally, the company has expanded its capabilities in integrated smart controls, enhancing its position in instrumentation and system solutions.

AMPO remains committed to its core principles of excellence, innovation and reliability. The company continuously invests in research and development to stay at the forefront of valve technology. Its commitment to excellence is reflected in a diverse portfolio of valves designed to handle a wide range of challenging applications. AMPO looks forward to its future as a global industry leader, backed by experience and focused on innovation. **www.ampo.com**

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Beyond Gravity Austria Masters the Cold Frontier

by Erhard Prechelmacher, Cryogenics/Hydrogen, Beyond Gravity Austria GmbH

Beyond Gravity Austria, formerly known as RUAG Space Austria and Austrian Aerospace, has undergone a transformation and emerged as a leading player in the global space systems industry. With a rich history spanning more than three decades, Beyond Gravity specializes in the development, production and integration of thermal insulation for a wide range of applications, including space systems and cryogenic technologies.

Since its inception in 1991, Beyond Gravity has played a pivotal role in the space industry, contributing to the success of more than 800 satellites designed for scientific research, Earth observation and communication missions. These satellites rely on Beyond Gravity's thermal insulation solutions to maintain optimal operating temperatures in the harsh conditions of space.

One of the company's standout achievements is its expertise in developing thermal insulation for cryogenic systems. Since 1993, Beyond Gravity has been a key player in creating insulation solutions for superconductors cooled with liquid helium. These superconductors are integral to technologies like magnetic resonance imaging (MRI) and nuclear magnetic resonance (NMG) machines, superconducting accelerators and helium liquefiers. The company's innovations have also extended to insulating infrastructure for liquid gas tanks, such as those used for hydrogen or liquefied natural gas (LNG), using nonflammable materials like aluminum and glass-fiber spacers.

In recent years, Beyond Gravity has intensified its efforts to develop insulation for liquid hydrogen, with a particular focus on long-haul transport vehicles, ships and aircraft powered by liquid hydrogen propulsion systems. Additionally, the company has ventured into partnerships aimed at advancing high temperature superconducting cables and superconducting generators, underlining its commitment to innovation and technological progress.

Beyond Gravity innovates to meet customer demands, and its insulation products excel under vacuum conditions. *Credit: Beyond Gravity*

With Beyond Gravity's impressive track record in engineering and production spanning more than three decades, it has positioned itself as a trusted partner in the space and cryogenic industries. This is evidenced by Beyond Gravity's operation of a semiautomatic production line that handles tasks like perforation, cutting and assembly of insulation resulting in standard insulation sheets, rolls and customized assemblies. This streamlined production process ensures minimal boiloff, reduced outgassing and efficient insulation installation.

Beyond Gravity Space, the company's space-focused division, has established itself as a prominent European supplier of multilayer insulation for spacecraft. Topping 80 successful projects to its name, Beyond Gravity Space has become a leader in providing MLI for satellites and instruments. Furthermore, its expertise extends beyond space insulation, as the company has also made significant strides in the field of cryogenic insulation. It offers cryogenic superinsulation solutions for various applications, including helium liquefiers, superconducting magnets and liquid gas tanks.

The development and production process at Beyond Gravity encompasses thermal and mechanical engineering, layout and design, and production and integration. The company's value chain includes CAD design, prototyping, production (both standard and tailor-made products) and build-to-print services. Beyond Gravity Space is certified to ISO 9001, ISO 14001 and EN 9100 standards by DNV, ensuring the highest quality in its products and services.

One of Beyond Gravity's notable products is COOLCAT, a versatile family of insulation solutions, which includes various types of insulation:

- COOLCAT 2 NW- Used in MRI and NMR systems, offering high thermal performance with a spacered superinsulation design, suitable for cryogenic applications.

- COOLCAT 2 NF- Designed for hydrogen and LNG systems, nonflammable, ideal for applications involving flammable gases.

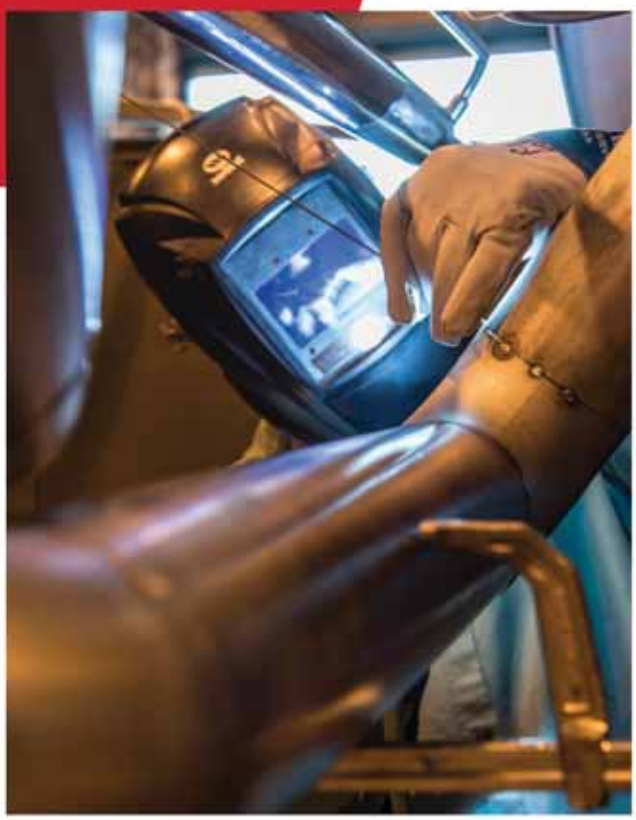
- COOLCAT 2 LOX- Developed for liquid oxygen systems, compatible with liquid oxygen and nonflammable.

- COOLCAT 2 NI- Tailored for applications with varying magnetic fields, minimizing eddy currents while offering high thermal performance.

Beyond Gravity innovates to meet customer demands, and its insulation products excel under vacuum conditions. COOLCAT H provides welding protection, reflecting heat and offering insulation properties. Beyond Gravity also offers technical support, insulation installation and consulting services for cryogenic systems, superconducting technology and space applications, ensuring tailored solutions. Beyond Gravity Austria is a dynamic company with a rich history in space and cryogenic industries. It aims to continue pushing boundaries and remain a key player in global space and cryogenic sectors. **www.beyondgravity.com**

Moving you ahead.

Gardner Cryogenics is a world leader in the storage and transport of liquid hydrogen and helium. We help you move and store molecules with near-zero loss.



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RegO Revolutionizes Precision with Pressure Builder–Economizer Regulator

by DJ Slater

In the field of cryogenics, where precision and innovation are paramount, RegO® has elevated the industry standard with its latest offering: the CBE504 Series Half-Inch Pressure Builder/Economizer Regulator. RegO, a company with a rich history of more than a century, has consistently demonstrated its commitment to excellence and continuous improvement. With the introduction of the CBE504 Series, RegO proves that it is at the forefront of revolutionizing cryogenic technology.

The CBE504 Series stands out with its compact design, making it a versatile choice for cryogenic applications with limited space. This compactness not only simplifies installation but also optimizes the utilization of valuable resources. In addition, it boasts a maximum inlet pressure of 600 psig and an extensive pressure setting range from 25 to 550 psig, catering to a wide spectrum of cryogenic needs.

Cryogenic environments are known for their extreme temperatures, and the CBE504 Series is engineered to excel in such conditions. With a temperature rating ranging from -320 °F to 150 °F (-96 °C to 65 °C), this regulator thrives in the harshest settings. However, the true sophistication of the CBE504 Series lies in its ability to deliver rapid pressure-build speeds, a feature reminiscent of RegO's successful PB504 Series Pressure Build Regulator.

This capability to produce pressure-build speeds up to twice as fast as competitive models is a game-changer in cryogenics, where precise pressure control can make all the difference. Furthermore, the CBE504 Series merges pressure building and economizer functions into one unit. This ingenious design not only reduces the overall weight of cryogenic vessels by 40% but also minimizes potential leak points, enhancing operational safety.

RegO introduces the future of cryogenic precision with the CBE504 Series Half-Inch Pressure Builder/Economizer Regulator. *Credit: RegO®*

Designed to excel with a wide array of cryogenic industrial gases, including nitrogen, oxygen, argon, CO_2 and LNG, the CBE504 Series Half-Inch Pressure Builder/Economizer Regulator demonstrates exceptional versatility. Its pioneering design seamlessly integrates both pressure-building and economizer functions into a single unit, resulting in reduced weight, space-saving benefits and fewer potential leak points.

Additionally, the CBE504 Series boasts various enhancements, such as an economizer seal design, a precisely calibrated pressure adjustment feature and the inclusion of Monel screens, all contributing to heightened performance and extended product longevity. Moreover, this regulator proudly holds PED (SEP) certification and CRN registration, ensuring its steadfast adherence to industry standards. For optimal efficiency with CO_2 and nitrous oxide, it is recommended for use in the gas phase.

Yet the merits of the CBE504 Series extend far beyond its technical specifications. RegO's steadfast commitment to customer satisfaction shines through every facet of this product. The CBE504 Series is constructed from top-tier materials, including copper alloy (brass), PTFE and stainless steel, ensuring compatibility with cryogenic temperatures down to -320 ºF. To ensure safety and reliability, the product undergoes meticulous cleaning for oxygen service and adheres to stringent industry standards. It also comes with an impressive 10-year product warranty, a testament to RegO's dedication to quality and longevity, as well as a customer-first commitment.

RegO's reputation extends across a diverse range of industries, including residential, agriculture, transportation and energy. Its expansive portfolio of valves and flow control products set the gold standard in terms of performance, certification and service life.

As the world transitions to alternative fuels such as bio/renewable LPG, LNG and hydrogen, RegO is a reliable go-to partner for those navigating these emerging markets. RegO's extensive expertise in gas and liquid equipment positions it as a trusted ally for companies seeking to capitalize on these innovative energy sources.

The launch of the CBE504 Series Half-Inch Pressure Builder/Economizer Regulator represents another milestone for RegO and invites users to experience the next level of cryogenic excellence, where innovation meets precision to propel operations to new heights. **regoproducts.com**

Hydrogen Liquefaction Systems based on Stirling Cryogenerators

by Francesco Dioguardi, Stirling Cryogenics

Stirling cryogenerators were widely used during the 1960s and 1970s for the production of LH_2 at various institutes and research laboratories worldwide. In materials science, small-scale production was employed to study the properties and behavior of LH_2 and its effects on materials.

In scientific devices, Stirling cryogenerators were used as LH_2 reliquefiers to cool cold neutron moderators and to operate H_2/D2/T2 distillation columns. Some of these vintage machines are still in use today. For instance, the one at the National Institute of Cryogenic and Isotope Separation in Romania was installed in 1973 and continues to operate.

With the accelerated interest in a carbon-free society over the past few years, hydrogen and liquid hydrogen have once again taken center stage. Many green H_2 gas production facilities are being built or planned in institutes and industries, many of which require (partial) liquefaction. Stirling Cryogenics has designed a range of system sizes based on the trusted two-stage Stirling cryogenerators used for over 40 years, ranging from small laboratory-scale units producing 5 kg/day of LH_2 to containerized systems for industrial-scale production of up to 400 kg/day. These systems only require H_2 gas and electric power as input, producing converted para LH_2 into a transfer vessel.

Hydrogen Liquefier Concept

The two-stage cryogenerator is available as a one-cylinder machine for liquefying 5 kg/day and as a four-cylinder machine for 22 kg/day of LH_2. Incoming hydrogen gas is cooled to 80 K in the first stage and then liquefied at 20 K in the second stage. The liquid flows into a transfer vessel by gravity, from which the LH_2 is transferred to the storage tank. A Stirling Cryogenics LH_2 system includes all necessary internal piping, instrumentation, a transfer vessel, and system control. All systems are built in accordance with ATEX or other relevant codes. Optionally, catalytic ortho-para conversion, containerization, and GH_2 inlet gas purification can be offered. Stirling cryogenerators can also be supplied as modules to a system integrator, with the cryogenerators serving as the core.

2019 Stirling Cryogenics hydrogen reliquefier for cold neutron source at RID. *Credit: Stirling Cryogenics*

For larger capacities, multiple cryogenerators can be operated in parallel. The design concept of the larger Stirling systems is that all cryogenerators run independently of each other. Should one of the cryogenerators be offline, the liquefaction capacity of the other machines remains available. The second advantage is that the liquefaction capacity is easily adaptable to the momentary availability of H_2. The number of operational cryogenerators can easily be adjusted by simply turning them on or off. Because a Stirling cryogenerator will start producing LH_2 within 20 minutes of warm startup, the system can react swiftly when GH_2 flow increases again.

LH_2 Boiloff Re-Liquefaction

In addition to the production of LH_2 from H_2 gas production, the two-stage Stirling cryogenerator can also be used as a reliquefier for boiloff gas from a storage tank, preventing the release of cold GH_2. In such a setup, the cold GH_2 is not fed into the cryogenerator, but the 20 K cooling power is transported into the storage tank using a cold helium flow.

This is achieved using Stirling's CryoFans, creating a cold He gas loop that connects the 20 K heat exchanger of the cryogenerator with the reliquefaction heat exchanger built into the top side of the LH_2 vessel. The evaporated GH_2 will then remain inside the vessel.

Stirling Cryogenics invites readers to visit its website and is available to discuss the design setup of a project-specific Stirling system for LH_2 liquefaction and boiloff gas systems. **www.stirlingcryogenics.eu**

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) and one high-resolution JPEG of the product using the form at **http://2csa.us/psc**.

Generant - LTAP: Low Temperature Actuation Probe

Ratermann Manufacturing Inc.

The Generant LTAP Series Low Temperature Actuation Probe serves as a controlled pneumatic two-way valve, ideally suited for cryogenic systems. It utilizes a pressurized copper probe that responds to fluid temperature, opening a passage in the control head as the fluid temperature approaches the device's setpoint. This feature ensures user safety by preventing high draw rates or excessively cold conditions. Notable features of the LTAP Series include precise operation with a ±3 °F setpoint tolerance, rapid opening within 3 °F of the setpoint and dependable activation across various ambient conditions. The design emphasizes robustness, employing solid brass for pressures up to 600 PSIG and being suitable for oxygen service. Technical specifications highlight a maximum probe and control head pressure of 600 PSIG, a temperature setpoint range of -40 °F to -10 °F and an exposed fluid temperature range spanning from -320 °F to +150 °F. Its reliable performance and technical capabilities make it well-suited for demanding applications. **www.rmiorder.com**

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Introducing the Malinmaus -150 °C Cryogenic Freezer, designed for versatile and reliable long-term preservation. This ultralow temperature freezer safeguards viruses, germs, vaccines, biological tissues, organs, special food, medicines and reagents with precision. With a temperature range of -40 °C to -150 °C and 0.1 °C accuracy, it operates seamlessly within ambient temperatures of +10 °C to +30 °C. The insulated inner door ensures uniform cooling, while the 304 stainless steel chamber guarantees easy cleaning and user-friendliness. A Tecumseh compressor and patented refrigeration technology maintain system stability. Security is paramount with a safety door lock, visual and audible alarms for temperature fluctuations, sensor failures and controller errors. Power failure protection and controller error protection mechanisms ensure continuous operation even during sensor failures. **www.malinmaus.com**

Thermal Straps

Technology Applications, Inc. (TAI)

TAI offers over 150 standard model (and fully custom) thermal straps made from OFHC copper and graphite. Our Copper Thermal Strap (CuTS®) product line is the largest standard line in our industry, and each year we publish our popular CuTS® Catalog. CuTS® are offered in 120 standard models (dozens of which are designed for popular cryocoolers), with customization options such as gold and nickel plating, aluminum end fittings, mylar sleeves. Tens of thousands of TAI CuTS® products are used annually by national laboratories, universities, aerospace organizations and laboratory equipment manufacturers across the globe. TAI always offers free front-end design services to all customers, and because it designs, manufactures and tests each of its straps (never outsourcing its products), TAI can offer the industry's lowest prices and best warranty. **www.techapps.com**

Basic Research Benchtop Freeze Dryer-LyoQuest

Telstar

The LyoQuest laboratory freeze dryers are versatile and compact units designed for research and development. With unbeatable capacity, a state-of-the-art control system and specially designed accessories, they set the benchmark in their category. Offering outstanding performance in a small space, these freeze dryers can handle products in flasks, vials, ampoules, or bulk. The equipment includes a PLC controlled unit with digital display and touch screen, allowing for continuous monitoring and fully automatic functioning. With two configurations, LyoQuest-55 and LyoQuest-85, catering to different needs, these freeze dryers provide optimized technical features for reliable and efficient performance. Accessories and options such as various chambers and manifolds enhance the unit's flexibility and functionality. **www.telstar.com**

Loading Bay

Demaco

The Demaco loading bay is an essential solution for transporting liquid hydrogen safely and efficiently over long distances. It enables the easy transfer of cryogenic liquid from on-site storage to ships or trucks through vacuum insulated pipes. This system features valves, pressure relief mechanisms and cutting-edge monitoring and control technology. For enhanced safety and efficiency, all components can be integrated into a vacuum insulated box, optimizing cost effectiveness. This loading bay plays a pivotal role in facilitating the widespread use of liquid hydrogen, especially in areas distant from production sources. Constructed from stainless steel with vacuum insulation, Demaco offers both mobile and fixed installation options catering to various project sizes. They provide turnkey solutions tailored to specific loading bay requirements. **www.demaco-cryogenics.com**

Cryogenic Stepper Motors and Resolvers

Empire Magnetics Inc.

Cryogenic temperatures (down to 20 K) demand motors designed with materials carefully selected for compatible thermal expansion characteristics and resistance to brittleness. The CY Series Cryogenic Stepper Motors feature special cryogenic dry lubrication and proprietary metal and/or metal alloy components. Applications for these motors include deep space exploration, scientific research, satellite and antenna controls, observatory instrumentation, liquid oxygen pumping, plasma processing, superconductor research, and frozen food handling, among others. Empire Magnetics can also manufacture custom motors wound with superconducting wire or perform other user-specified alterations, as required, at an additional cost. **www.empiremagnetics.com**

The Callisto

P3 Technologies

The newest addition to its SCAMP product line, the Callisto incorporates the fourth generation SCAMP technology, offering long-life and energy-efficient performance. Featuring its most powerful solenoid to date, P3 Technologies' Callisto achieves an unprecedented continuous duty pressure rise of over 3,500 pounds per square inch differential. With state-of-the-art hybrid valves, Callisto showcases exceptional performance and minimal internal leakage in single-phase liquid, saturated condition and two-phase flow, making it an optimal choice for cryogenic applications involving propellants or hazardous fluids. Joining the existing SCAMP products, Callisto provides a comprehensive range suitable for various applications, encompassing aerospace, medical equipment, cryogenic environments and hazardous fluids. This product line caters to a wide spectrum of pressure and flow rate requirements, offering versatility and reliability in different industries. **www.p3-tech.com**

Tech4Imaging Announces Development of a Capacitance-Based Multiphase Cryogenic Mass Flowmeter

by Matthew Charleston, Benjamin Straiton, and Dr. Qussai Marashdeh, Tech4 Imaging, LLC

Cryogenic Multiphase Mass Flow Meter

Tech4Imaging, LLC has spent the last few years researching, developing and testing a new capacitance-based multiphase cryogenic flowmeter. Originally presented at CEC/ICMC'23 in Honolulu, the new design was able to achieve high accuracy across a broad range of flow rates, volume fractions and flow regimes. This development required overcoming several significant technological hurdles.

Tech4Imaging's patent-pending mass flow meter relies on cross-correlation of a capacitance flow signal as fluid moves through the sensor. Measurement of flow velocity via cross-correlation required the development of a very high-speed data processing architecture, capable of collecting over 20,000 frames per second. The instrument measures the volume fraction of liquid in the region based on the difference in the dielectric constant between the liquid and gas phase of the cryogen. The volume fraction is then converted to a mass fraction based on the densities of the phases at the measured operating temperature. From the mass fraction and velocity, the mass flow rate can be calculated.

Multiphase Cryogenic Calibration Flow Loop

Calibrating and verifying the flowmeter required the construction of a multiphase cryogenic flow loop. This system

Parameter	Tested Range
Mass Flow Rate	0.0025 – 0.2817 kg/s
Volume Fraction	0 – 100%
Velocity	0 – 30 m/s
Overall Error	±4% Full scale

Tech4Imaging's capacitance-based mass flowmeter. *Credit: Tech4 Imaging*

was also a significant development by Tech4Imaging, capable of independently varying the flow rate and volume fraction to achieve a wide range of fluid flow conditions. The instrument and flow loop have been extensively tested with LN_2 and are in the process of being tested with LH_2. Adaptation to other cryogens like LOX or liquid methane is expected to follow. A paper summarizing the construction of the flow loop, the overall test regime, and the results will soon be published in the IOP Conference Series: "Materials Science and Engineering, Advances in Cryogenic Engineering."

Cryogenic Multiphase Mass Gauging

Tech4Imaging is at the forefront of cryogenics research. Tech4Imaging's other main technology called Electrical Capacitance Volume Tomography, or ECVT, is able to record images and phase distribution data of multiphase mixtures. Tech4Imaging has recently applied this technology to study microgravity mass gauging.

Fluids, often propellants, in microgravity don't maintain a consistent and easy-to-measure level state. This limits the techniques that can be used to measure the amount of fluid remaining in a tank, a critical parameter for long-term space missions. Traditional methods have serious drawbacks in terms of accuracy, reliability and response time. ECVT, however, has tremendous potential to solve these problems. In an upcoming series of papers in the journal *Cryogenics* and the journal *Sensors*, Tech4Imaging will demonstrate the construction and testing of a prototype sensor, as well as a variety of techniques to improve the accuracy of the reconstructed mass fraction using imaging and newly developed machine learning algorithms.

Capacitance technology has many advantages in the field of cryogenics due to its non-intrusive, non-hazardous nature, its fast response times and its high degree of sensitivity. Tech4Imaging hopes to continue to push the boundaries of new research into cryogenic fluid dynamics using its newly developed technology.

People & Companies in Cryogenics

Brad Senstra has been named CEO of **ReproTech LLC**, a leading human reproductive tissue cryogenic storage company. With over 30 years of experience, ReproTech focuses on long-term cryostorage and secure transportation of reproductive tissues, operating facilities across several states. Senstra, with more than 16 years of expertise in fertility and reproductive medicine, assumes this role after the company received a majority investment from Red Barn Equity Partners in 2021.

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The US Department of Energy Office of Science (DOE-SC) has allocated $529 million over five years to support nuclear science research at **Michigan State University's Facility for Rare Isotope Beams (FRIB)** (CSA CSM). This funding facilitates FRIB's operation as a

FRIB enables scientists to explore rare isotopes, nuclear astrophysics, fundamental interactions, and practical applications in fields like medicine, homeland security and industry. Credit: FRIB

DOE-SC user facility, serving 1,800 scientists and advancing the DOE-SC Office of Nuclear Physics' mission. FRIB's research focuses on rare isotopes, nuclear astrophysics, fundamental interactions and practical applications in fields such as medicine, homeland security and industry.

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Credit: Domainex

Domainex is thrilled to introduce **Alex Parker**, its newest addition to its growing protein sciences team. Parker holds a Ph.D. in Molecular Biology and Biotechnology from the University of Sheffield, with a focus on structural studies related to chromosome segregation in *Vibrio cholerae* while working under the guidance of Daniel Bose and Julien Bergeron. Her doctoral research equipped her with valuable expertise in protein expression and purification, X-ray crystallography, and cryogenic electron microscopy. Building on her cryo-EM specialization during her Postdoc Research Associate role in Julien Bergeron's labs at King's College London, Parker further explored gram-negative bacterial membrane protein complexes responsible for membrane maintenance and toxin excretion.

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NASA's OSIRIS-REx mission is bringing home samples from the asteroid Bennu, offering scientists a rare opportunity to study

Michelle Thompson, planetary scientist and expert in space weathering, will be one of the first six humans — and the first woman — to analyze samples of asteroid Bennu brought to Earth by OSIRIS-REx. Credit: Purdue University photo/Rebecca Robiños

these pieces of our solar system's history. The mission, a culmination of years of effort, will land samples in the Utah desert this month, and **Michelle Thompson from Purdue University** will be among the first to analyze them. Bennu's carbonaceous composition, rich in carbon, holds clues about the origins of life on Earth. This endeavor, encapsulating the mission's goal of exploring the solar system's origins, underscores the importance of laboratory analysis over remote observations and offers insights into planetary science, space weathering and more.

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Credit: CPC-Cryolab

Ryan Felsenthal has joined **CPC-Cryolab** as Cryogenics Senior Account Manager. With an extensive 18-year career in ultracold cryogenics, Felsenthal's exceptional contributions make him a respected figure in the field. His collaborative work with major OEMs, global industrial gas leaders and esteemed space agencies in Florida has earned him a reputation for excellence.

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Meetings & Events

Hydrogen Aviation Summit 2023
November 28-29, 2023
Online
https://zeroavia.com/summit/2023

23rd International Cryocooler Conference
June 3-6, 2024
Madison, Wisconsin
https://cryocooler.org

Cryogenic Operations 2024
July 17-19, 2024
Grenoble
www.cryo-ops-2024.fr

International Cryogenic Engineering Conference/ International Cryogenic Material Conference 2024
July 22-26, 2024
Geneva, Switzerland
https://icec29-icmc2024.web.cern.ch

2024 Applied Superconductivity Conference
September 1-6, 2024
Salt Lake City, Utah
www.appliedsuperconductivity.org/asc2024

Construction is now underway in Granada, Spain, on the **International Fusion Materials Irradiation Facility–Demo Oriented NEutron Source (the IFMIF-DONES)** project. The facility aims to solve one of the key roadblocks towards harnessing fusion for

Construction is getting underway at the IFMIF-DONES site in Granada, Spain. Credit: IFMIF-DONES

large-scale electricity production—figuring out which materials are sufficiently resistant to the neutron irradiation that will be present in next-generation fusion reactors. Spain and Croatia are the project leads, with Spain funding 50% of all construction costs and 10% of operating costs, and Croatia responsible for 5% of each.

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Email: membership@cryogenicsociety.org • Web: cryogenicsociety.org
A non-profit technical society serving all those interested in any phase of cryogenics
SSN 1085-5262 • November 2023
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