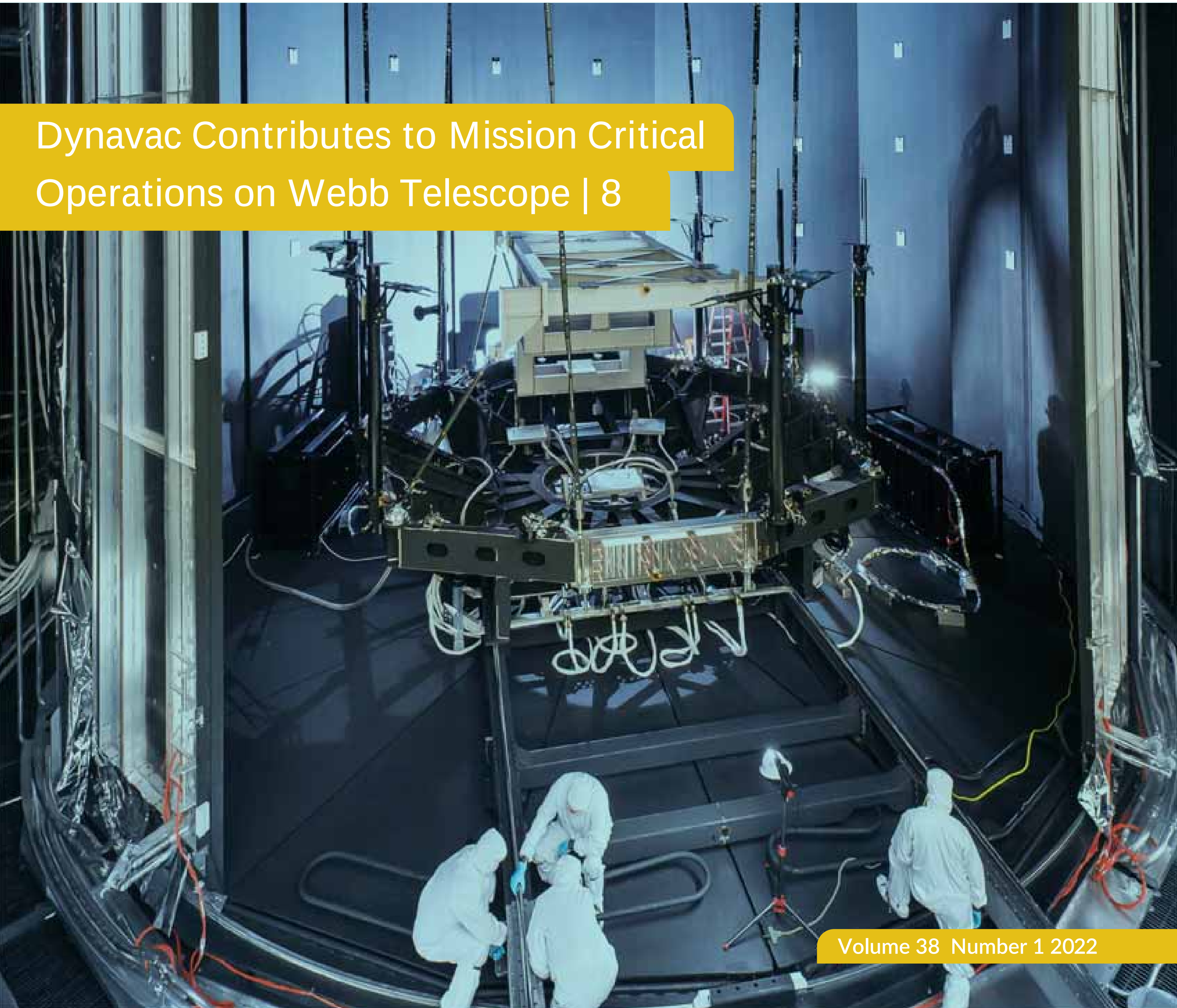
Cold Facts

The Magazine of the Cryogenic Society of America, Inc. INTERNATIONAL



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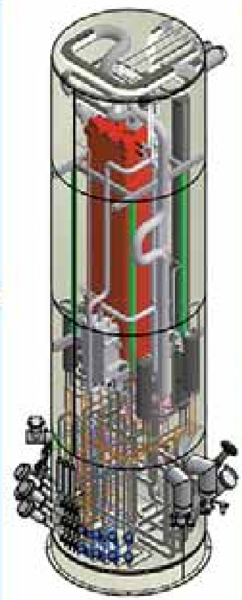

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* New member since last issue

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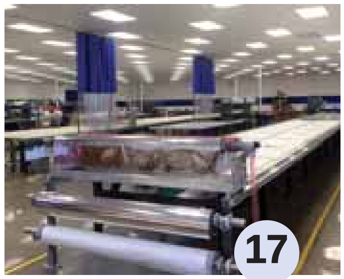

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ON OUR COVER

A leading supplier of space simulation test systems and equipment, Dynavac designed and fabricated the cryogenic cold walls to support testing as low as 30 K. *Image: NASA/Chris Gunn*

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Cold Facts

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From the Executive Director

Over the last year, it seems as though I am consistently bringing up the theme of 'change' every time I sit down to write my letter for *Cold Facts*. This month is no different. After 3 years with CSA, *Cold Facts* editor Tate Paglia has moved on to a new opportunity. On behalf of CSA, I'd like to thank Tate for all the hard work, time and effort he put into this magazine and other facets of the Society's work.

In February, CSA welcomed new *Cold Facts* editor Anne DiPaola to the CSA family! Anne is from New Orleans, Louisiana, where she has been contributing to and editing several regional and industry publications for more than 20 years. Anne has a keen interest in science and technology as well as an enthusiasm for profiling people with unique stories to tell. She's looking forward to bringing these interests to *Cold Facts* in upcoming issues and working with present and future innovators in cryogenics. She can be reached at editor@cryogenicsociety.org or at 630-686-8889.

Another big change in the last month: we are pleased to announce the launch of the new Cryogenic Society of America website at **cryogenicsociety.org**! We hope that you will find the site more functional, easier to navigate, and a useful source of information for the greater cryogenics community.

More than just a website, the system serves as a simple way to interact with CSA by incorporating CSA's membership database, event registration platform, membership dues billing, and more! In the coming months, we will be sending a series of emails to further introduce different aspects of the new CSA website to all of our members and readers.

CSA staff has worked to present the wide range of content in an easily accessible way, but we recognize this is an ever-evolving process. CSA values suggestions from the community. Please send any ideas for additions or improvements along to us via an email to membership@cryogenicsociety.org.

Along with the launch of the new website, we have opened registration for the upcoming Foundations of Cryocoolers Short Course, which will take place on Monday, June 27, 2022, prior to the ICC22 Conference in Bethlehem, PA. The course will be instructed by Ray Radebaugh, NIST (retired) and Ralph Longsworth, Sumitomo Cryogenics of America, Inc. We will be offering both in-person and virtual attendance options. For full details and registration, please visit the CSA website at **cryogenicsociety.org**.

I am looking forward to attending the aforementioned short course in person and finally getting to meet many of you face to face!

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

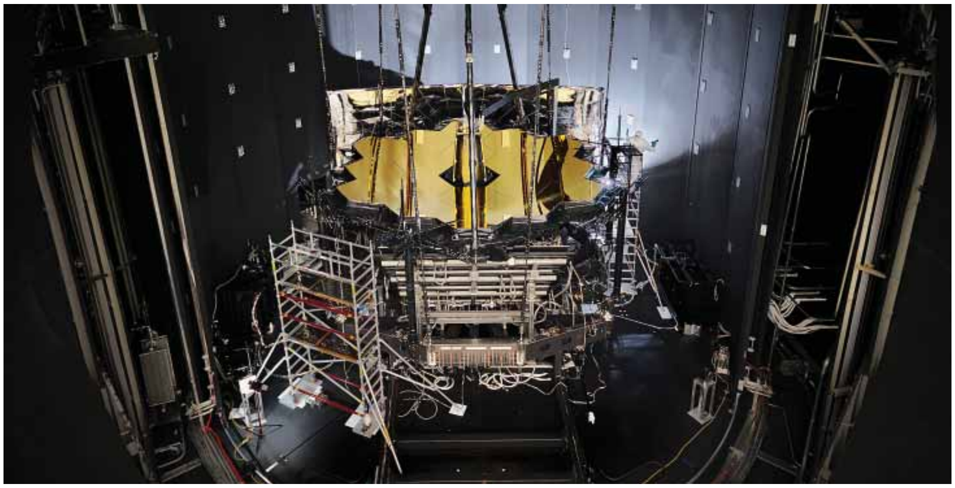
Dynavac Contributes to Mission Critical Operations on Webb Telescope

The Christmas Day launch of the James Webb Space Telescope (JWST) was a welcome and long-awaited gift for the many people and companies involved in this program since serious planning began in the early 1990s. As a successor to the Hubble Space Telescope, the JWST has ambitious goals that include looking back in time for infrared light from the first stars and galaxies formed in the Big Bang – making for a novel spacecraft with a most challenging mission.

Observing faint infrared signals demands instrumentation operating at temperatures on the order of 40-50 K. Several key aspects of the mission are driven by this thermal consideration – including the orbital position at the L2 Lagrange point, which allows the massive solar shield to protect the telescope and instrumentation from radiation emitted from the sun and the earth/moon.

Unlike Hubble, there is no possibility of repair missions now that the JWST is on station at the L2 point 1,500,000 km from earth. Accordingly, a rigorous test program in advance subjected the components, subsystems, systems and the entire spacecraft to the vacuum and cold of space. Existing thermal vacuum testing systems at several US locations were upgraded to meet the test requirements, which included presenting a thermal background of 40 K, absorbing the radiated energy from the spacecraft and working with test articles with sizes up to the entire assembled spacecraft.

Major JWST partners including Northrop Grumman, Ball Aerospace, Lockheed Martin, and NASA Goddard tapped Dynavac to outfit their existing thermal vacuum systems with cryogenic cold walls to support testing as low as 30 K. Dynavac designed and fabricated the cryogenic cold walls for the critical environmental testing of JWST's many sub-systems, including the Near-Infrared Camera (NIRCam), the Integrated Science Instrument Module (ISIM) and the Solar Shield. Typical space missions are tested with cold walls using liquid or gaseous nitrogen, giving a thermal background



The James Webb Space Telescope emerging from NASA's Chamber A after the full operational test.
Image: NASA/Chris Gunn

of 70-80 K. For JWST testing, Dynavac built cold walls cooled with gaseous helium (GHe) to operate as low as 20 K. The GHe-cooled walls operate inside of liquid nitrogen (LN_2) cooled shrouds to minimize thermal load on the cryogenic walls.

Following integration of all systems, the fully assembled JWST was tested for nearly 100 days in the historic Chamber A at NASA's Johnson Space Center (JSC). Originally built for the Apollo program, Chamber A is the world's largest thermal vacuum facility. The chamber underwent extensive upgrades, including installing a combined nitrogen-helium refrigerated cold wall to present a deep space environment for full operational testing of the mechanical, electronics and radiation cooling systems aboard the vehicle.

Test requirements dictated a working envelope inside the chamber of 43-foot diameter by 65-foot high, resulting in one of the largest cryogenic walls ever built. NASA and its primary contractor, Jacobs Engineering, turned to Dynavac to construct this unprecedented LN_2/GHe shroud system. The interior cryogenic wall is fabricated from aluminum sheet and angle/I-beam and is built from an array of panels, each approximately 12 feet wide and 40 feet long. Dynavac built the panels at its 50,000-square-foot Hingham MA facility and then performed the extensive assembly and commissioning on site at the JSC.

A massive and specialized refrigeration system cools gaseous helium below 20 K to power the thermal shroud environment. The gaseous helium passes through a network of extruded tubing welded to the aluminum panels. The shroud – with its 23 metric tons of aluminum – can be cooled down to 20 K from room temperature in 24 hours and can maintain 20 K with a stability of +/- 0.1 K.

Dynavac collaborated extensively with Jacobs Engineering to optimize the design for the operating and thermal performance specifications. More than 7,000 critical welds were needed to fabricate the wall, with each weld subjected to X-ray inspection. Further, the interior side of each panel was coated with special high optical absorptivity/emissivity black paint meeting stringent thickness and uniformity requirements.

An impressive collection of skills, technologies, people, and organizations made contributions to the JWST. With the spacecraft now on station so distant from earth, and as telemetry relays a primary mirror temperature of 62 K, it is satisfying to think of the role cryogenic cold walls played in the critical testing of this magnificent instrument of discovery.

"Dynavac is honored to have played a part in the mission, and with many, many others, we look forward to the first images from the dawn of the universe," the company added in a release. ■

DOE Establishes New Office of Clean Energy Demonstrations

On December 21, the US Department of Energy (DOE) announced the establishment of the Office of Clean Energy Demonstrations, a new DOE office that will help deliver new, good-paying jobs for American families and workers, and reduce pollution while benefitting disadvantaged communities. The Bipartisan Infrastructure Law provides more than $20 billion to establish the Office of Clean Energy Demonstrations and support clean energy technology demonstration projects in areas including clean hydrogen, carbon capture, grid-scale energy storage, small modular reactors and more.

Demonstration projects prove the effectiveness of innovative technologies in real-world conditions at scale to pave the way towards widespread adoption and deployment. The founding of this office represents a new chapter that builds on DOE's long-standing position as the premier international driver for clean energy research and development, expanding DOE's scope to fill a critical innovation gap on the path to net zero emissions by 2050.

"Thanks to the investments Congress made in the Bipartisan Infrastructure Law, the Office of Clean Energy Demonstrations will move clean energy technologies out of the lab and into local and regional economies across the country, proving the value of technologies that can deliver for communities, businesses and markets," said Secretary of Energy Jennifer M. Granholm. "This new office will hire the best and brightest talent to invest in cutting-edge clean energy projects, and DOE is calling on anyone dedicated to addressing the climate crisis to roll up their sleeves and join us."

This investment in the Office of Clean Energy Demonstrations is part of the $62 billion in the Bipartisan Infrastructure Law that will supercharge DOE's work on clean energy demonstrations to deliver cutting-edge clean energy technologies to communities and businesses across the country. These demonstrations will fund projects totaling hundreds of millions or multiple billions of dollars in scale and will unlock massive follow-on investment from the private sector to deploy these technologies, delivering clean energy and creating good-paying jobs.

The office's programs also include billions of dollars to invest in demonstration projects in rural areas and economically hard-hit communities, a critical focus of the Justice40 initiative aimed at delivering 40% of clean energy investment benefits to disadvantaged communities and those that are experiencing the first and worst impacts of climate change. The office will consistently engage environmental justice groups, labor and communities to help shape program development and execution. In addition to large-scale projects, DOE will continue to support many smaller-scale pilots and demonstrations that are needed to meet the administration's climate goals. ■

Look who's NEW in the Cold Facts Buyer's Guide

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

API Technologies (APITech)*

Manufactures fixed coaxial attenuators, DC-40 GHz (SMA, SMPM, and 2.92mm), standard (0,3,6,10 and 20 dB) and custom attenuation values, 50 ohms. Also: Powerfilm SMT chip attenuators, DC-18 GHz, 0-20 dB, 50 ohms, alumina substrate, 4mK to 150 Celsius.

CryoHiVac Consulting LLC

CryoHiVac provides consulting services and proposes affordable solutions for cryogenic and high vacuum applications used by high-tech industries and government programs. The company represents high-tech products in US domestic and international markets.

Cryonos Co.

Cryonos is an engineering company that serves its clients' needs on cryogenic insulation, design, equipment, and consultancy. In addition, Cryonos is a producer of cryogenic inventories for biological samples.

Habonim Industrial Valves & Actuators

Manufacturer of standard floating ball valves, trunnion, cryogenic, high pressure and metal seated valves, as well as control and automation systems, pneumatic actuators and complex manifold assemblies for economical solutions to specialized tasks.

Instrucan Scientific Ltd.

Liquid nitrogen generators for both lab and industrial dosing applications, small compact fully automated systems to large skid-based systems, cryogenic flex hoses, helium recovery and liquefiers.

SIAD Macchine Impianti S.p.A.

SIAD is a leading Italian chemical group with sites in Europe and the rest of the world, specializing in the design, manufacture and installation of air separation units and compressors.

Tobin Scientific

Tobin Scientific, a single-source provider of life science laboratory relocation, holds patents and specializes in frozen biological and cryogenic transportation, repository, and temperature-controlled storage. ■

***CSA CSM**

NASA's Webb Telescope Keeps Cool with Ultrathin DuPont™ Kapton® Polyimide Films

After 30 years in development, NASA's James Webb Space Telescope (JWST) was launched on December 25, 2021, from the European Space Agency's launch site at Kourou in French Guiana. DuPont technology, in the form of ultrathin Kapton® polyimide films, is the crucial material protecting the JWST from the light and heat of the sun, enabling it to function properly in space.

Space is one of the most hostile and extreme environments imaginable. Above the insulating atmosphere of the Earth, spacecraft are subjected to extreme temperature, both hot and cold, and a significantly increased threat of radiation damage.

The $10 billion JWST is the largest space telescope ever built and features a deployable mirror measuring more than 21 feet in diameter, made up of 18 hexagonal mirror segments. The gold-plated beryllium mirror segments are more than eight feet in diameter and will focus on four main areas: first light in the universe, assembly of galaxies in the early universe, birth of stars and protoplanetary systems and planets (including the origins of life). At the heart of the JWST is the Integrated Science Instrument Module (ISIM), a suite of four instruments including a near-infrared camera, a mid-infrared instrument, a fine guidance sensor and two different near-infrared spectrographs.

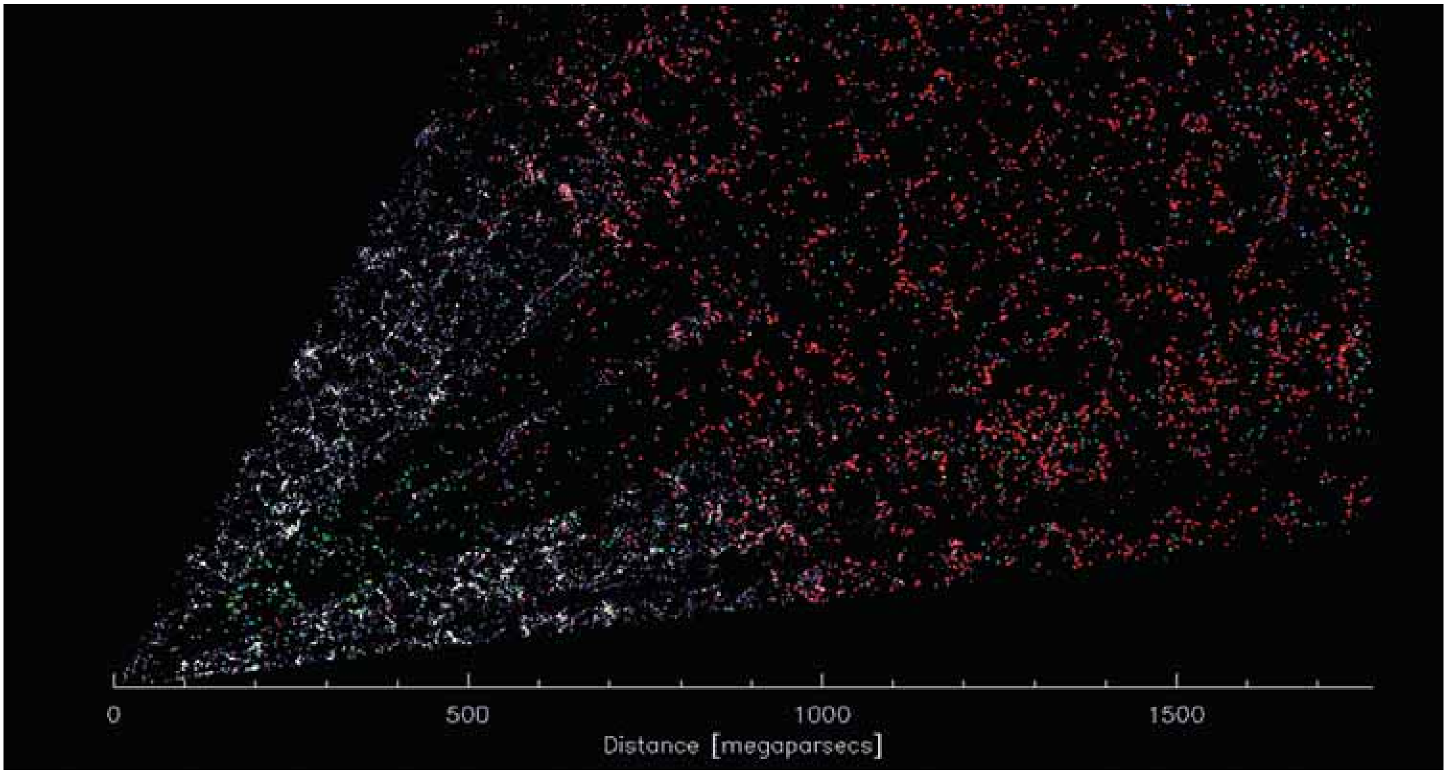
The JWST is the successor to the 30-year-old Hubble space telescope and improves on Hubble in two key ways. The first is its size: Hubble is about the size of a school bus, whereas Webb is about half the size of a 737 aircraft. Hubble's mirror is approximately eight feet in diameter, while JWST's deployable mirror is more than 21 feet in diameter, making it 100 times more powerful than the Hubble. The JWST will operate near the Earth–Sun L2 (Lagrange point), approximately 1,500,000 km (930,000 mi) beyond Earth's orbit. By way of comparison, Hubble orbits 550 km (340 mi) above Earth's surface, and the Moon is roughly 400,000 km (250,000 mi) from Earth.

The five-layer sunshield, shown here outstretched, keeps sunlight and background heat from interfering with the ISIM instruments. *Image: NASA/Northrop Grumman*

Crucial to the JWST's performance is a five-layer sunshield that keeps sunlight and background heat from interfering with the ISIM instruments. The sunshield is a diamond-shaped system of five layers of Kapton polyimide film approximately 70 feet long and 47 feet wide. Each layer of this film is coated with aluminum, and the sun-facing side of the two hottest layers (Layer 1 and Layer 2) also has a treated silicon coating to reflect the sun's heat back into space. Each layer of the sunshield made by Kapton polyimide film is incredibly thin. Layer 1 will face the sun and is only 50 microns (0.002 inches) thick, while the other four layers of Kapton polyimide film are 25 microns (0.001 inches). The aluminum and silicon coatings are even less thick. The silicon coating is approximately 0.05 microns (50 nanometers) thick, while the aluminum coating is approximately 0.1 microns (100 nanometers) thick. JWST's sunshield was designed to be folded origami-style, 12 times, to fit inside the Ariane 5 rocket – so the Kapton polyimide film layers needed to be ultrathin. "The excellent thermal and mechanical properties of Kapton polyimide film make it an ideal material for space applications," said Tim Scott, business development leader, Aerospace and Defense at DuPont Electronics and Industrial. "For more than 50 years, Kapton polyimide film has been an integral technological material supporting spacecraft missions, beginning with the Apollo 11 mission in July 1969."

The Kapton-enabled sunshield is a critical part of the Webb telescope design because the infrared cameras and instruments aboard must be kept very cold, under -370 °F, and out of the sun's heat and light to function properly. Each successive layer of the sunshield is cooler than the one below. The sunshield separates the observatory into a warm, sun-facing side with a maximum temperature of the outermost layer of 230 °F, and a cold side with a minimum temperature of roughly -394 °F.

This isn't the first time that NASA has selected DuPont technology to protect spacecraft designed for exploration missions. For more than 50 years, DuPont has demonstrated that its technology performs reliably in extreme temperature flux, atomic oxygen, particle and electromagnetic radiation, space debris and other space weather conditions experienced by satellites. As space missions become more complex, DuPont continues to research and create new ruggedized variations of Kapton to better withstand the unique conditions found in space. ■



DESI's three-dimensional "CT scan" of the Universe. The earth is in the lower left, looking out over 5 billion light years in the direction of the constellation Virgo. As the video progresses, the perspective sweeps toward the constellation Bootes. Each colored point represents a galaxy, which in turn is composed of hundreds of billions of stars. Gravity has pulled the galaxies into a "cosmic web" of dense clusters, filaments and voids. *Image: D. Schlegel/Berkeley Lab using data from DESI*

DESI Creates Largest 3D Map of the Cosmos

The Dark Energy Spectroscopic Instrument (DESI) has capped off the first seven months of its survey run by smashing through all previous records for three-dimensional galaxy surveys, creating the largest and most detailed map of the universe ever. Yet it's only about 10% of the way through its five-year mission. Once completed, that phenomenally detailed 3D map will yield a better understanding of dark energy, and thereby give physicists and astronomers a better understanding of the past – and future – of the universe. Meanwhile, the impressive technical performance and literally cosmic achievements of the survey thus far are helping scientists reveal the secrets of the most powerful sources of light in the universe. DESI is an international science collaboration managed by the Department of Energy's (DOE) Lawrence Berkeley National Laboratory (Berkeley Lab) with primary funding for construction and operations from DOE's Office of Science.

DESI scientists presented the performance of the instrument and some early astrophysics results in January at a Berkeley Lab-hosted webinar called CosmoPalooza, which also featured updates from other leading cosmology experiments. "There is a lot of beauty to it," said Berkeley Lab scientist Julien Guy, one of the speakers. "In the distribution of the galaxies in the 3D map, there are huge clusters, filaments and voids. They're the biggest structures in the universe. But within them, you find an imprint of the very early universe, and the history of its expansion since then."

DESI has come a long way to reach this point. Originally proposed over a decade ago, construction on the instrument started in 2015. It was installed at the Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory near Tucson AZ. Kitt Peak National Observatory is a program of the National Science Foundation's (NSF) NOIRLab, which the DOE contracts with to operate the Mayall Telescope for the DESI survey. The instrument saw first light in late 2019. Then, during its validation phase, the coronavirus pandemic hit, shutting down the telescope for several months, though some work continued remotely. In December 2020, DESI turned its eyes to the sky again, testing out its hardware and software, and by May 2021 it was ready to start its science survey.

But work on DESI itself didn't end once the survey started. "It's constant work that goes on to make this instrument perform," said physicist Klaus Honscheid of Ohio State University, an instrument scientist on the project, who delivered the first paper of the CosmoPalooza DESI session. Honscheid and his team ensure the instrument runs smoothly and automatically, ideally without any input during a night's observing. "The feedback I get from the night observers is that the shifts are boring, which I take as a compliment," he said.

But that monotonous productivity requires incredibly detailed control over each of the 5,000 cutting-edge robots that position optical fibers on the DESI instrument, ensuring their positions are accurate to within 10 microns. "Ten microns is tiny," said Honscheid. "It's less than the thickness of a human hair. And you have to position each robot to collect the light from galaxies billions of light-years away. Every time I think about this system, I wonder how could we possibly pull that off? The success of DESI as an instrument is something to be very proud of."

Seeing dark energy's true colors

That level of accuracy is needed to accomplish the primary task of the survey: collecting detailed color spectrum images of millions of galaxies across more than a third of the entire sky. By breaking down the light from each galaxy into its spectrum of colors, DESI can determine how much the light has been redshifted – stretched out toward the red end of the spectrum by the expansion of the universe during the billions of years it traveled before reaching Earth. It is those redshifts that let DESI see the depth of the sky.

The more redshifted a galaxy's spectrum is, in general, the farther away it is. With a 3D map of the cosmos in hand, physicists can chart clusters and super-clusters of galaxies. Those structures carry echoes of their initial formation, when they were just ripples in the infant cosmos. By teasing out those echoes, physicists can use DESI's data to determine the expansion history of the universe. "Our science goal is to measure the imprint of waves in the primordial plasma," said Guy. "It's astounding that we can actually detect the effect of these waves billions of years later, and so soon in our survey."

Understanding the expansion history is crucial, with nothing less than the fate of the entire universe at stake. Today, about 70% of the content of the universe is dark energy, a mysterious form of energy driving the expansion of the universe ever faster. As the universe expands, more dark energy pops into existence, which speeds up the expansion more, in a cycle that is driving the fraction of dark energy in the universe ever upwards. Dark energy will ultimately determine the destiny of the universe: will it expand forever? Will it collapse onto itself again, in a Big Bang in reverse? Or will it rip itself apart? Answering these questions means learning more about how dark energy has behaved in the past – and that's exactly what DESI is designed to do. And by comparing the expansion history with the growth history, cosmologists can check whether Einstein's theory of general relativity holds over these immense spans of space and time.

Black holes and bright galaxies

But understanding the fate of the universe will have to wait until DESI has completed more of its survey. In the meantime, DESI is already driving breakthroughs in our understanding of the distant past, more than 10 billion years ago when galaxies were still young. "It's pretty amazing," said Ragadeepika Pucha, a graduate student in astronomy at the University of Arizona working on DESI. "DESI will tell us more about the physics of galaxy formation and evolution."

Pucha and her colleagues are using DESI data to understand the behavior of intermediate-mass black holes in small galaxies. Enormous black holes are thought to inhabit the cores of nearly every large galaxy, like our own Milky Way. But whether small galaxies always contain their own (smaller) black holes at their cores is still not known. Black holes on their own can be nearly impossible to find – but if they attract enough material, they become easier to spot.

When gas, dust and other material falling into the black hole heats up (to temperatures hotter than the core of a star) on its way in, an active galactic nucleus (AGN) is formed. In large galaxies, AGNs are among the brightest objects in the known universe. But in smaller galaxies, AGNs can be much fainter, and harder to distinguish from newborn stars. The spectra taken by DESI can help solve this problem – and its wide reach across the sky will yield more information about the cores of small galaxies than ever before. Those cores, in turn, will give scientists clues about how bright AGNs formed in the very early universe.

Quasars – a particularly bright variety of galaxies – are among the brightest and most distant objects known. "I like to think of them as lampposts, looking back in time into the history of the universe," said Victoria Fawcett, an astronomy graduate student at Durham University in the UK. Quasars are excellent probes of the early universe because of their sheer power; DESI's data will go back in time 11 billion years.

Fawcett and her colleagues are using DESI data to understand the evolution of quasars themselves. It is thought that quasars start out surrounded by an envelope of dust, which reddens the light they give off, like the sun through haze. As they age, they drive off this dust and become bluer. But it has been hard to test this theory because of the paucity of data on red quasars. DESI is changing that, finding more quasars than any prior survey, with an estimated 2.4 million quasars expected in the final survey data.

"DESI is really great because it's picking up much fainter and much redder objects," said Fawcett. That, she adds, allows scientists to test ideas about quasar evolution that just couldn't be tested before. And this isn't just limited to quasars. "We're finding quite a lot of exotic systems, including large samples of rare objects that we just haven't been able to study in detail before," Fawcett said.

There's more to come for DESI. The survey has already cataloged over 7.5 million galaxies and is adding more at a rate of over a million a month. In November 2021 alone, DESI cataloged redshifts from 2.5 million galaxies. By the end of its run in 2026, DESI is expected to have over 35 million galaxies in its catalog, enabling an enormous variety of cosmology and astrophysics research. "All this data is just there, and it's just waiting to be analyzed," said Pucha. "And then we will find so much amazing stuff about galaxies. For me, that's exciting."

The DESI collaboration is honored to be permitted to conduct scientific research on Iolkam Du'ag (Kitt Peak), a mountain with particular significance to the Tohono O'odham Nation. ■

NASA Hall of Fame Inventor, *Cold Facts* Columnist James E. Fesmire Named GenH2's Chief Technology Officer

On December 15, GenH2, a leading developer of liquid hydrogen infrastructure solutions, formally announced the appointment of renowned NASA veteran and company co-founder James E. Fesmire as Chief Architect and Chief Technology Officer. In his role, Fesmire will shape GenH2's technology vision and drive product evolution and expansion. Known for his world-class expertise and trailblazing contributions to developing cryogenics, materials, and energy technologies, Fesmire specializes in all aspects of liquid hydrogen storage and transfer.

"Hydrogen is the heart of the promise of green energy," said Fesmire. Energy-dense liquefied hydrogen has the potential to store vast amounts of renewable energy and serve as an energy carrier for end-use applications on land, sea, air and space. "As the technology continues to be driven by goals for a sustainable world, I look forward to my role as Chief Architect and Chief Technology Officer for the infrastructure build-out in the emerging hydrogen economy. With overlapping goals and targets across companies, institutions, governments, and countries, we ultimately want to help make energy and transportation work better for all people."

Fesmire has more than 38 years of experience in cryogenics and low-temperature problem-solving, specializing in all aspects of liquid hydrogen storage and transfer. His pioneering cryogenic systems design work helped to advance the Space Shuttle, the International Space Station, future moon and Mars exploration, experimental rocket programs, commercial space launch vehicles and facilities, superconducting power, hydrogen storage and transfer, and many commercial and industrial applications. As founder and visionary for the one-of-a-kind Cryogenics Test Laboratory at NASA Kennedy Space Center, Fesmire has extensive publications and patents in thermal insulation systems, novel materials, advanced composites, energy storage, heat management and testing technology. He also regularly contributes to *Cold Facts* magazine as the author of the "Clean Energy Future" column.

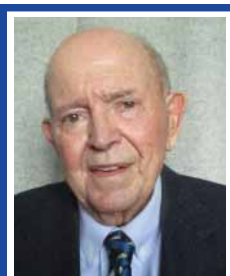
A recipient of NASA medals for Distinguished Service, Exceptional Technology Achievement, and Exceptional Service, Fesmire's work has also been recognized with the Space Technology Mission Directorate's Silver Achievement Medal and the NASA Engineering and Safety Center (NESC) Director's Award for Engineering Excellence. Fesmire has also received an R&D 100 award and the Space Technology Hall of Fame medal for aerogel insulation technology, the world's highest thermal performance insulation material. With 20 issued patents and more than 200 publications, he is a recent inductee of the NASA Inventors Hall of Fame for developments in cryogenics, materials and energy technologies.

"We are looking forward to our collective efforts to build the GenH2 team and move the global hydrogen infrastructure forward," said Cody Bateman, founder and CEO of the company. "His impactful work at NASA is unparalleled and he is well known as a cryogenics and hydrogen expert, including technical standards leadership and technology market implementation, making him an international icon in this sector."

Fesmire's industry leadership has included Cryogenic Society of America, former president; International Institute of Refrigeration Commission A1 (Cryophysics/Cryoengineering), US delegate; Cryogenic Engineering Conference (CEC), board member; ASTM International, committee member and task groups chair; and International Standards Organization, committee member. Fesmire holds a Master of Science in Mechanical Engineering (Materials Science) from the University of Central Florida and Bachelor of Mechanical Engineering from Auburn University. **https://genh2hydrogen.com** ■

CSA's FOUNDATIONS OF CRYOCOOLERS

Dr. Ray Radebaugh
NIST Fellow Emeritus



Dr Ralph Longsworth
Sumitomo Cryogenics

Short Course at ICC22
June 27, 2022
Bethlehem, PA

Take advantage of this excellent opportunity! Dr. Ray Radebaugh, consultant emeritus, NIST Boulder, is a world-renowned expert in the field of cryogenics known to many as “Mr. Cryocooler.” Instructing with him will be Ralph Longsworth, from Sumitomo Cryogenics of America, Inc.

The course begins with a discussion of cryocooler applications, followed by a study of thermodynamic and heat transfer fundamentals, which are then used to explain how various types of gas-cycle cryocoolers achieve temperatures from about 2 K to 150 K. The operating principles and advantages/disadvantages of the three major recuperative cycles and the three major regenerative cycles will be explained. Ralph Longsworth will provide a special emphasis on the Gifford-McMahon cryocooler including its early development history, operating principles, and applications. Register today at cryogenicsociety.org.

Custom Manufacturing of MLI Blankets: Top Three Outsourcing Considerations

by Lee Smith, Business Development Manager, lsmith@webindustries.com and Tom Miller, Applications Engineer, tmiller@webindustries.com, Web Industries Inc.

Multilayer insulation (MLI) blankets must conform to exacting specifications to insulate high value products, from MRI machine components in the medical sector to satellites and other spacecraft. Partnering with an MLI blanket contract manufacturer relieves the OEM of many processing steps and can expedite production cycle time for these highly customized products.

In this article, we will discuss three of the most important considerations to keep in mind when deciding whether to outsource custom MLI blanket manufacturing and what capabilities to seek in a contract manufacturing organization (CMO).

When OEMs and contract manufacturing organizations (CMOs) partner on custom MLI blankets, the OEM typically supplies a 3D model of the product requiring insulation. The CMO uses this model to develop a 3D blanket design, then transforms that 3D design into a 2D pattern, cuts insulation material layers into pattern pieces, and sews the pieces into a 3D blanket to fit over the product. Image courtesy of Web Industries. *Image: Web Industries, Inc.*

Working Across Dimensions

MLI blankets often must be uniquely designed and configured to insulate a one-of-a-kind product, such as a satellite or a spacecraft component or part, like a rocket engine. For space applications, MLI covers sensitive equipment, protecting it from solar radiation and, in some cases, flying space debris. On medical equipment such as MRI machines, the MLI helps maintain ultracold temperatures around the superconducting magnets.

Using CAD technology such as PTC Creo, a custom MLI blanket contract manufacturer can take an OEM's 3D product model to develop a 3D blanket design. During this stage, the CMO:

- Assesses which parts of the product must be insulated
- Develops a blanket design to suit the application
- Determines how it will be secured to the product

Then the CMO transforms that 3D blanket design into a 2D pattern, which in turn is used as a template for cutting insulation material layers into pattern pieces. This cutting might be done with automatic, CNC conveyorized cutters or manually, or some combination of the two methods. Finally, if the CMO has in-house product assembly capabilities, such as sewing equipment and skilled personnel, then it will sew the cut pieces into a 3D blanket to fit perfectly over the product. This is 3D-to-2D-to-3D in action, working across dimensions.

Supply Chain and Inventory Management

Supply chain challenges, including raw material shortages, have made headlines globally during the past two years. MLI

Highly customized multilayer insulation (MLI) blankets require many development and production steps, as shown in this graphic for the typical path to market for an MLI blanket used in an MRI machine. Outsourcing of custom MLI blanket manufacturing enables OEMs to devote resources to other priorities. Image courtesy of Web Industries. *Image: Web Industries, Inc.*

blankets, which can contain dozens of materials and components, are not immune to these issues. When an OEM outsources MLI blanket production to a CMO, that contract manufacturing partner assumes much of the responsibility for procuring and managing the raw materials inventory. In the case of large minimum order quantities for specialty materials, the CMO relieves the OEM of the logistical and financial burden of stocking multiple widths of many different materials in greater quantities than are needed. Raw material inventory costs can run in the millions of dollars for OEMs if they manage MLI blanket raw materials in-house.

A CMO also can lighten the OEM's labor and overhead when it comes to raw material inspection and quality assurance. A CMO can validate that all incoming materials are accompanied by proper bills of quality certification and perform in-line inspections. Outsourcing raw materials inventory management, inspection and quality assurance to a CMO partner also saves the OEM time. This is especially true if the OEM initiates collaboration early with the CMO regarding the thermal analysis for the product and the required MLI properties. Then the CMO can move ahead with material procurement while the OEM finalizes the product design. If one material is in short supply, threatening to slow down the project timeline, a CMO can often recommend an alternative material or processing method.

Custom MLI blanket manufacturing should be done in a clean factory environment, such as this Denton TX facility of Web Industries, which is AS9100D certified and whose associates have been trained in foreign object debris prevention. Use of conveyorized spreading and CNC cutting optimizes efficiencies and helps ensure precise adherence to design specifications. Image courtesy of Web Industries. *Image: Web Industries, Inc.*

A contract manufacturing partner can work with an OEM to not only precision cut MLI blanket materials but also install fasteners, such as the snaps shown here. Then the blanket is ready for final installation on the end product, whether a satellite, rocket engine or MRI machine. Image courtesy of Web Industries. *Image: Web Industries, Inc.*

Installation Readiness

There is much more to MLI blanket converting than cutting. A full-service CMO will form the finished blanket, sewing or bonding the parts together and adding straps and fasteners to enable final installation. These might include snaps, grommets and hook-and-loop closures, such as Velcro® brand tapes or 3M Dual Lock™ reclosable fasteners. The CMO also will provide detailed installation instructions.

Some CMOs have added MLI blanket cleaning services. They not only manufacture the blankets in a near-sterile factory environment but also chemically clean the blankets, such as with a comprehensive isopropyl alcohol rubdown, before packing and shipping. This helps to ensure there is no foreign object debris on the blankets, which could potentially impair product functionality.

Finally, the greater a CMO's end-to-end capabilities for customized MLI blanket manufacturing, the faster and more efficiently the blanket can be installed, helping OEMs to keep product launches on schedule and meet their customers' expectations.

Lee Smith is business development manager and Tom Miller is a design and applications engineer for Web Industries Inc., a contract manufacturer serving customers in the aerospace, industrial, medical and personal care industries. ■

New Intelliconnect Website Showcases RF, Microwave Cryogenic Connectors, Cable Harnesses

Intelliconnect (Europe) Ltd, the UK-based specialist manufacturer of RF, microwave, waterproof and cryogenic connectors and cable harnesses, has launched a new website offering visitors easier navigation, improved search facilities, a "Quote Basket" allowing customers to automatically request a quotation for selected products and a new chat facility to assist with sales and technical questions.

Intelliconnect is proud to be the supplier of choice for many of the leading European and North American defense, medical and marine OEMs and have been awarded the SC21 Silver Performance Standard Award for a third year running. Equally at home responding to smaller projects and companies, Intelliconnect also manufactures a wide range of standard connectors and adapters including the market leading Pisces range of IP67/IP68 waterproof RF connectors, their Precision range as well as Covert, Triaxial and Multipin connector ranges.

"We believe Intelliconnect is a different kind of interconnect solutions provider," says Roy Phillips, managing director. "We use our long experience and innovative thinking to tailor our services to each individual customer. Our experience tells us that every product is unique, and every project requires its own strategy and outlook."

Intelliconnect has provided technology companies with solutions to issues relating to electrical performance, physicality, interface, water resistant materials, finish and obsolescence since 2003 and champions innovation – from its IP67/68 system for internally and externally sealing connectors to its new cryogenic range; Intelliconnect is constantly seeking new solutions. In addition, the company offers the fastest turnaround in the industry for drawings (24 hours), samples (from three weeks) and delivery (delivering custom-designed products in a matter of weeks).

Intelliconnect (Europe) Ltd is the largest UK-based manufacturer of RF, microwave, waterproof and cryogenic connectors and cable harnesses suitable for applications including wearable technology, medical, telecoms, satcoms, military, aerospace, space, general microwave communications, rail traction, oil and gas and marine. Intelliconnect also manufactures the market leading Pisces range of waterproof RF connectors, coaxial adaptors to facilitate inter-series connection and gender change dust-caps and other value added services.

Their recently launched and fast-growing cryogenic cable assembly business CryoCoax (CSA CSM) supplies the growing market for quantum computing, medical, research, test and measurement and the emerging low temperature computing markets.

Intelliconnect's cable division manufactures of affordable, high quality, high frequency microwave cables, specializing in triaxial assemblies, semi-rigid, semi-flexible and cryogenic cables as well as standard RG/LMR type products. Cables can be waterproofed to IP68 and include special features such as phase matching and ruggedized assemblies for use in harsh environments. **https://cryocoax.com** ■

Dover Announces Two Acquisitions Focused on Clean Energy

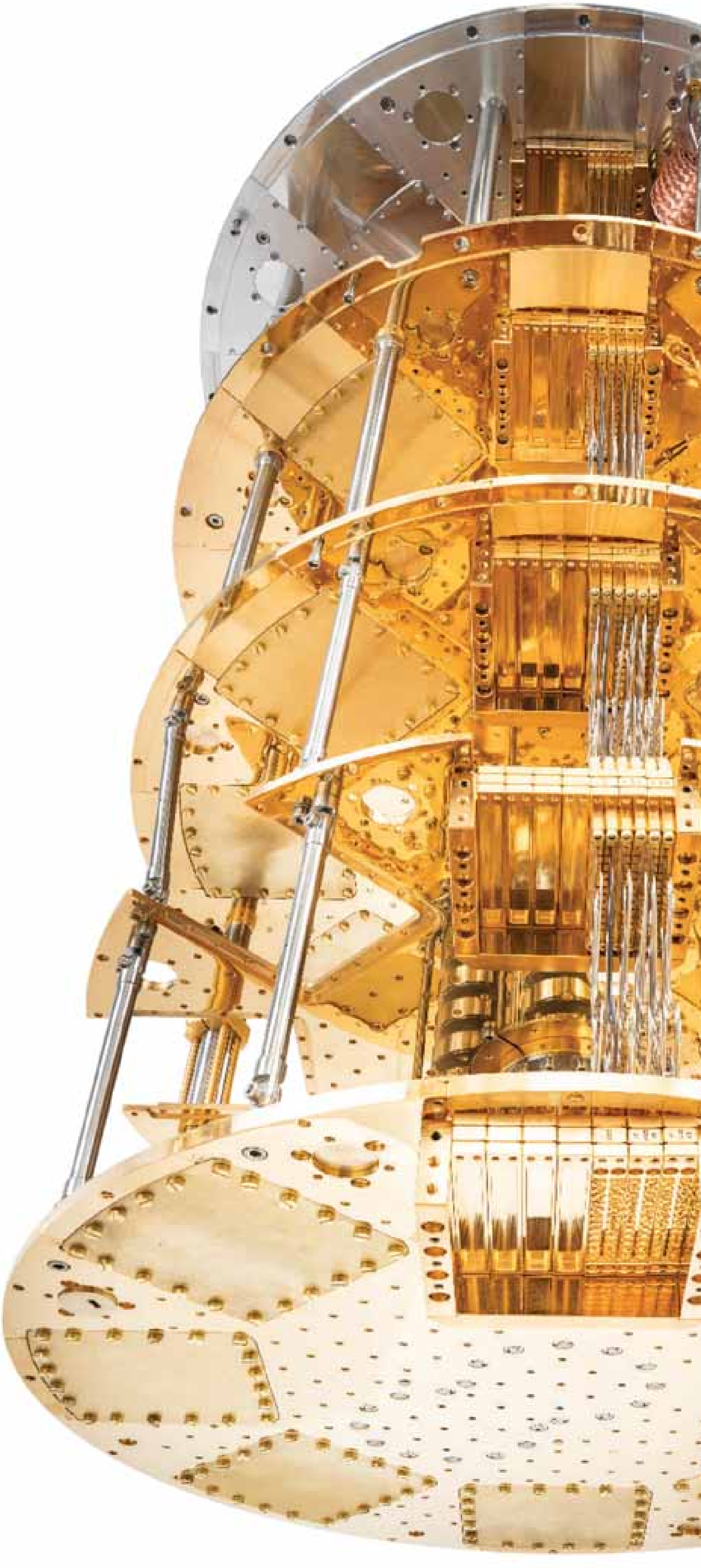
On December 16, Dover announced that it has completed the acquisition of Acme Cryogenics, Inc. (Acme) for $295 million in cash, and that it has entered a definitive agreement to acquire Engineered Controls International, LLC (RegO) for $631 million in cash, subject to customary purchase price adjustments. Additionally, the RegO acquisition includes tax step-up benefits with a net present value of approximately $35 million. Both businesses will become part of the OPW Global (OPW) operating unit within Dover's Fueling Solutions segment.

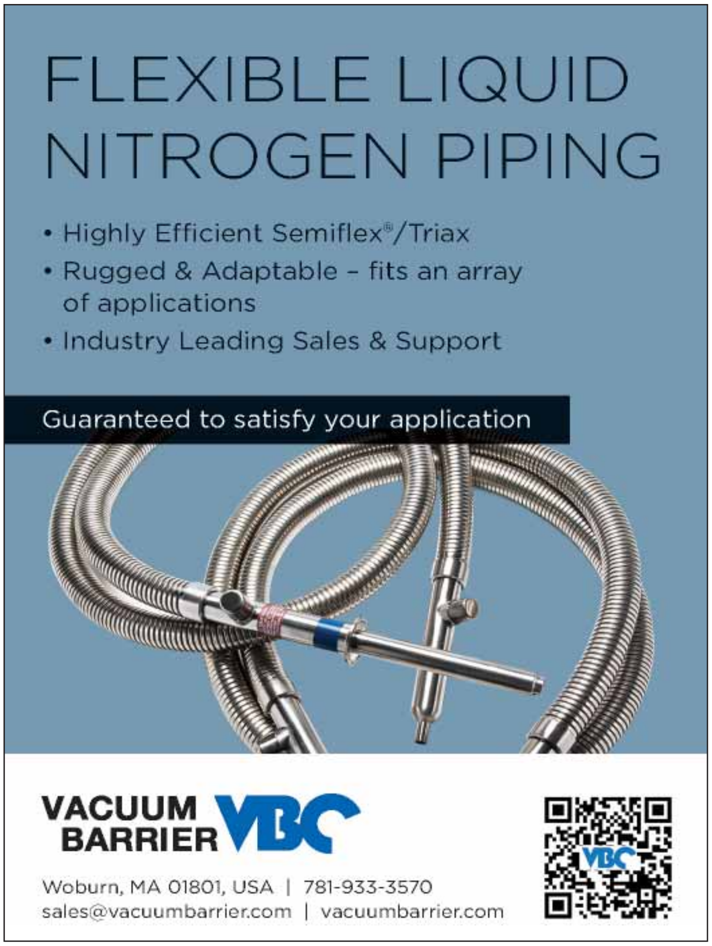
Acme, established in 1969 and headquartered in Allentown PA, and RegO, established in 1918 and headquartered in Elon NC, are well-established and growing providers of highly engineered, mission-critical components and services that facilitate the production, storage, and distribution of cryogenic gases used in a diverse set of applications. The businesses (both CSA CSMs) supply engineered components such as valves, regulators, vacuum jacketed piping, fittings, safety devices, liquefied natural gas fueling components and other specialty flow control devices to blue chip customers from a variety of end markets exposed to high secular growth trends.

Acme employs approximately 205 people and is expected to generate approximately $70 million in sales in 2021, and RegO employs approximately 725 people and is expected to generate approximately $210 million in sales in 2021. Acme has generated double-digit average annual revenue growth (excluding impact of acquisitions) over 2018-2021, and RegO has delivered annualized growth in the high single digits over the same period. Both businesses grew in 2020. The acquisitions are expected to be accretive to Dover's consolidated EBITDA margins, with additional significant synergy potential from leveraging Dover's operating scale and capabilities.

Acme's and RegO's products are highly complementary to Dover's existing clean energy solutions and will enhance its offerings for the hydrogen, liquefied natural gas, and liquefied petroleum gas applications, as well as Dover's participation in the attractive cryogenic industrial gases end market. Upon closing of both acquisitions, the expanded clean energy applications within fueling solutions are expected to generate over $300 million in annual sales, including approximately $100 million of sales from cryogenic gas applications.

Dover's president and chief executive Officer Richard J Tobin, said, "The acquisitions of Acme and RegO are the next step in our strategy to enhance the Fueling Solutions portfolio with growing participation in clean fuels and other attractive adjacencies. On the back of our recent acquisition of LIQAL and our partnerships in electric vehicle charging, these two acquisitions will scale up our position as a leader in the growing clean and alternative fuel applications as investments in this space are rapidly accelerating. We are also excited to establish a position in an attractive cryogenic gas adjacency, which offers robust organic and inorganic growth prospects. The business models of Acme and RegO are a great fit for Dover, as their offerings mainly include components that are critical to performance, safety and compliance of larger systems, their go-to-market models are based on a mix of long-tenured loyal OEM, distribution and end-customer relationships, and their long-term success in the marketplace is driven by innovation, engineering and manufacturing excellence." **www.regoproducts.com** and **www.acmecryo.com** ■

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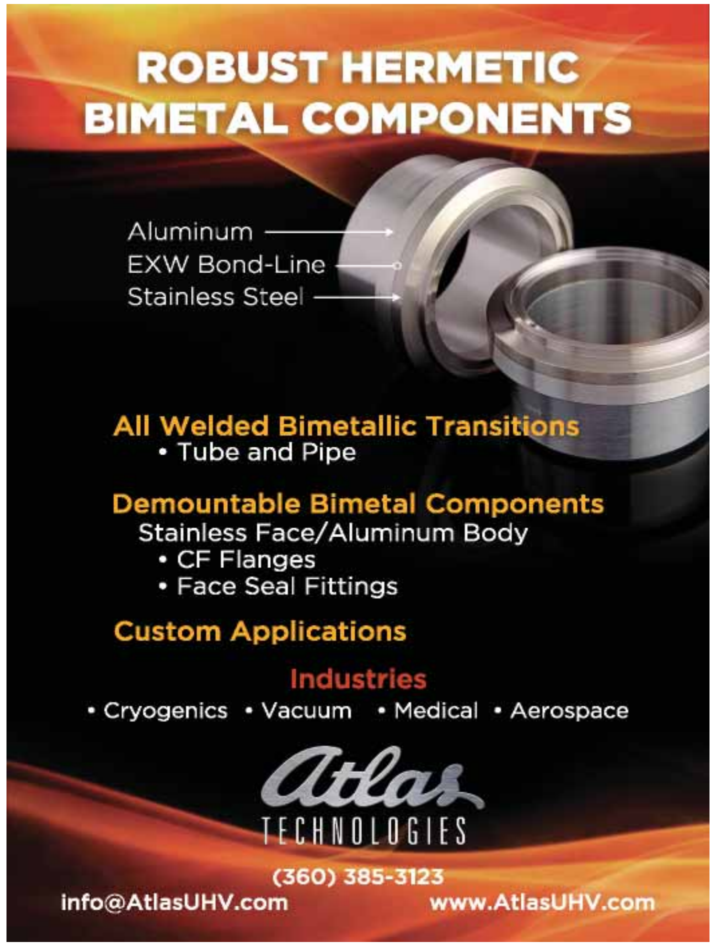
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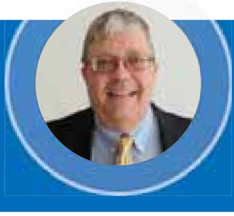
The conference will be preceded by the Cryogenic Society of America's Foundations of Cryocoolers short course.
For details, registration, and the latest virtual attendance options, visit cryocooler.org



Cryo Bios

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

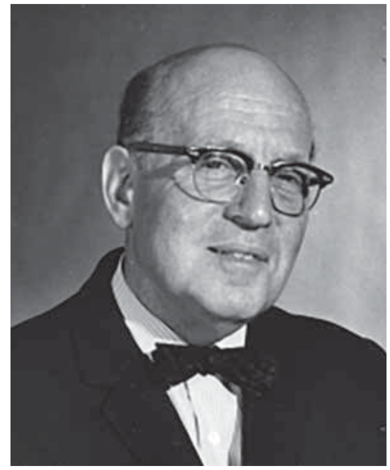
Nicholas Kurti

Nicholas Kurti made significant advances in the field of cryogenics, including at one point reaching the lowest temperature ever achieved up to that time. He also helped develop the technology of gaseous diffusion to enrich uranium and and was one of the founders of the field of molecular gastronomy.

Born in Budapest, Kurti earned his undergraduate degree at the Sorbonne in Paris where he studied chemistry, physics and mathematics. In 1928 he moved to the University of Berlin for graduate studies. Kurti's first choice for a research topic was the study of gaseous diffusion for uranium enrichment, but there were no positions available in that group. Instead, he started work in Francis Simon's (*Cold Facts* Vol. 37, No. 2) low temperature physics group. Kurti had become interested in the physics of paramagnetic salts, particularly in the interaction of these materials with magnetic fields at cryogenic temperatures. In 1924 W. Giauque (*Cold Facts* Vol. 35, No. 3) and Peter Debye had independently proposed the technique of adiabatic demagnetization refrigeration (ADR) to provide cooling at low temperatures using the interaction of paramagnetic salts and magnetic fields. Kurti began experimental work on these materials and paramagnetic salts along with ADR, and related cooling approaches remained an important part of his research throughout his career. Kurti was awarded his PhD in Physical Chemistry in 1931 for experimental studies on the paramagnetic salt gadolinium sulfate.

Kurti then joined Simon when he moved to the Technische Hochschule in Breslau, Germany (currently Wroclaw, Poland) in 1931. However, due to the rise of Hitler, it shortly afterwards became clear that Kurti, who was Jewish, would have to leave Germany. In 1933, Kurti, along with Simon, Kurt Mendelssohn (*Cold Facts* Vol. 37, No. 1) and Heinz London were recruited by F. Lindemann to join the Clarendon Laboratory at Oxford University. This group of scientists would create an extremely productive and well-regarded cryogenics research program at Oxford.

Oxford was Kurti's home for the rest of his life, and much of his research concerned work at temperatures below 1 K. Working at these temperatures required new cooling techniques, new ways of measuring temperature and the development of very low heat leak cryostats. Kurti was a very gifted experimental scientist and was able to develop clever ways to achieve and measure very low temperatures. He and Simon continued to develop ADR systems and also worked to develop nuclear demagnetization cooling. Nuclear demagnetization is analogous to ADR, but instead of employing the electronic magnet moments of parametric salts, it uses the magnet moments in the nuclei of atoms. This technique could provide cooling to much lower temperatures. Nuclear demagnetization cooling was first proposed by C.J. Gorter in 1934, but using it in practice required the solving of many subtle technical issues. In 1956, Kurti, Simon and other researchers at Oxford announced that they developed a nuclear demagnetization system that reached a temperature of 1 microkelvin (1×10^{-6} K). At the time, this was by far the coldest temperature reached on Earth and this result was recognized by the Guinness Book of World Records.[1] Both ADR and nuclear demagnetization required high magnetic fields, and part of Kurti's efforts included arranging for the installation of high field magnets at Oxford.



Nicholas Kurti

Born May 14, 1908

Died November 24, 1998

Oxford, England

During the Second World War, all research at the Clarendon Laboratory was directed to supporting the war effort. Kurti and Simon both worked on the problem of using gaseous diffusion to separate the isotope ^{235}U from more common uranium isotopes. This is known as uranium enrichment. Kurti and Simon carried out this work in the United Kingdom and then later in the United States as part of the Manhattan Project. One oft-repeated story has Kurti using a modified kitchen strainer to conduct some early scaling experiments. Their efforts were quite successful, and a large gaseous diffusion plant was built at Oak Ridge, Tennessee. For many years, until newer techniques were developed, gaseous diffusion was the principal means of uranium enrichment for both commercial and military applications.

In 1969, Kurti gave a talk at the Royal Institution titled the "The Physicist in the Kitchen." He had always been an avid amateur cook and the theme of this talk was that scientific techniques and principles should be applied to cooking and that doing so would be both interesting and useful. This approach, taken up by others as well, is known as molecular gastronomy. Examples from molecular gastronomy include the use of liquid nitrogen to produce very smooth ice cream, using chemistry to understand how the protein in eggs links the oil and water in mayonnaise, and inserting thermocouples into soufflés to better understand their cooking process. Kurti continued this work, along with his cryogenics research, for the rest of his career; collaborating with

▶ continues on page 25

Cool Fuel

by Dr. Jacob Leachman, Associate Professor, Washington State University, jacob.leachman@wsu.edu with Reece Adams, Team Lead, Cryogenic Accelerated Fatigue Tester (CRAFT) Team, reece.adams@wsu.edu

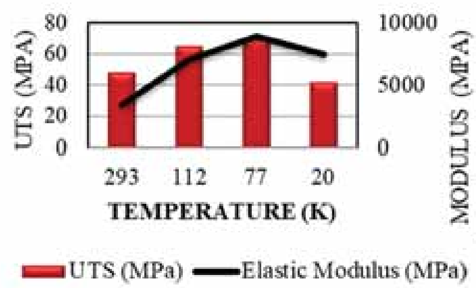
CRAFTing Future Cryogenic Materials

Additive manufacturing is fundamentally changing the possible forms and functions of cryogenic hardware. Two projects in my lab recently learned the hard way that although you can find an array of companies capable of printing incredible structures from incredible new materials, almost none of these materials have properties characterized for use at cryogenic temperatures. To make matters worse, nobody seems to have the slightest idea how changing the fill percentages and print settings (two previously inaccessible material constituent variables) will change cryogenic properties. This article delves into why this gap in ability versus understanding matters and what we're trying to do about it.

The strength-to-weight ratio, also known as the specific strength, is an important metric for the design of liquid hydrogen fuel tanks used in aerospace vehicles. These vessels have traditionally been metallic and are most recently constructed of carbon fiber. We chose to use additive manufacturing to develop the tank for our Genii drone prototype simply because it was a rapid way to produce a conformable form factor we were interested in. After having an array of materials printed and tensile tested in liquid nitrogen, we chose one (PA840-GSL, a Nylon-11 blend for Selective Laser Sintering [SLS]), simply out of convenience. The material selected used glass microbubbles and carbon fiber filaments as reinforcing filler. We were surprised to discover several hidden advantages:

1. The specific strength ended up 2.48 times higher than Al-6061T6 and 1.81 times higher than SS-304.

2. The presence of the fillers caused the coefficient of thermal expansion to be less than the base constituent material, meaning less thermal stresses.



Temperature (K)	UTS (MPa)	Elastic Modulus (GPa)
293	48	3.38
112	65	7.08
77	69	8.90
20	42	7.46

Table 1. Tensile Results of XY Orientation PA840-GSL Tested at 293 K, 112 K, 77 K, and 20 K.[3] *Image: Reece Adams*

3. The presence of microcracking typically seen with nylon at cryogenic temperatures, hypothesized to be from water adsorption during casting, was not observed with microscopy.

4. The permeation of liquid hydrogen through porous materials that plagued early weldments in metallic vessels, has not been observable with a mass spectrometer. (We are in the process of testing permeation through odd, non-orthogonal print angles.)

Clearly, additive manufacture is bestowing new tricks on some of our traditional cryogenic materials.

To investigate these properties more rigorously in liquid hydrogen, Matthew Hunt (now employed at Maxar) and Reece Adams constructed the Cryogenic Accelerated Fatigue Tester (CRAFT) shown in Figure 1.

Figure 1. Cryogenic Accelerated Fatigue Tester (CRAFT) Load Frame and Vacuum Chamber.[2] *Image: Reece Adams*

CRAFT is capable of measuring tensile or compressive specimens with cyclic fatigue loads up to 12 kN and 100 Hz. Use of a PT-415 Cryomech cooler allows for measurements at temperatures as low as 14 K. During the initial measurements Reece completed, we were surprised to discover a key disadvantage of PA840-GSL. Unlike the majority of traditional materials used in cryogenics where the Ultimate Tensile Strength (UTS) tends to increase below 77 K, we saw the dramatic decrease in Table 1. Yet another reminder that a quick LN_2 test may not be sufficient for liquid hydrogen!

We hypothesize that this decline in mechanical performance is due to the coefficient of thermal expansion differential between the additives and the matrix of the PA840-GSL composite. This differential results in forces at the matrix-reinforcement interfaces that cause premature failure compared to what would be expected from temperature-dependent embrittlement.

The neat part about SLS is the relative ease of manipulating the manufacturing process parameters including laser power and scan spacing. The PMC employed in the liquid hydrogen fuel tank was printed via SLS without any modifications to the supplier recommended process; these modifications could cater to an improved cryogenic application performance. To investigate this, we are collecting mechanical strength and thermal conductivity data of the tank constituent with an array of scan spacing parameters at 20 K. Modification of the manufacturing process for polymers less susceptible to microcracking and alterations to additives are also being investigated. Doing so will help characterize the effect that this print parameter has on the thermomechanical performance of additively manufactured PMCs in cryogenics.

Polymers are not the only class of materials being revolutionized by additive manufacturing for cryogenics. We recently grew a heat exchanger for hydrogen liquefaction composed of the aluminum alloy AlSi10Mg. Utilizing CRAFT, tensile specimens of the heat exchanger constituent and a proposed alternative, Elementum's A6061-RAM2, have been mechanically tested. Thermal conductivity measurements are also being collected for thermal performance. The data from these materials will help design future heat exchanger and structural applications.

After our first two attempts at growing cryogenic materials we know one thing for sure: there is plenty of room for CRAFTing future materials.

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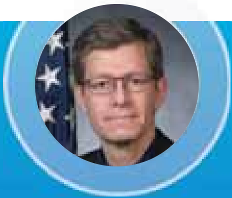
Cryo Bios... *Continued from page 23*

chefs, organizing conferences and appearing on television cooking shows. A BBC broadcast on Kurti and science in the kitchen can be found here: https://www.bbc.co.uk/sounds/play/m000dpn5

Nicholas Kurti received many honors, including becoming a Fellow of the Royal Society and being awarded the Hughes Medal. In 1973 he was awarded a Most Excellent Order of the British Empire, an order of chivalry. Two particular honors seem very appropriate; Oxford University named their High Magnetic Field Laboratory after Nicholas Kurti and Oxford Instruments established the Nicholas Kurti Science Prize for Europe to recognize talented young scientists in Europe.

A good sense of the talent and breadth in Nicholas Kurti's life may be found by reading his paper on achieving 1 μK : "Nuclear Cooling," N. Kurti et al., ***Nature*** vol. 178 (1956) and *But the Crackling is Superb, An Anthology on Food and Drink* by Fellows and Foreign Members of the Royal Society, edited by Nicholas Kurti and his wife Giana Kurti.

[1] In 2021, scientists at the University of Bremen, using very different techniques, very briefly achieved a temperature of 38 picokelvin (38 x 10^{-9} K) ■



Space Cryogenics

by Mike Meyer, NASA Technical Fellow for Cryogenics, NASA Langley Research Center, michael.l.meyer@nasa.gov

Crewed Mars Mission Concepts

From NASA's inception, a long-term goal has been to enable humans to explore Mars. But the reality is that traveling to Mars will be extremely challenging from a technological perspective and will include significant risk to the crew. The propulsive demands are immense, and exposure to the microgravity and radiation environments of space will affect astronauts' health. The orbital mechanics of a trip to Mars will necessitate a round trip time of two to three years, at least double the longest in-space experience of an astronaut to date. Past mission studies have evaluated the longer "conjunction class" missions (approaching three years) which, while increasing mission risk due to duration, require significantly less total impulse and are therefore more feasible from a propulsion perspective.

NASA recently conducted a mission concept study to evaluate the feasibility and propulsion technology development requirements for reduced travel duration of "opposition class" crewed missions to Mars. A high-level study goal was to minimize mission risk and space environment impact on crew health. As a result, the study limited the crew to a total of approximately two years of in-space operations and travel time. For the initial mission, the crew would spend about 30 days on the Martian surface. The study selected two advanced propulsion options to evaluate, each with the potential to meet mission requirements. Both options rely on nuclear fission to provide efficient propulsive energy, requiring the storage of large amounts of cryogenic propellant – either liquid oxygen/liquid methane (LO_2/LCH4) or liquid hydrogen (LH_2) – for multiple years in space without loss, transferring propellants between tanks in space, and managing the propellant in microgravity. These operations far exceed state-of-the-art in-space cryogenic fluid management (CFM) capabilities. To enable these new capabilities, the team assumed the use of several advanced CFM technologies, summarized below. They analyzed integrated system performance and vehicle-level impacts on size, mass, and power requirements. Further, the team evaluated the CFM technology development required to enable such a mission in the mid-2030s and determined that it was feasible.

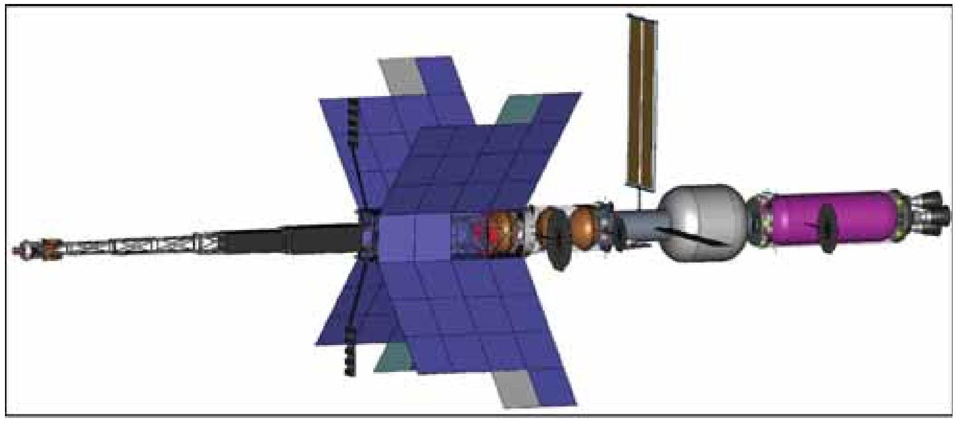


Figure 1. NEP/Chem Hybrid Propulsion Mars Transportation Vehicle Concept. Image: NASA

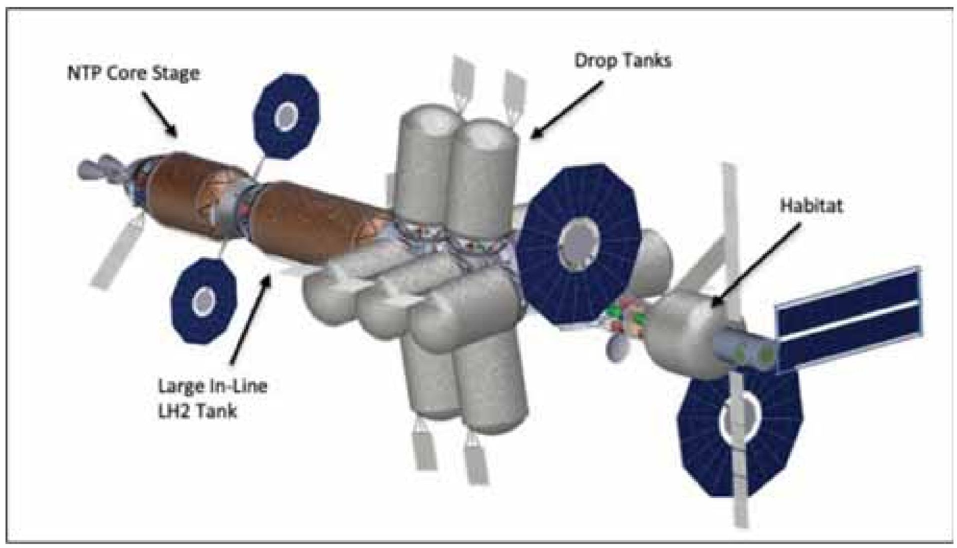


Figure 2. NTP Mars Transportation Vehicle Concept. Image: NASA

Both concept vehicles studied are large, on the scale of the International Space Station, and require multiple launch vehicles to deliver elements and propellant into Earth orbit, where they will be assembled. The aggregation and assembly will add to the time the cryogens must be stored without loss and will require automated fluid couplers and propellant transfer.

One propulsion option is a hybrid with nuclear electric propulsion (NEP) and chemical propulsion ("NEP/chem hybrid"). This concept uses a reactor and energy conversion system to power xenon propellant ion thrusters (electric propulsion), providing a highly efficient but lower-thrust push for most of the mission duration. It also relies on a large LO_2/LCH4 chemical propulsion stage to provide high thrust for maneuvers while near the Earth and Mars, to minimize so-called “gravity well” losses. This concept vehicle is shown in Figure 1. At the far left is the nuclear reactor and energy conversion system, generating 1.9 megawatts of electric power. A deployable boom provides separation between the reactor and the rest of the NEP module, and two clusters of ion thrusters are deployed from the primary axis on smaller booms. Because the energy conversion process has inefficiencies, large deployable radiators (shown in purple) are also needed. The final piece of the NEP element is xenon propellant, stored at supercritical pressure in several tanks along the vehicle’s axis. A large cylindrical habitat element provides for crew needs during the trip to and from Mars. Finally, on the right end of the vehicle is the chemical propulsion stage, also launched separately and partially fueled to maximize tank volume within the launch vehicle. This stage is then filled in orbit by tankers and carries approximately 200 tons of LO_2/LCH4.

The second propulsion option is nuclear thermal propulsion (NTP), in which the reactor heats LH_2 propellant, causing it to expand through a nozzle for thrust at about twice the efficiency of the best chemical propulsion systems. The NTP vehicle requires significant amounts of hydrogen, and due to the low density of LH_2, many tanks will be required to hold it, as shown in Figure 2. The NTP vehicle includes three reactors, each integrated with turbomachinery and a nozzle into a rocket engine, at the far left of the rendering. The two largest LH_2 tanks (the in-line core stage and core tank) are a bronze color, and then a number of silver drop tanks are visible. As their name indicates, drop tanks are disposed of as the LH_2 is consumed to reduce vehicle dry mass for subsequent maneuvers. For the NTP concept, the same large cylindrical habitat is located at the end of the vehicle.

As noted, advanced CFM technologies were necessarily assumed to enable the zero-loss storage, microgravity handling, and in-space transfer of propellants required for this mission. CFM technology assumptions for the LO_2/LCH4 and LH_2 tanks were similar, with a few noted exceptions. These technologies included zero-g thermodynamic venting for limited mission operations where venting may be required, surface tension-based propellant management devices, and zero-G propellant gauging. Of course, the thermal control strategy will be critical to mission success. Figure 3 shows a conceptual stack-up of the insulation and active cooling layers to achieve zero boiloff storage. Spray-on foam insulation was assumed on the tank wall to protect against freezing of moisture or air during launch operations. For the hydrogen tanks, two-stage active cooling was analyzed. This included 20 K broad area cooling (BAC) at the wall with a 90 K BAC shield in the insulation. As these propellant tanks must survive long periods in space, including Earth orbit during assembly, it will be necessary to include micrometeoroid and orbital debris (MMOD) protection layers. To support the MMOD layers and the BAC, the team assumed the use of load-bearing multilayer insulation (LB-MLI) developed through the NASA Small Business Innovative Research program. Insulation for LO_2 and LCH4 tanks was similar to the approach shown in Figure 3 for the LH_2 tanks, except the 20 K BAC shield and inner 10 layers of LB-MLI were not necessary. BAC system cooling was assumed to be provided by spaceflight reverse turbo-Brayton coolers currently in development with NASA funding. The 20 K coolers were assumed to provide 20 W of lift, and the 90 K coolers were assumed to provide 169 W of lift.

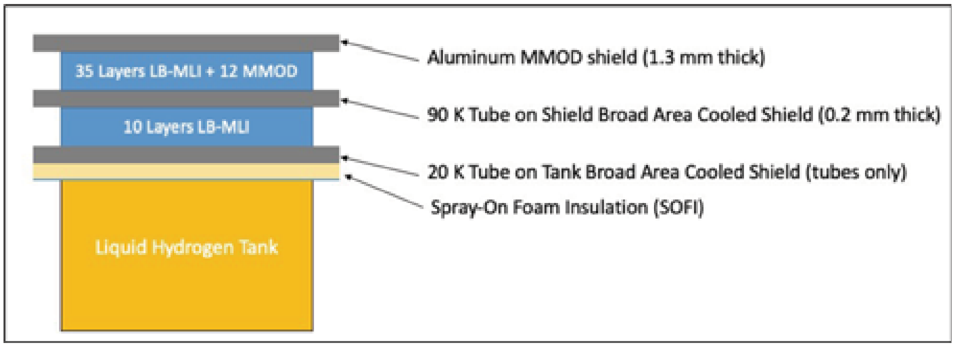


Figure 3. Insulation and Integrated MMOD Protection for LH2 Tanks. *Image: NASA*

The study demonstrated that with the advanced CFM assumptions noted above, a propellant storage and supply system that met the mission requirements was possible. A final question was whether these CFM technologies could be ready for a mission in the targeted timeframe. NASA is currently investing in maturing most of the needed CFM technologies. This includes Tipping Point Flight Demonstration Missions, led by the NASA Space Technology Mission Directorate, to prove various CFM technologies are ready for in-space application. The study team determined that by continuing these investments, along with addressing several remaining gaps, the CFM technologies needed can be ready to enable a crewed Mars mission in the mid-2030s.

Excerpted from: “Recent Concept Study for Cryogenic Fluid Management to Support Opposition Class Crewed Missions to Mars,” Michael L. Meyer, Jason W. Hartwig, Steven G. Sutherlin, Anthony J. Colozza, presented at the Space Cryogenics Workshop, November 2021, and to be submitted to ***Cryogenics****.* ■

Clean Energy Future

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

Misconceptions in Cryogenic Heat Management

Misconceptions abound in the world, and some are more important to address than others. In the area of cryogenic heat management there are misconceptions that usually have no ill effect but sometimes can become big stumbling blocks. These center around the confusion of temperature and heat (with the word "thermal" thrown in here and there). Temperature is an indicator of what the heat is doing, but it is not heat.

Liquid nitrogen cold shock of a flight tank simulator. *Image: James Fesmire*

In cryogenics, like all other fields in the known universe, heat flows from the hotter region to the colder region. This simple fact, based entirely on observation, is at the center of the laws of thermodynamics. The notion of temperature, an indicator of the amount of heat in an object, provides the basis for those laws. But what is this energy called heat? No one knows, but whatever it is, it flows from the hotter side to the colder side. If there are two different temperatures, and some physical proximity or connection between the two, the heat is flowing. Directing or re-directing, organizing, or orchestrating – and promoting or inhibiting this flow of heat is the job of the cryogenic engineer.

So here are five misconceptions in the world of cryogenics, as well as any world that deals with heat or "heat energy."

1. Thermal energy and heat are the same thing. No, they are not. Thermal energy is thermal energy, and heat is heat. Heat is not heat energy. Heat is heat. What is the difference? Thermal energy has to do with the intrinsic nature of solid matter at the microscopic and smaller levels. Heat has to do with systems and is coupled with the production of work. If you don't agree with this first one, let me hear about it. There is no universal consensus on it, but we must start somewhere.

2. Insulation does not "keep the liquid hydrogen cold." Or any cryogenic liquid, ever. Coming up through the Space Shuttle program and working in connection to the cryogenic propulsion systems, LO_2 and LH_2, for 38 years, I would hear that all the time on the news. Does it matter? Not usually. But sometimes it can. That liquid in that vessel will stay at the same temperature if it has a ten-meter-thick insulation or if it is completely uninsulated. It is the rate of vaporization of the liquid, or loss of the product, that really matters.

3. Heat transfer occurs through the insulation of the cryogenic tank at steady-state conditions. There is a bit of semantics here, but the point is that *heat is continually being transmitted* through the thickness of the material from the warmer surface to the colder surface. There is not some quantity of heat in one location that is transferred to another location. Most cryogenic systems (and their insulation systems), like storage tanks or refrigeration process towers, are cooled and put into operation for continuous steady-state operation for days, weeks, months, or even years at a time. Heat transmission is the correct term. In the beginning, at those first moments of cooldown or cold shock, there was a lot of heat transfer going on as the materials were adjusting from their starting ambient temperature conditions. Thereafter, the heat is being continually transmitted in steady-state fashion from the outer surface (ambient) to the inner surface (cold mass).

4. Heat does not flow as a function of temperature. Heat flows according to the temperature *difference* imposed on the system. This one is a two-part misconception, as data are often given as follows: thermal conductivity as a function of temperature. This is an especially tricky one as now there is the moment that the distinction between heat and temperature really matter. First, there is the error of using the word "thermal" when it really is "heat." Then there is the word "conductivity" which has to do with the transmission of heat through a solid material that is isotropic and homogeneous (a limited case). Finally, heat does not flow if everything is at the same temperature.

5. There is no such thing as hot and cold. There is only hotter than and colder than.

I'm sorry to bring this sad news on number 5, but there is a bright spot and that is the Third Law of Thermodynamics. The Third Law gives us our foundation, absolute zero (0 K). We can't go down from there; we can only go up. If we go up to 0.1 K, then there is some heat. If we go up further to 1 K, there is more heat. And up to 10 K, more heat. And so on, up and up, as high as we can imagine. At absolute zero, there is no heat. Above that, it's all heat.

Cryogenics is about the "cold." But when we look carefully, we see that cold and hot are not opposites, but rather two sides of one coin called heat. ■

SPOTLIGHT ON A CORPORATE SUSTAINING MEMBER (CSA CSM)

Valcor Releases New White Paper on Cryogenic Launch Vehicle Valves

Launch vehicles, particularly the upper stages, often use cryogenic rocket propellants such as liquid oxygen, liquid hydrogen and liquid methane because of their high specific impulse and high storage density. The pressurization, control and distribution of these propellants requires sophisticated valving that can operate and seal at these extreme temperatures.

Designing critical fluid control systems for space launch vehicles requires a deep understanding of the performance of the components under the most challenging conditions. A launch vehicle (LV) experiences huge shocks, vibrations and constantly changing forces during the flight to deliver its payload. All fluid control components and systems involved in the performance of the rocket must be designed and tested to assure their reliable operation during the entire flight. For the most critical systems, it is imperative to design in redundancy in the event of a component failure to ensure the success of the mission. The project engineer and supporting design team must take all of this into account, while keeping the system as light and small as possible.

One of the biggest challenges to designing valves for launch vehicle applications, particularly for the upper stages, is meeting flow requirements within tight envelope and weight specifications. Valcor specializes in the design and manufacture of pilot-operated valves capable of achieving high flows in a compact, lightweight design. Another complex challenge is meeting internal and external leakage requirement over a wide temperature range and under extreme shock and vibe conditions. Differing expansion rates of the valve's materials of construction at temperature extremes has the potential to create leak paths that are difficult to seal against. Valcor has perfected proprietary, advanced sealing geometries to counteract this effect and achieve reliable and repeatable sealing performance.

Compact Pilot Operated Valve. *Image: Valcor*

Space launch vehicle OEMs are evaluating the integration of more complex fluid control components into their designs, such as the use of proportional or modulating control valves to control flow instead of typical on/off solenoid valves. A modulating control valve (MCV) is typically a motor-operated device. Valcor has a line of MCVs for the LV industry, with new features added as applications change and become more difficult for existing designs to fulfill.

Further, the launch vehicle market is looking to its suppliers for the design and build of complete fluid control systems, rather than simply procuring stand-alone components. Valcor's sales and design engineers will evaluate the total system requirements and propose a custom-designed manifold that incorporates most, if not all, of the fluid control components needed for the application. Using Model-Based Systems Engineering methodology, the proposed design can be evaluated, simulated, tested, and ready for production in short order. The use of manifolded components results in the lightest, most compact system that also minimizes the potential for external leakage by eliminating individual component fluid connections. Custom manifolds utilize Valcor valves, regulators and check valves, but may also include third-party components including pressure and flow sensors. The ability to procure a complete, ready-to-install fluid control system gives the LV OEM a highly efficient and cost-effective method of building their product. Manifolds provide a modular approach to system design, rather than a complex assembly of individual components. Construction, maintenance and ability to upgrade the LV system design are greatly enhanced as a result.

Valcor has been a major innovator in these types of valves for the workhorse launch vehicles of the past 20 years. Building on this heritage, Valcor continues to provide advances in cryogenic valves for applications using high flow isolation valves, low delta P propellant tank vent valves, passively and actively actuated quick disconnects, and chatter-free check valves. Versions of these valves are used in the largest of the new launch vehicles, but also on the smallest satellite launch vehicles and landers.

With a rich 70+ year history of customized valve and system design, Valcor is poised to meet any challenges for fluid control in future launch vehicles. **www.valcor.com** ■

Jobs in Cryogenics

Cryogenic Plant Technical Team Lead
Commonwealth Fusion Systems

Cryogenic Engineer
Commonwealth Fusion Systems

Cryogenic Engineer
Ability Engineering Technology Inc

Magnet/Cryogenic R&D Associate
Oak Ridge National Laboratory

Assistant in Research – Materials Test Engineer
National High Magnetic Field Laboratory (NHMFL)

Job openings from CSA Sustaining Members and others in the cryogenic community are included online, with recent submissions listed above. Visit **http://2csa.us/kz** to browse all current openings or learn how to submit your company's cryogenic job to our list of open positions. Listings are free for Corporate Sustaining Members.

YOUNG PROFESSIONALS 2022

The Next Generation in Cryogenics and Superconductivity

This feature introduces outstanding young professionals (under 40 years of age) who are doing interesting things in cryogenics and superconductivity and who show promise of making a difference in their fields. Debuted in the Summer 2006 issue, the feature has presented many young persons whom we are proud to see have indeed lived up to that promise.

Reece Adams, 23

My educational and professional background: I obtained an engineering associate in science-transfer degree at Spokane Falls Community College in 2018, a bachelor's degree in materials science and engineering at Washington State University in 2020 and am currently finishing a materials science and engineering master's degree at WSU. In my undergraduate career, I maintained an internship at an aerospace composite layup facility, Unitech Composites. I also had an undergraduate research position at the Hydrogen Properties for Energy Research (HYPER) Laboratory and a technical assistantship at the Composite Materials and Engineering Center (CMEC). Much of my educational and professional experience is centered around mechanical testing and manufacturing of polymer and polymer-matrix composite systems.

How I got into cryogenics: I was first introduced to cryogenics at the HYPER Laboratory at Washington State University. As an undergraduate researcher here, I supported a transition of research to plastically deforming thin polymer films for cryogenic fuel storage bladders through the gelbo flex testing of mylar and PEEK in liquid nitrogen. I quantified the ability for these thin polymer films to endure a combined torsional and compressive load at 77 K. Moreover, I aided in the development of the Cryogenic Accelerated Fatigue Tester (CRAFT), a mechanical load frame capable of performing tensile testing and tension-tension fatigue testing in a liquefied hydrogen environment.

My mentor and my experience with them: The mentor that I currently frequent the most is P.K. Northcutt II. He is the skills manager at the HYPER lab, and I utilize his insight often for a variety of professional questions, reviewing presentations, or helping me improve my cover letter, curriculum vitae, or resume. His professional background has minimal overlap with mine, which permits a unique and essential perspective on how I can improve both in academics and industry.

My present company/position: I am a research assistant at the HYPER Laboratory.

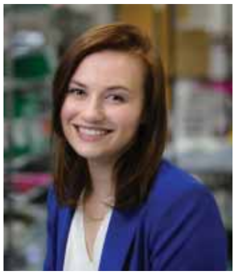
My contributions to the cryogenic field: I have developed a full mechanical and thermal characterization of selective laser sintered (SLS) AlSi10Mg, A6061-RAM2, and PA840-GSL. The AlSi10Mg testing results were employed in characterizing the cryogenic performance of an additively manufactured heat exchanger composed of this constituent. The ceramic reinforced Al6061 (A6061-RAM2) results demonstrated the improvement observed both mechanically and thermally over the current heat exchanger constituent. Lastly, the polymer matrix composite (PA840-GSL) data was incorporated in characterizing the effect that scan spacing and print orientation have on thermal insulation and mechanical performance at cryogenic temperatures so that boiloff may be reduced in liquid hydrogen fuel tanks while sufficient mechanical strength is maintained.

What are the most important developments in cryogenics? Developing material testers that exhibit the capability to simulate the environment and loading of cryogenic applications is one of the most significant developments in recent years for cryogenics. A variety of systems and subsystems are required to simulate these environments and ensure repeatedly accurate and precise results. To definitively assert that a material is a safe and effective solution for a cryogenic application, these load frames are an essential piece of the puzzle. Therefore, much of my work features the use of a cryogenic load frame in determining fundamental material performance at cryogenic temperatures.

What advances do you hope to see in the future? Complex problems often require complex solutions. As such, I hope to see the utilization of highly complex, multi-material composites for applications where extreme thermomechanical loading is present. Currently, research surrounding composite employment in these applications is limited, especially for composites manufactured via additive manufacturing. To fully harness the potential of composites and ensure their safe deployment in a cryogenic environment, much more materials testing will be required. I think that we are still a decade or two away from seeing this level of material complexity in extreme environments.

Where can readers find out more about your projects? To know more about my experience and education, here is my LinkedIn: www.linkedin.com/in/reecemadams

Del Pierson, 23



My educational and professional background: I hold a BA in Physics from Colby College in Waterville ME, and I currently work at XMA Corporation. Previous to XMA, I interned for Nanocomp Technologies in Merrimack NH, now part of Huntsman Corporation. I worked in their carbon nanotube fuel department before transitioning to their heater department. At XMA, a manufacturer of passive RF and millimeter wave components, I work as a sales engineer focusing on the space and quantum computing industries.

How I got into cryogenics: I began in cryogenics through my role at XMA. As the liaison between our engineering team and cryogenic customers, I am able to shape the way XMA solves problems and creates new products.

My mentor and my experience with them: I have had a variety of mentors throughout my professional career, including Kelly Patton from Colby College, Mark Banash from Nanocomp, and Marc Smith from XMA Corporation. Dr. Patton taught me quantum mechanics and is a very inspiring woman in the field. Dr. Banash gave me freedom at Nanocomp to pursue projects I was interested in and helped me discover my love of thermodynamics and material science. Marc pushes me outside of my comfort zone and celebrates my successes, lending a hand when I am in need. I am very thankful to have started my career in a variety of nurturing environments.

My current company/position: At XMA, I am a sales engineer largely focusing on quantum computing and space applications. This sets me in the front and center of our cryogenic products. I have helped develop a multitude of high density and high thermalization products for the quantum computing field. I have also helped with the design and production of cryogenic calibration tools and brand new infrared filters.

My contributions to the cryogenic field: My contributions to the cryogenic field focus on cryogenically compatible passive RF components. These include high density multiport attenuator blocs, high density single port attenuators, TRL and SOLT cryogenic calibration products, and IR filters. In addition to the design and launch of these products, I have helped conduct material research on resistive chip substrates to determine the material with the best combined thermal and RF performance. Finally, I am a coauthor on an upcoming paper from the QED-C focusing on enabling technologies for quantum computing. I believe I have made a large impact on the quantum computing hardware industry throughout my time in the field.

What are the most important developments in cryogenics? One of the biggest challenges I see in the cryogenics arena is calibration at low temperatures. The RF industry is guided by a league of mil/aero standards and has high fidelity equipment for test and measurement procedures. These standards are not yet set for cryogenic temperatures, largely due to a lack of capable equipment. Through my sales role, I have been able to chat with a multitude of professionals to gather information on next steps. As a manufacturer of hardware, XMA can easily and immediately take this information directly from the sources and make turnkey solutions to start addressing this lack of equipment. This has been one of the most exciting parts of my time in the cryogenic field.

What advances do you hope to see in the future? In the future, I look forward to seeing the outcomes of quantum computing, including advances in the medical field and climate change. As we ramp up cryogenic equipment, we are supporting more and more qubits, which I see leading to advances such as new drug development and better weather forecasting to predict catastrophes. I believe these advances, ultimately enabled by cryogenic research, will save and improve lives.

Where can readers find out more about your projects? In order to keep users and students informed about the crossroads of cryogenics, quantum computing, and RF, I have a blog on XMA's website. In addition, I write regular LinkedIn updates outlining our advanced products and successes in the industry. Blog: **www.xmacorp.com/resources/dels-blog**, LinkedIn: **www.linkedin.com/in/madeline-pierson**

Matthew P. Shenton, 23

My educational and professional background: I received a B.S. in mechanical engineering at Montana State University in May 2020. At that point, I had held an engineering internship with the Boeing Company and had fielded job offers from Boeing and other engineering companies. However, I decided to pursue a graduate degree and in August 2020, I began my graduate studies at Washington State University, pursuing a Doctorate in mechanical engineering in the Hydrogen Properties for Energy Research Laboratory (HYPER) under Dr. Jacob Leachman.

How I got into cryogenics: When I had decided to go to graduate school, I started researching potential topics and advisors. I knew I wanted to stay in the west, close to my roots, and I wanted a research topic in the thermo-fluid sciences. I came across Dr. Leachman and the HYPER lab at Washington State University and wanted to know more about liquid hydrogen. Dr. Leachman and I had a few phone calls back and forth, discussing the projects and the future of this industry. Those conversations created excitement about the research that was being conducted with liquid hydrogen as a renewable energy. I visited the facilities in person and discussed the project that I would be working on when I started my graduate studies, and I was hooked. It was the perfect fit. The huge potential of liquid hydrogen for a wide variety of applications and my interest in heat transfer and fluids aligned, so I signed on as a graduate student.

▶ *continues on page 34*

My mentor and my experience with them: Dr. Jacob Leachman has been my mentor for the past two years. I came into this field with zero background knowledge. His experience and guidance throughout my studies have been invaluable for my confidence that I can successfully work in this field. Working with Dr. Leachman has felt like working with a colleague trying to solve complex issues regarding liquid hydrogen rather than a more traditional mentor/apprentice approach. His teaching style uses his own personal examples in the cryogenic field to try and teach new techniques effectively by asking how I would solve the problem rather than just telling the answer. He fosters a collaborative work environment within the lab.

My present company/position: I am still a graduate student at Washington State University working towards a Doctorate in mechanical engineering.

My contributions to the cryogenic field: To reduce boiloff losses in liquid hydrogen systems I am working on numerous projects to characterize thermal properties of different materials at liquid hydrogen temperatures (20 Kelvin). With the support of the DOD, I am part of a larger project to create a long-term storage vessel that will reduce the boiling losses significantly and provide proof that different machines can be powered effectively off liquid hydrogen. I am characterizing the thermal conductivity of an additively manufactured aluminum and a polymer composite. I am also looking at characterizing the thermal conductivity of aerogel in different environments including vacuum, immersed in gaseous hydrogen, and immersed in liquid hydrogen. Finally, I am characterizing the hydrogen boiling curve to effectively derive and utilize hydrogen convective heat transfer coefficients for novel storage vessel designs. I recently wrote an extensive literature review that is in review to be published at the Cryogenic Engineering Conference in 2021.

What are the most important developments in cryogenics? The developments in long-term storage and infrastructure for liquid hydrogen systems are concepts that are limiting the field at the current time. Boiloff losses account for a large amount of unused energy. We need to mitigate or eliminate these losses to address the challenges of making liquid hydrogen a commercially viable energy carrier. All my graduate research has been to characterize different thermal properties of materials or fluids so that we can design better storage vessels which will mitigate these boiloff losses.

What advances do you hope to see in the future? I envision a world that runs off liquid hydrogen. The benefit of hydrogen's high specific energy (energy per mass) isn't utilized at full advantage due to the low energy density (energy per volume) of gaseous hydrogen. Liquid hydrogen storage provides the answer. I want liquid hydrogen to not only be used to propel humanity into the stars for long-term space flight, but also utilize it as the primary power source for terrestrial applications. Long-term space flight is the key to understanding the outer reaches of our universe, and we need a long-term power source to sustain these deep space missions. On the terrestrial side, agricultural applications are limitless due to the amount of power provided by equipment and other assorted energy costs on a year-to-year basis. This field is gaining traction, so now is the perfect opportunity to get in on this interesting, rapidly advancing field.

Where can readers find out more about your projects? The website for the HYPER lab can be found at this url: https://hydrogen.wsu.edu/. This website details all the projects, facilities, and colleagues that we have working on this research.

Jacob Lesauis, 24

My educational and professional background: In May of 2021, I completed my bachelor's degree in mechanical engineering at Washington State University (WSU). During my undergraduate degree, I held internships in systems, manufacturing and new product development engineering. In addition, I worked in the Hydrogen Properties for Energy Research Laboratory (HYPER) under Dr. Jacob Leachman. I have since transitioned into pursuing a master's degree in mechanical engineering at WSU where I am currently beginning my second semester. My thesis involves quantifying ortho-parahydrogen reaction rates of common cryogenic materials.

How I got into cryogenics: During my sophomore year of college, I began searching for a lab that incorporated both renewable energy and aeronautical engineering, two of my passions. I began emailing professors to discuss their work and ran into Dr. Jacob Leachman's small, yet rapidly growing lab. I was invited to interview and was impressed by both his passion and intensity. I was hired on to lead the core team, a group of undergraduate students who help improve the culture, efficiency, and professionalism of the lab before moving on to specific research projects. The following semester, I joined the Cryocatalysis Hydrogen Experimental Facility (CHEF). For over two years, I helped then Phd candidate Carl Bunge rebuild CHEF, run liquid hydrogen tests, and ultimately develop an automated safety system to passivate the experiment in case of emergencies. Now that Dr. Bunge has graduated and moved on to MIT as a postdoc, I have taken over as the graduate lead.

My mentor and my experience with them: My mentor for the past three years has been Dr. Jacob Leachman. His guidance throughout the years has been exactly what I needed to become both confident in my abilities as an engineer and comfortable in asking for help when needed. He gives me the freedom to fail but also the support to succeed. Immensely complex engineering problems, encouraging words, and tough love have culminated in a great experience at WSU and have prepared me for my challenges ahead.

My current company/position: I am a master's candidate in the Hydrogen Properties for Energy Research Laboratory at WSU.

My contributions to the cryogenic field: In the quest for zero boiloff liquid hydrogen storage, I have worked on the Heisenberg vortex tube project that aims to reduce boiloff by utilizing the ortho-parahydrogen endothermic reaction to reduce ullage temperatures. With support from our partners at Plug Power and the Department of Energy, our team has performed over 100 liquid hydrogen tests, and we have successfully identified a method to reduce liquid boiloff significantly. This technology, in conjunction with any liquid hydrogen storage vessel, can drastically improve the long-term storage and viability of hydrogen as a fuel for the future.

What are the most important developments in cryogenics? Being on a team that is focused on reducing boiloff and increasing hydrogen's viability has opened my eyes to the logistical challenges of storing, transporting, and efficiently utilizing cryogenic fluids. With that being said, I feel that some of the most important advances in cryogenics are going to be improvements in both long-term storage and efficient hydrogen production.

To address these problems, we have developed a method to actively cool ullage gases, and my thesis aims at determining the ortho-parahydrogen reaction rates of common cryogenic materials. By knowing these reaction rates, engineers will be more equipped to design more efficient systems for both terrestrial applications and those above.

What advances do you hope to see in the future? In the future, I would like to see more liquid hydrogen powered transportation. Gaseous hydrogen is a great starting place, but the density benefits of hydrogen's liquid form far outshine its less dense companion.

Luckily, we are already seeing these vehicles come to life. From ferries like the MF Hydra to a Baja 1000 truck produced by the company First Mode, liquid hydrogen powered vehicles are here to stay.

Where can readers find out more about your projects? If you would like to see more of what the HYPER lab has to offer check out our website: **https://hydrogen.wsu.edu**

Wenjuan Song, 32

My educational and professional background: I hold a PhD in electrical engineering, with expertise in applied superconductivity, awarded by Beijing Jiaotong University, China, in 2019. I worked as a research assistant at Robinson Research Institute, Victoria University of Wellington, New Zealand from 2016 to 2018.

My research expertise is the protection of electrically powered aircraft propulsion systems using superconducting fault current limiter, R&D of high efficiency and low loss superconducting applications for electrical aircraft systems in a cryogenic environment, including superconducting fault current limiters, superconducting cables, electromagnetic analysis for superconducting power applications, AC loss calculation and measurement.

How I got into cryogenics: I first heard about "superconductivity" when I was a Masters student. I heard some PhD students in our lab talking about how superconductors can revolutionize power system and its apparatuses by reducing their losses and weight significantly. Furthermore, I had a chance to assist one of the PhD students carrying out cryogenic testing for a superconducting coil using liquid nitrogen. For a Masters student who majored in electrical engineering in 2013, it was amazing, inspirational, and unbelievably awesome. From that time on, a seed was planted into my mind that I would like to pursue my PhD career in the field of superconductivity and cryogenic technology. After getting a scholarship and entering my PhD, I was lucky to work on superconductivity with Professor Fang, one of the most famous researchers on large scale power applications of superconductors in China. Soon after that, I realized that superconductors without cryogenics are not superconducting at all; therefore, learning about cryogenics went to the top of my priority list.

Later on, during my PhD and postdoc careers, I carried out many characterization experiments in the cryogenic environment, at 77 K and 65 K using liquid nitrogen. Recently, with the current development around bringing liquid hydrogen into aviation, cryogenics becomes a more critical topic to investigate.

My mentor and my experience with them: I do have some mentors who encouraged, inspired, and guided me towards high quality and meaningful research for the cryogenic and superconductivity communities and human life, including Emeritus Professor Du-Xing Chen, Dr. Zhenan Jiang, and my PhD supervisor Professor Jin Fang.

My present company/position: Since May 2019, I have worked as a postdoctoral research associate at Applied Superconductivity laboratory, University of Bath, United Kingdom. In March 2022, I will join The University of Glasgow, UK as a lecturer/assistant professor for "electrically powered aircraft and operations."

Awards and honors received: I was endorsed as "Global Talent" by the Royal Academy of Engineering, United Kingdom in 2021 and have been featured as a talented Women Early Career Researcher for International Women's Day, representing the Department of Electronic & Electrical Engineering from The University of Bath in 2021. I also received the "Best Presentation Award" in 2020 and 2018 from IEEE's International Conference on Applied Superconductivity and Electromagnetic Devices and an "Excellent PhD Thesis Award" from Beijing Jiaotong University, China, in 2019.

My contributions to the cryogenic field: I was involved in an international project to build a 6.5 MVA/25 kV superconducting traction transformer in a subcooled cryogenic environment at 65 K in liquid nitrogen. The project is a collaboration between Beijing Jiaotong University, China, China Railway Rolling Stock Corporation (CRRC), Innost, Times New Material, Lince, and Robinson Research Institute, Victoria University of Wellington, New Zealand. I was in charge of the numerical modelling of superconducting windings to reduce AC loss, i.e., the thermal load for the cryogenic

▶ *continues on page 36*

cooling system. For the first time, I successfully built a finite element model for the 6.5 MVA traction transformer windings at 65 K, which could calculate the thermal load accurately. This assisted the design stage of the superconducting transformer.

My contribution to the cryogenic field is also through conducting experiments and fabricating demonstrations on superconducting fault current limiters used as a protection solution for an electric propulsion system in electric aircraft. At the University of Bath, I successfully developed a helical superconducting fault current limiter with compact size and light weight. Many AC loss measurements and fault limiting experiments were carried out with liquid nitrogen, which shows that the proposed fault current limiter could halve the AC loss and limit the fault current peak by up to 75%.

What are the most important developments in cryogenics? From my viewpoint, the most challenging development in cryogenics is cryocooler advancement and development of high efficiency high power cryogenic cooling systems for future electrical powertrains in transportation applications that offers low mass density, low heat leakage with low cost, simultaneously.

What advances do you hope to see in the future? I would like to see more off-the-shelf cost-effective cryogenic components, cryocoolers and cryogenic cooling systems with large cooling capacity for large-scale power applications. I believe current developments around implementation of superconducting devices in power systems and electric aircraft will provide the right motivation for cryogenic manufacturers to invest in accelerating cryocooler and cooling system advancement.

Where can readers find out more about your projects? My projects and research outputs can be found through: LinkedIn: **www.linkedin.com/in/wenjuan-song-428306194**, Google scholar: **https://scholar.google.com/citations?user=u0osotEAAAAJ&hl=zh-CN**, ResearchGate: **www.researchgate.net/profile/Wenjuan-Song-3**, University of Bath Pure system/research portal: **https://researchportal.bath.ac.uk/en/persons/wenjuan-song**

Marco A. Guerrero Nacif, 33

My educational and professional background: I hold a B.S. in Mechanical Engineering, Cryogenic Fluid Management.

How I got into cryogenics: I joined NASA in the summer of 2018 as a Mechanical Experimental Equipment Engineer, and I've been supporting the Cryogenics Test Laboratory in Kennedy Space Center since day one as a cryogenics research engineer.

My mentor and my experience with them: I consider myself incredibly lucky for having Adam Swanger of the Cryogenic Test Laboratory at NASA Kennedy Space Center, as my mentor. Beyond cryogenics, he's mentored me in engineering, physics, manufacturing, design, and many other applications. His dedication to my success is why I am in the cryogenics engineering field today.

My present company/position: NASA/Cryogenics Research Engineer

My contributions to the cryogenic field: Classification of cryo-adsorption within nanotube composite materials (aerogels). Exploration of passive cooling insulation in composite materials as a product of desorption. Thermal insulation system testing, at full range vacuum ($1x10^{-5}$ torr to 760 torr) and 77 K – 353 K temperature range. The principle of measurement is a steady state boiloff calorimetry using LN_2 as direct energy meter.

What are the most important developments in cryogenics? I see energy storage (rocket fuel, automobiles, etc.), superconductivity and quantum computing as very important. We are currently working on projects that cover energy storage and quantum computing.

What advances do you hope to see in the future? I hope I get to see a hydrogen utopia where we maximize the utilization of hydrogen in every industry as an energy source. This could take several decades but we already start seeing some of those advances today. Also, I would also like to witness ITER developments as well as CERN and JWST. Great time to be alive!

Where can readers find out more about your projects? I am the creator of UniversoXplicado, a social media channel for science communication for Spanish speakers. We are currently expanding our reach to many different apps, including YouTube, Facebook, Instagram, Twitter and TikTok. Having the big majority of impact in TikTok with an audience of 400,000+ followers currently. One of the missions of the channel is to promote STEM with a primary focus on physics engineering and cryogenics. **https://linktr.ee/universoxplicado**

Chelsea Crabb, 34

My educational and professional background: Master of Science in Mechanical Engineering, Washington State University, August 2022.

How I got into cryogenics: When attending an event showcasing research labs in the engineering college, Dr. Jacob Leachman's HYdrogen Properties for Energy Research (HYPER) Lab stood out. We discussed lab projects and the extreme conditions under which experimentation was done, and I was hooked. I'd made the connection between cryogenics, aerospace and renewable energy applications. I now continue with my graduate degree to advance technologies in green hydrogen as an energy carrier.

My mentor and my experience with them: Thanks to Dr. Leachman's nomination I attended a Blue Origin U@Blue Mentorship Event and was paired with Dawn, a senior manager in aerospace engineering. Two and a half years later, we continue the mentorship and through our conversations I've learned it's okay that we all have good days and challenging days. What's important is to persevere, problem solve and move forward. The discussions also encourage me to stay focused, reinvigorate my excitement (It's always fun to share a passion!), and inform my decisions as I navigate my career.

My current company/position: Research Assistant on the HYPER team, building a thermal model of a polymer matrix composite (PMC) liquid hydrogen fueling tank and leading the operation of the Mobile Hydrogen Generation Unit (MHGU). MHGU is a self-contained unit which generates and liquefies hydrogen used to support off-site fueling of an industry drone tank.

Awards and honors received: I was listed on the Presidents Honor Roll for six consecutive semesters where I was recognized for having a 3.75 GPA or higher in the first semester and maintaining a 3.50 GPA or higher thereafter. Being within the top 12.5% of my junior class, I was invited to join Tau Beta Pi and was inducted in 2018.

My contributions to the cryogenic field: Producing and fine-tuning a thermal resistance network to model the thermal behavior of a lightweight PMC fuel tank and better understand the boiloff time. Designed to hold 2.5 liters of liquid hydrogen, the PMC material is lightweight and the thermal coefficients are not yet known experimentally. My research has determined upper and lower limits of these coefficients, effectively bounding best- and worst-case scenarios to inform future revisions to the tank geometry.

What are the most important developments in cryogenics? The climate crisis motivates a need for alternative sources of energy. Continued investigation into applications for hydrogen-powered vehicles is a key component due to the current levels of CO_2 emissions. As autonomy of self-contained hydrogen fueling stations improves, more obscure locations will become a possibility and change the landscape for hydrogen as a renewable energy source.

My work addresses this need with an emphasis on system development and concept of operations for small-scale and medium-scale hydrogen generation and fueling stations. We will need scientists in the field and at the chalkboard with an exceptional understanding of the fueling stations to troubleshoot existing issues and to provide continuous development of the next generation of fueling stations.

What advances do you hope to see in the future? Large-scale vehicles, such as airplanes, commercial trucks and cargo ships transitioning from traditional fuels to the use of liquid hydrogen as an energy carrier, would be a game changer. A lack of infrastructure to generate and supply liquid hydrogen, and a need for government funding to build this infrastructure, challenge these developments. The international collaboration between companies to move this technology forward and get the infrastructure in place will be critical to this development. I would also like to see the integration of wind and solar energy as an input to power hydrogen electrolysis to make green hydrogen such that all input resources and products are not harmful to the environment in any way.

Where can readers find out more about your projects? If anyone would like to discuss specific areas of my research, I invite them to reach me at chelsea.crabb@wsu.edu, or at **linkedin.com/in/chelseacrabb**. My profile can also be found via **hydrogen.wsu.edu**. ■

DOE Nuclear Physics Program Approaches Important FRIB Milestone

The Department of Energy's Nuclear (DOE) Physics program is rounding a corner in 2022, with its new user facility, the Facility for Rare Isotope Beams (FRIB, CSA CSM), set to open at Michigan State University on time and on budget. Meanwhile, preparations are continuing for construction of the program's next flagship project, the Electron-Ion Collider, which is slated to get underway at Brookhaven National Lab (Brookhaven) in 2024.

Over the past year, the program has also been considering its approach toward another high priority: detecting the hypothesized neutrinoless double beta decay (NDBD), an exceptionally rare radioactive-decay process. Finding such a decay would be a major breakthrough because it is forbidden by physics' Standard Model of particle interactions and would point toward answers to fundamental questions such as why matter is prevalent over antimatter in the universe.

So far, DOE has only provided token funding to new efforts to search for the decay, but at the latest meeting of the government's Nuclear Science Advisory Committee (NSAC) in November, program head Tim Hallman said there is international interest in funding up to three NDBD experiments simultaneously. Those discussions are still preliminary, though, and Hallman also observed that strained budgets are threatening to leave even current efforts underfunded.

Budget constraints weighing on current outlook

Describing the budget situation for the Nuclear Physics program, Hallman said that, while DOE requested a relatively large increase for it, that increase would follow a year in which its budget shrank. He also noted that FRIB and the Electron-Ion Collider are placing increasing demands on program funding.

Hallman further pointed out that, although Senate appropriators proposed providing more funding for the program this year than DOE requested, their House counterparts proposed substantially less. Referring to that split, he remarked, "At the lower end of the possible range, it's difficult to see how we would not have to have a reduction in scope or level of effort in order to make things fit."

As of this writing, Congress has still not negotiated its fiscal year 2022 appropriations for the government and is keeping all agencies running at last year's funding levels as a stopgap. Hallman explained that, even under the requested budget, some areas would not be fully funded. In particular, he said funding for construction and equipment projects would only be "adequate to keep things at stay-alive levels, in some cases better than others." His slide presentation noted that the Electron-Ion Collider budget would stay about even at $30 million and that the project requires about $120 million to meet its last pre-construction milestone in early 2023. Given that gap, its schedule could "need to be stretched."

Among smaller projects, the Gamma-Ray Tracking Array (GRETA) to be installed at FRIB would continue to be funded at beneath its planned level. Likewise, the Neutron Electric Dipole Moment experiment at Oak Ridge National Lab's (CSA CSM) Spallation Neutron Source would be funded at "significantly less" than its planned level, potentially impacting its schedule. Hallman reported that funding for facility operations and research at FRIB would be somewhat below their planned levels, though he also noted the facility was on track to begin science operations in February and would operate on a full schedule.

The draft text of the Build Back Better Act legislation that the Senate released in December, after Hallman's presentation, includes $387 million for the program's construction and equipment projects that the House did not include in the version of the bill it passed in November. However, the overall bill still lacks a clear path through the Senate.

Interest growing in expanded beta-decay hunt

Should the Build Back Better Act ultimately deliver funding for the Nuclear Physics program, it could benefit the search for the neutrinoless double beta decay. Although such a project would not be nearly as expensive as the Electron-Ion Collider, the decay is so rare that the next efforts to find it are expected to require a sizeable "ton-scale" detector that would still weigh heavily on the program's budget.

NSAC's 2015 Long Range Plan for Nuclear Science envisioned that work on a ton-scale NDBD experiment would proceed as the construction of FRIB ramped down and that construction of the Electron-Ion Collider would then follow FRIB's completion. As things have unfolded, though, the collider is moving ahead first.

Nevertheless, reporting on a summit on NDBD that convened in Italy in September, Hallman expressed enthusiasm about the prospects for an ambitious multinational effort. Explaining that even a ton-scale detector might not yield clear-cut evidence for the NDBD, he said that summit participants broadly agreed it would be desirable to have near-contemporaneous confirmation from independent experiments. "That's a pretty important conclusion that wasn't obvious would be made going into this summit," he said. He related that participants from Italy and Canada were the "most outspoken" in favor of the idea and that the meeting also yielded support for exploring a more formal international collaboration.

Hallman said that a review the Nuclear Physics program conducted in July 2021 of potential ton-scale NDBD experiments focused on three promising candidates: CUPID, nEXO and LEGEND-1000. He reported the estimated overall costs of those efforts are $64 million, $406 million and $442 million, with DOE respectively covering 55%, 85% and 60% of the total.

Observing that building all three projects would involve spending $1 billion over 10 years, he said it would not be an "exceedingly outrageous" amount if several countries contribute. He also compared it to the much larger sums spent on experiments that require accelerators to produce the phenomena they study. He asserted that "the potential discovery of a neutrinoless double beta decay would be every bit as much of a game changer as the discovery of supersymmetry at CERN, and as compelling as any accelerator-based research currently underway."

Hallman also suggested that a formal collaboration would be well positioned to support even larger follow-on efforts if they are needed. "If this really is a campaign, if the next round of experiments is not going to be decisive because nature is not kind, then you need sort of an ecosystem to carry this through to conclusion. And it's not going to be a two-decade outlook, it's more like a four-decade outlook; and you want that ecosystem to be able to carry through," he remarked.

New long-range plan on the horizon

The future direction of the Nuclear Physics program will be subject to guidance through NSAC's next long-range plan, which Hallman said the program is considering initiating after its fiscal year 2022 budget is finalized. To review the process through which NSAC produces the plan, the committee heard from Don Geesaman and John Wilkerson, who respectively chaired NSAC and the American Physical Society's Division of Nuclear Physics (DNP) when the last plan was produced.

They reflected that the process lasted about a year and a half and involved a series of DNP-organized "town meetings" early on, followed by the submission of white papers to NSAC. The working group that assembled the report comprised about 60 members and was responsible for formulating its recommendations in view of different budget scenarios.

Geesaman contrasted the NSAC process with the "P5" process undertaken by the government's High Energy Physics Advisory Panel in that NSAC focuses more on science priorities than specific projects. He argued that NSAC's approach gives DOE and the National Science Foundation more flexibility around how to satisfy those priorities. "The funding agencies have well-established procedures to evaluate the scientific value and cost and technical effectiveness of the projects. NSAC has to trust that the agencies will move forward in a rational and optimized way, even under the constraints of budget challenges," he said. **https://frib.msu.edu** ■

The Aerospace Corporation To Develop Low Gravity Cryogenic Pressurization Test Approach

With funding from NASA Flight Opportunities, The Aerospace Corporation (Aerospace) is developing an experimental cryogenic apparatus to understand the impact of low gravity on tank pressurization. The project will test the pressure control capability of a liquid nitrogen storage tank in low gravity using two separate gas injection methods (into the ullage and into the liquid) with two different pressurant gases (helium and nitrogen). Ground tests will take place at the Mechatronics Research Laboratory in El Segundo CA, an Aerospace facility. Three flight tests are planned for November 2022 aboard a Zero-G Corporation aircraft for low gravity simulation.

Overall, the experiments will investigate the effect of low gravity on pressurant gas consumption and pressurization ramp rates. While it is clearly advantageous to minimize the consumption of pressurant gas to reduce the cost and mass of the space vehicle, the evaluation of the tank pressure control strategies is more nuanced. An effective pressurization system must have sufficient precision to maintain the pressure of a small ullage without excessive overshoot when the tank is nearly full, as well as sufficient flow capacity to pressurize a large ullage when the tank is nearly empty.

Prior ground tests at NASA compared direct and subsurface pressurization under normal gravity.[1-3] However, to date, there are no publicly available unsettled cryogenic pressurization datasets in low

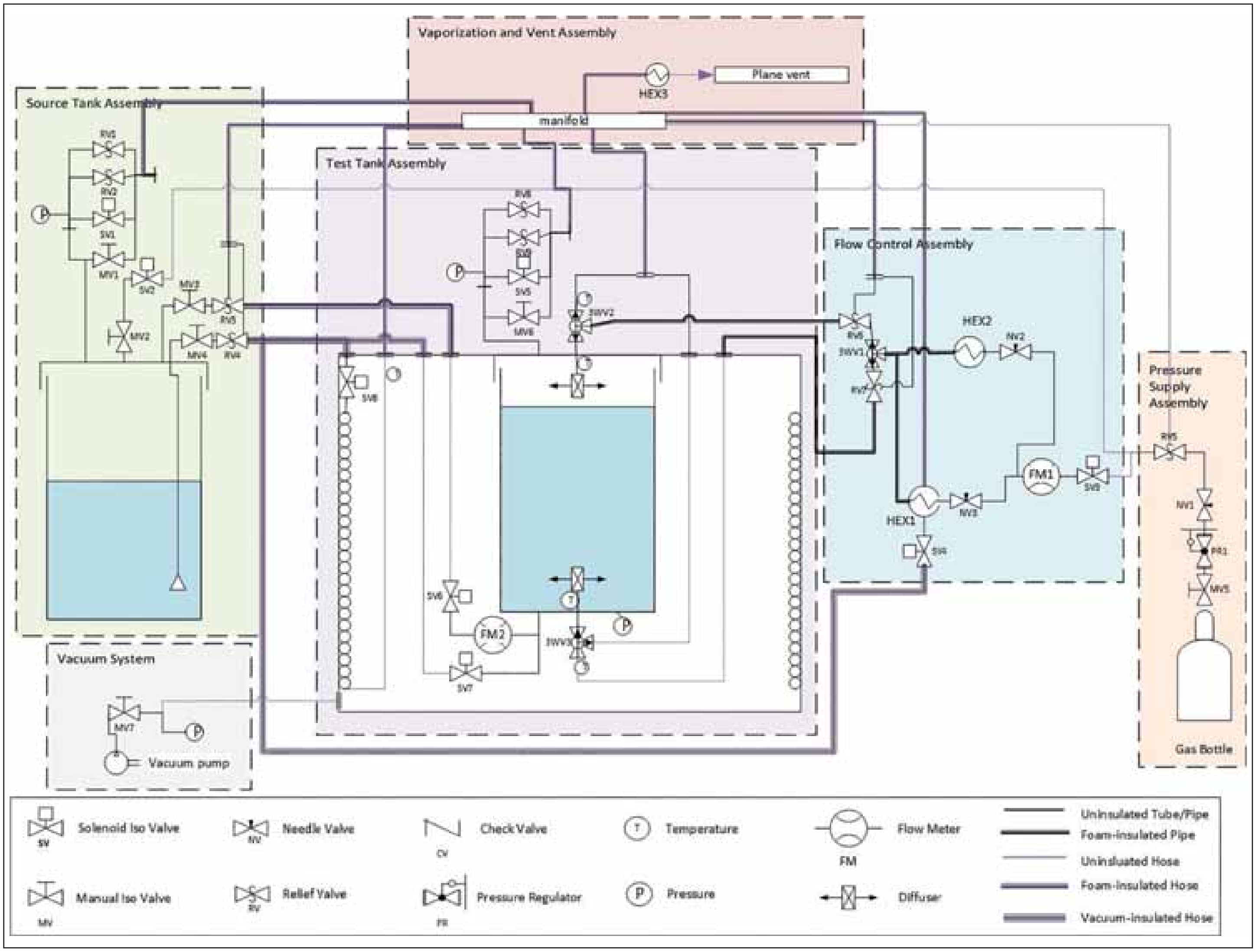


Figure 1. Conceptual design stage. Tank propellant management device not shown. *Image: The Aerospace Corporation*

gravity, so pressurization performance predictions for low gravity vehicles must rely on ground test data and unvalidated numerical simulations of low gravity tank pressurization. Unsettled helium pressurization is at a Technology Readiness Level (TRL) of 5 while unsettled autogenous pressurization is at TRL 4.[4-5] Advancing the TRL and enabling flight cryogenic pressurization system design require tank pressurization models anchored by data obtained in microgravity.

Gravity plays a key role in cryogenic two-phase flow phenomena. The flow patterns and heat transfer in low gravity differ markedly from those in terrestrial gravity. In one example, natural convection significantly contributes to the energy lost to the wall during pressurization in an applied acceleration field. However, with minimal natural convection driving ullage flow in low gravity, the energy exchange in the system is qualitatively different. In another example, liquid cooling due to subsurface pressurization may be inhibited by reduced gravity. In normal gravity, buoyancy drives bubbles through the liquid, spreading evaporation to a larger volume of the liquid. In low gravity, however, bubble motion is minimal so that the evaporation is limited to near the diffuser inlet.

A major consideration of tank pressurization in low gravity is that the pressurization gas may be directly injected into the liquid propellant if free-floating liquid submerges the gas inlet. Cryogenic propellant tanks can also use subsurface pressurization intentionally to conserve pressurant gas and provide propellant thermodynamic conditioning. The incoming gas evaporates some liquid propellant, which reduces the pressurant mass required to achieve the target pressure and decreases the liquid temperature.

For the experimental apparatus shown in the figure, helium and nitrogen gas bottles pressurize the liquid nitrogen tank at controlled flow rates through either a bottom or top port fitted with diffusers to spread the incoming gas. The heat exchanger conditions the incoming gas to temperatures ranging from cryogenic to ambient. Energy exchanges between the wall, ullage and liquid during pressurization are estimated based on temperature data. During the low gravity portions of the flights, liquid outflow tests will simulate propellant transfer to explore the effects of injection type, pressurant gas type, injection flow rate, injection gas temperature, liquid outflow rate, initial bulk saturation state, initial liquid level, initial tank pressure and final tank pressure on pressurant consumption and pressurization rate.

The data obtained from this experiment will enable accurate low gravity tank thermodynamic modeling, thereby improving estimations of pressurant gas consumption and tank pressurization rates. Additionally, optimal pressurization schemes and conditions to minimize pressurant consumption, achieve target tank pressurization rates and de-stratify the temperature gradients in the tank will be investigated. This information is essential to the design of the in-space cryogenic propulsion systems envisioned by NASA and future commercial exploration missions, including nuclear thermal propulsion systems, ascent stages, descent stages, in-space fuel depots and liquefaction systems on the surfaces of the Moon and Mars.

Team members on this project include Samuel Darr and Matthew Taliaferro of The Aerospace Corporation and Jason Hartwig of NASA Glenn Research Center. **https://aerospace.org**

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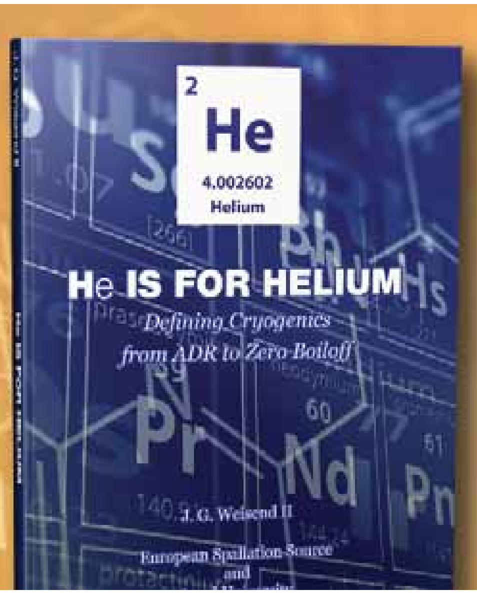

Product Showcase

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

Cryofab, Inc.

CLH Dewar Series

Cryofab manufactures a range of portable dewars and transfer hoses for LH_2. The CLH series portable liquid hydrogen container is expertly designed for low pressure transport, storage and dispensing of liquid hydrogen. Because these containers employ state-of-the-art vapor-cooled multi-shield technology in conjunction with superinsulation, Cryofab can guarantee low loss rates. The CLHs feature all stainless steel welded construction, robust design, built-in vacuum insulated fill/withdrawal port, bayonet connection for low heat leak transfers, purge ports for safety on all valves, DOT certified 4L50, bellows-sealed vent, pressurization and isolation valves, compact size, common vent for piping away relief devices and exhaust port. **www.cryofab.com** ■

Cryoguard, LLC

M-5 Cryoguard™ Thermal Exposure Indicator

The new M-5 Cryoguard™ Thermal Exposure Indicators are used at or below -30 °C to continuously monitor cryopreserved materials such as laboratory specimens, vaccines, frozen blood samples, biologics, clinical products, pharmaceuticals, medication and other heat sensitive materials. They signal thermal exposure at or above -5 °C by irreversibly changing color from green to red within two hours. An activated M-5 indicator remains green at or below -30 °C. At 20 °C, an activated M-5 indicator changes color within minutes. The distinct real-time signal allows recipients and users of perishable cryopreserved materials to quickly and reliably verify that the cryo environment was maintained. The indicators fit inside freezer box partitions, on cryovials and freezer canes for continuous monitoring of frozen materials during shipping, storage and handling by personnel. **https://cryoguard.com** ■

Cryomech, Inc.

Pulse Tube Cryocoolers

In the industry that harnessed superconducting quantum technology, customers require large capacity cooling coupled with ultra-low vibration performance. Cryomech's PT425 with remote motor and the upcoming PT300 series are two examples of how Cryomech addressed the market's needs. PT425 offers a powerful 2.7 W (integrated motor) or 2.35 W (remote motor) cooling capacity at 4.2 K. The PT300 series offers optimized cooling power at 3 K, yielding up to 50% more power compared to the equivalent pulse tubes optimized at 4.2 K, while keeping the power consumption low. **www.cryomech.com** ■

INOX India

Vacuum Insulated Flexible Hoses

Vacuum insulated flexible hoses consist of two coaxially arranged flexible pipes with the inner process line containing the cryogenic fluid while the outer line is under vacuum to thermally insulate the process line. The insulation is enhanced by multilayer insulation (MLI) wrapped around the process line. Vacuum insulated flexible hoses can be joined with other elements of the cryogenic system by means of bayonet/Johnston's coupling or butt-welded connections by providing a rigid pipe piece at the end. Vacuum insulated hoses are used to transport cryogenic fluids – nitrogen, oxygen, helium, argon, LNG, CO_2 – with low heat leak by their unique designed sliding spacers (patent pending) and use of MLI for internal hoses. Vacuum insulated hoses are available for any standard size from to DN150 for different lengths as per requirement with any cryogen temperature and pressure application. **https://www.inoxcva.com** ■

Lake Shore Cryotronics

MeasureReady™ M81-SMM Synchronous Source Measure System

This modular, multichannel system combines the convenience of DC and AC sourcing with DC and AC measurement – including a lock-in's sensitivity – for low level, precision I-V characterization of electronic materials. Designed to eliminate the user complexities of single-function multi-instrumentation setups, the extremely low-noise system design ensures inherently synchronized measurements from 1 to 3 source channels and from 1 to 3 measure channels per a single half-rack instrument. It easily integrates with cryogenic probe stations and other low temperature systems. When used with a cryostat, it allows simultaneous measurement of up to three devices at different frequencies. It is also ideal for measuring small photo detector currents in cryogenic environments. Owing to its modular architecture, the system allows signal and source amplifiers to be located as close as possible to the sample, which minimizes signal wiring, reduces noise, and increases measurement sensitivity. For details, visit **www.lakeshore.com/M81**. ■

PBS Velka Bites

Cryogenic Drive Unit with Aerodynamic Gas Bearings

PBS Velka Bites introduces a new cryogenic drive unit designed to drive various cryogenic devices, especially compressors, pumps or circulators. Its main advantage is the same as for other PBS cryogenic products, namely the use of aerodynamic gas bearings, which ensure many years of maintenance-free operation. The non-contact bearings arrangement also makes it possible to achieve high operating speeds, which in the case of a cryogenic drive unit exceed 70,000 rpm. Aerodynamic bearings operate without risking the contamination process medium. With an actual output of 3.5 kW to 7 kW, the unit has a wide range of applications and can be tailored to customer requirements. **www.pbs.cz/en** ■

Tempshield Cryo-Protection

Cryo-LNG™ Gloves

Tempshield's Cryo-LNG™ Gloves are the gloves of choice when working with LNG or liquid nitrogen in an industrial setting. They provide the same high level of thermal and splash protection as Tempshield's other gloves. The rugged, abrasion-resistant palm offers flexibility and dexterity when function is important and safety is critical. They also have a wicking inner lining to maintain comfort over extended periods. Available in mid-arm and elbow lengths, and in colors blue or brown, Tempshield's cryo-industrial gloves are certified to EU Cat. III standards: EN 388, EN 511 and EN 420. Applicable for LNG fueling and delivery, cryogenic gas delivery and servicing and the oil and gas and mining industries. **https://tempshield.com** ■

Web Industries

MLI Blanket Cleaning Services

Web Industries Inc. has introduced cleaning services for multilayer insulation (MLI) blankets. These customized blankets are used in some applications in which foreign object debris (FOD), dirt, grease, human sweat or oils could seriously impact product performance. For example, satellite camera functionality can be impaired if FOD or other contaminants outgas during launch and deployment, occluding the camera lens. To enhance its quality procedures, Web Industries has added specialized MLI blanket cleaning services as an option for customers who require the highest levels of disinfection and cleanliness. Web Industries engaged an industrial hygiene consultant to advise its Denton TX MLI blanket manufacturing facility on optimal, safe cleaning procedures, which it has implemented. These include use of isopropyl alcohol for chemical cleansing of MLI blankets. For more information, please visit **www.webindustries.com/markets/aerospace** ■

FormFactor Launches <50 mK Cryogenic Test Service to Accelerate Quantum Development

Quantum computing developers require access to milli-Kelvin temperatures to reduce thermal noise, access critical transitions, develop new materials, and explore new quantum processor chip architectures. For some developers, acquiring a cryostat with a <50 mK base temperature can be a challenge, due to prohibitive capital cost and lead time. These factors can cause new quantum computing startups to struggle with slow development cycles and prevent component suppliers from properly qualifying their products for operation at ultralow temperatures. FormFactor, Inc., a leading semiconductor test and measurement supplier, has launched the industry's first Cryogenic Test Services that provide immediate and low-cost access to 50 mK cryostats and leverages a high pin count RF and DC probe socket.

The race to develop a practical quantum computer is gaining momentum and has attracted a variety of developers from academia to the largest technology companies in the world. Fundamental to development is the speed at which data can be obtained to characterize and correlate device performance over a wide temperature range to optimize device sorting. By engaging in Cryogenic Test Services with FormFactor's application experts, customers reduce the need for in-house test expertise and the risk of not delivering timely test results.

Instead of allocating critical runway funding to capital expenditures, quantum computing startup companies are now able to put their immediate efforts into honing their device architectures and improving qubit operating performance parameters. It is straightforward to analyze a change to fabrication processes or improve quantum materials side-by-side with the main quantum processor development by using the <50 mK Cryogenic Test Service.

Users are engaging with the cryogenic test service on several fronts. Leading superconducting and spin quantum computing developers are leveraging the service to enhance their test and measurement capabilities by pre-characterizing qubits and new fabrication processes on the rapid turnaround <50 mK system. Quantum engineers can perform initial measurements on singulated die, which allows them to quickly determine key operating characteristics such as read-out resonator frequency, qubit frequency, and qubit lifetime. Initial qubit calibration steps, such as single qubit gates and multi-qubit gates, can also be performed to reduce the bring-up time on the final deployment system. The test service offering has led to improving device yield by providing rapid feedback on new fabrication processes and the impact on device performance.

Developers working in the milli-Kelvin regime have historically relied on time-intensive manual wire bonding and packaging processes to test and deploy their devices. FormFactor has further sped up the time-to-data by implementing the industry's first >10 GHz bandwidth cryogenic RF probe socket for <50 mK systems, which allows developers to avoid the hassle of wire bonding and packaging for a dilution refrigerator. The probe socket has significantly increased the feedback loop between test and measurement and fabrication processes. It is designed to the users' specifications and can be configured with >24 RF lines and >100 DC lines. The cryostats available through the test service program are outfitted with magnetic shielding to enable sensitive superconducting qubit work and can be optionally outfitted with magnets for spin qubit experiments.

The FormFactor Cryogenic Test Service provides the quantum supply chain with rapid and affordable access to the most important temperature regime for superconducting and spin-based qubit quantum computing development. Suppliers to the market use the <50 mK test service to characterize RF performance parameters and confidently offer their customers prequalified components. To further reduce the capital equipment barrier, FormFactor has a suite of test and measurement instruments available to the user base, including switch matrices for higher throughput testing and spectrum analyzers to characterize RF performance.

The Cryogenic Test and Measurement Service offering will be expanded in the summer of 2022 to include <4 K wafer-level probing. Interested users can visit **www.formfactor.com** for more information. ■

People, Companies in Cryogenics

Victorino Franco, professor of Condensed Matter Physics at the University of Seville, and **Lake Shore Cryotronics' (CSA CSM) Brad Dodrill** recently co-edited *Magnetic Measurement Techniques for Materials Characterization*, a book that discusses the most commonly used techniques for characterizing magnetic material properties and

Image: Lake Shore Cryotronics

provides examples and applications of measurement techniques to relevant magnetic materials. Franco is a collaborator with Lake Shore, having developed their magnetocaloric effect (MCE) analysis software; Dodrill is vice president and senior scientist at Lake Shore. The book is available at SpringerLink and all major book retailers.

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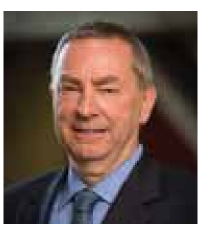

Image: Fermilab

Nigel Lockyer, director of **Fermi National Accelerator Laboratory** (Fermilab, CSA CSM), received the Distinguished Career Service Award from the Department of Energy's Office of Science for his dedication and service to the DOE and the nation. The award recognizes Lockyer's eight years at Fermilab and his work in facilitating international collaboration within the worldwide high-energy physics community.

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GenH2, a premier provider of hydrogen infrastructure solutions, announced an agreement with **Monfort Technology** to develop solutions for mass transit and long-haul trucking sectors. The agreement allows GenH2 to manufacture solutions for hydrogen production, liquefaction, and controlled storage and dispensing solutions to empower the fueling infrastructure of buses and Class 1-8 trucks. Monfort, known for building the first working 80-passenger electric school bus, will produce EV hybrid vehicle conversion kits utilizing its patented BMS and drivetrain technologies.

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Nikkiso Cryogenic Industries' Clean Energy & Industrial Gases Group, a subsidiary of **Nikkiso Co., Ltd (Japan)**, named **Marsel Khaliullin** their new Business Line Manager Aftermarket Services Russia & Cryogenic Industries Service for **Nikkiso Industrial Russia (NIR)**. Based in Russia, Khaliullin will manage and support aftermarket services. He has over 20 years of experience working at various positions in maintenance and engineering, specifically related to rotating equipment, six years in the oil and gas industry in Iraq, and ten years working with oil and gas at other international companies. For the past two years, Marsel managed the Rotating Equipment workshop for SPM Oil & Gas, a Caterpillar company. With this addition, Nikkiso continues its commitment to be both a global and local presence for its customers.

"Marsel's experience and industry knowledge will be of great benefit to NIR, and we look forward to his positive contributions," said Ayman Zeitoun, vice president and managing director for Russia operations.

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Meyer Tool & Manufacturing Inc. introduced a new tool in February. The **Hurco Companies, Inc.** VMX24i began production at Meyer and immediately impacted the company's productivity. "With the added high pressure thru-spindle coolant and programmable fourth axis options, it's surely going to allow us to get jobs out the door even faster than ever," said Kenny Urban, Machine Shop Supervisor for Meyer. "Our shop is filling up with more and more black and gray machines, and we wouldn't want it any other way. Hurco is our machine tool of choice."

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Leybold, one of the most successful suppliers of vacuum technology in the world market, has launched a new website. The fresh look allows easy navigation for those seeking information about repairs and services and manual and product downloads. It also provides quick access to free vacuum tools and Leybold's streamlined service offerings. Since 1850, Leybold has been developing and supplying vacuum pumps, systems, and standardized and customized vacuum solutions and services for multiple industries worldwide. You can read about their products, services, and history at **www.leybold.com**. ■

Meetings & Events

28th International Cryogenic Engineering Conference and International Cryogenic Materials Conference 2022
April 25-29, 2022
Virtual
http://2csa.us/ks

15th Workshop on Low Temperature Electronics (WOLTE-15)
June 6-9, 2022
Matera, Italy
http://2csa.us/kv

Foundations of Cryocoolers Short Course
June 27, 2022
Bethlehem, PA
http://2csa.us/l1

ICC 22
June 27-30, 2022
Bethlehem, PA
http://2csa.us/kn

29th International Conference on Low Temperature Physics
August 18-24, 2022
Sapporo, Japan
http://2csa.us/ha

National Symposium on Cryogenics and Superconductivity 28
October 18-21, 2022
Kharagpur, India
http://2csa.us/kw

ASC 2022
Oct 23-28, 2022
Honolulu, HI
http://2csa.us/ko

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