Cold Facts INTERNATIONAL

The Magazine of the Cryogenic Society of America, Inc.

CCAT Observatory Approaches First Light | 8

Volume 39 Number 3 2023


Cryo Technologies
A Chart Industries Company
Experts in Cryogenic Processing of High-Value Industrial Gases
1 H Hydrogen 1.008
2 He Helium 4.002602
7 N Nitrogen 14.007
10 Ne
18 Ar
CH4 Natural Gas
Custom 30 TPD Turnkey Plant Solutions
Liquefaction
Purification
Recovery
Recycling
Distribution
241 N Cedar Crest Blvd, Allentown, PA 18104 610.530.7288 www.chartindustries.com/cryotech


PHPK TECHNOLOGIES
WHEN PERFORMANCE AND RELIABILITY MATTER
• Cold boxes
• High vacuum chambers
• Pressure vessels
• Cryostats
• Helium compressor skids
• Thermal shrouds
• Thermal conditioning units
• Vacuum insulated piping
• Valves
• Couplings
CVI Torr Master
• Cryopumps
• Cryocoolers
Proudly Manufactured in the USA
info@phpk.com
(614) 486 4750
www.phpk.com

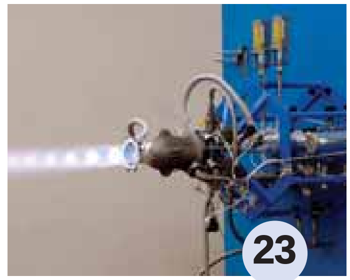
Join Our Growing Family of CSA Corporate Sustaining Members

Get connected to the cryogenic community worldwide.
Let your voice be heard and your contributions known.

Abbess Instruments and Systems, Inc.
Ability Engineering Technology, Inc.
Acme Cryogenics, Inc.
Ad-Vance Magnetics
Advanced Research Systems, Inc.
Aerospace Fabrication & Materials
Air Liquide advanced Technologies
Alkegen
Alloy Valves and Control
American Magnetics, Inc.
Amuneal Manufacturing Corp.
API Technologies
Argonne National Laboratory
Atlas Technologies
Barber-Nichols Inc.
Beyond Gravity GMBH
Bhiwadi Cylinders PVT*
Bluefors
Brugg Rohrsysteme Gmb
Canadian Nuclear Laboratories
CCH Equipment Company
Chart Inc.
Chase Research Cryogenics
Clark Industries, Inc.
Coax Co., LTD.
CoolCAD Electronics, LLC
CO2 Meter
CPC-Cryolab, an MEC Company
Creare LLC
Criotec Impianti SpA
Cryo Industries of America
Cryo Service LTDA
Cryo Technologies
Cryoco LLC
CryoCoax
Cryocomp
CryoEdge
Cryofab, Inc.
Cryogas Tech Sdn. Bhd.
Cryogenic Institute of New England
Cryogenic Limited
Cryogenic Machinery Corporation
Cryoguard LLC
Cryomagnetics, Inc.
Cryomech, Inc.
Cryonova Process Systems, LLC
Cryospain
CryoSRV, LLC
Cryotechnics LLC
CryoVac GmbH
CryoWorks, Inc.
Cryoworld BV
CSIC Pride (Nanjing) Cryogenic Technology Co., Ltd.
Danaher Cryogenics
Demaco Holland BV
DMP CryoSystems, Inc.
EPSIM Corporation
Equigas, Inc.
Essex Industries
Eta Space
Fabrum Solutions
Facility for Rare Isotope Beams—Michigan State University
Fermi National Accelerator Laboratory
Fin Tube Products, Inc.
FormFactor
Gardner Cryogenics
Gas Equipment Company
GenH2
IC Biomedical
Imtek Cryogenics
Independence Cryogenic Engineering, LLC
Kelvin International Corporation
KEYCOM Corporation
kiutra GmbH
Lake Shore Cryotronics, Inc.
Lihan Cryogenics
Linde Cryogenics, Division of Linde Engineering Americas
Magnatrol Valve Corporation
Magnetic Shield Corporation
Marathon Products, Inc.
Meyer Tool & Mfg., Inc.
Micro Harmonics Corporation
Midalloy
Molecular Products, Inc
NASA Kennedy Cryogenics Test Laboratory
National High Magnetic Field Laboratory
Nikkiso Cryogenic Industries
Niowave, Inc.
Oak Ridge National Laboratory
Omegaflex
Oxford Cryosystems
Oxford Instruments NanoScience
PBS Velka Bites
Penflex
Photon Spot*
PHPK Technologies
Quantum Design, Inc.
RegO
RIX Industries
Rockwood Composites
Rutherford & Titan, Inc.
Scientific Instruments, Inc.
shirokuma GmbH
SLAC-National Accelerator Laboratory
Sierra Lobo
Space Dynamics Laboratory
Spectrum Valves
SPS Cryogenics BV
STAR Cryoelectronics
Stirling Cryogenics BV
Stöhr Armaturen GmbH & Co. KG
Sumitomo (SHI) Cryogenics of America, Inc.
Sunpower, Inc.
SuperPower, Inc.
Technifab Products, Inc.
Technology Applications, Inc.
Tempshield Cryo-Protection
The Aerospace Corporation
The Phoenix Company of Chicago
Thermal Management Technologies
Thermal Space
Thomas Jefferson National Accelerator Facility
TRIUMF
Turbines Inc.
Vacuum Barrier Corporation
Vacuum Energy Inc.
Valcor Engineering Corporation
Web Industries
WEKA AG
Wessington Cryogenics
West Coast Solutions
XMA Corporation
ZeroAvia

* New member since last issue

Inside This Issue



FEATURES

COLUMNS

SPOTLIGHTS

ON OUR COVER

CCAT Observatory Inc. has spent six years developing the Fred Young Submillimeter Telescope (FYST) and its infrastructure in Chile, aiming to conduct large-scale submillimeter surveys to study star formation, galaxy evolution, and cosmic microwave background mapping. Equipped with a six-meter aperture mirror and energy-efficient focal plane instruments, the telescope is currently under construction and expected to achieve first light in early 2025. Pictured here is the milling of the gearbox and main bearing interfaces on the central section of the telescope traverse welded assembly. *Credit: CCAT Observatory, Inc.*

In all instances, "CSA CSM" indicates a Corporate Sustaining Member of CSA.

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

From the Executive Director

Aloha! By the time you're reading this, I will likely be in Hawaii for CEC/ICMC'23 and the 30th Space Cryogenics Workshop. I'm looking forward to seeing many of you face to face at these two events. During CEC/ICMC, CSA will have a table in the exhibit hall, so make sure to come say hello.

CSA is proud to be offering multiple short courses prior to CEC/ICMC. We'll have one full-day course and four half-day courses, which will cover various cryogenic-related topics. These courses are designed to provide a comprehensive understanding of different aspects of cryogenics and are an excellent opportunity for students and researchers to enhance their knowledge and skills in this field.

Following CEC/ICMC'23, CSA will be partnering with NASA to host the 30th Space Cryogenics Workshop (SCW), July 16-18, 2023. This workshop will be held at the Outrigger Kona Resort and Spa in Kailua-Kona, Hawaii. As of the composition of this letter, we have more than 90 attendees registered for SCW! I'd like to extend our deepest gratitude to our workshop sponsors – Alloy Valve and Control (AVCO), OmegaFlex, Aerospace Fabrication and Sunpower. Without their support, this workshop would not be possible. THANK YOU!

Next, if you haven't had a chance to browse the CSA website recently, I want to remind you of a couple online benefits CSA offers year-round, and at no cost:

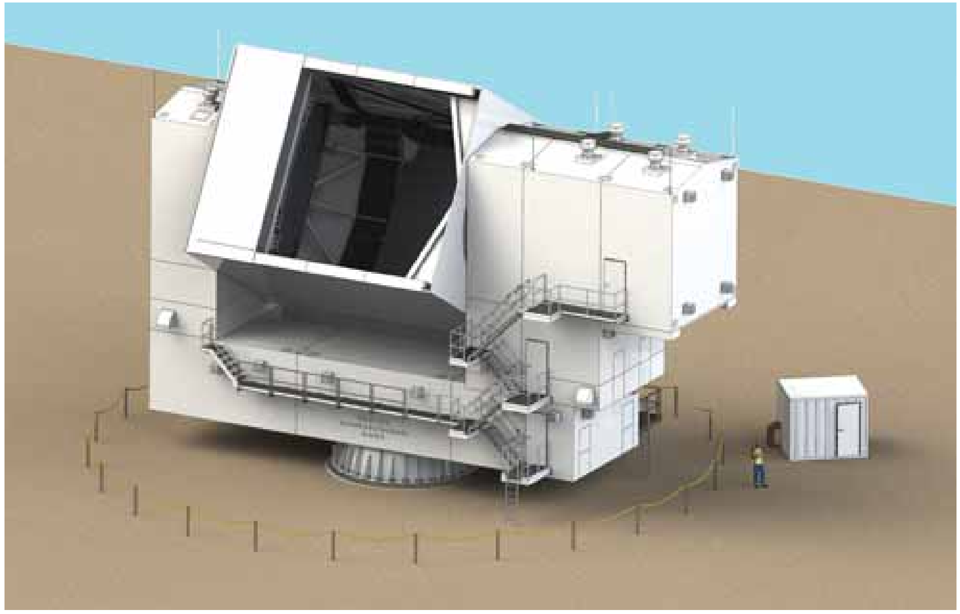
Cryogenic Treatment Database (**https://cryogenictreatmentdatabase.org**): This database is a leading resource for research and information in the field of cryogenic treatment — the use of extremely cold temperatures to improve the properties of materials. It is designed to be an impartial source of scientific information. Every effort is made to give fair evaluation of proposed content. An objective, professional committee has been formed to perform these evaluations. Updated quarterly, the database contains scientific and informational articles pertaining to the cryogenic treatment industry. You will find everything from white papers and conference proceedings to media transcripts and interviews, all organized and searchable.

CSA's Cryogenic Buyer's Guide (**https://csabg.org**): This resource of products and services designed for cryogenic applications includes everything from adhesives, cryocoolers, dewars and electronic controls to greases, liquefiers, magnets, tanks, test chambers, valves and wire used in ultralow temperature applications. Here you can also find engineering consultants, research and test laboratories, specialty manufacturing, cryogenic treatment services, materials research and cryogenic transport services. You will find company profiles for leading companies in cryogenics as well as contact information for many additional suppliers. Just this year, CSA has added 16 new companies to the Buyer's Guide.

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

CCAT Observatory Approaches First Light

by Stephen Parshley, CCAT Project Engineer, Cornell University



Rendering of the Fred Young Submillimeter Telescope. *Credit: CPI Vertex Antennentechnik GmbH*

Members of the CCAT Board of Directors and distinguished guests, accompanied by CPI Vertex staff, inspecting the trial assembly progress of FYST in Germany, December 2022. *Credit: Stephen Parshley*

For the past six years, CCAT Observatory Inc., a nonprofit research organization formed by more than a dozen academic institutions led by Cornell University, has been developing a new telescope, the Fred Young Submillimeter Telescope (FYST, pronounced "feast") and its supporting infrastructure to observe at submillimeter wavelengths. The infrastructure is currently under construction at an altitude of 5,600 m near the summit of Cerro Chajnantor in the Atacama Desert of northern Chile, one of the driest places on Earth. Since water vapor absorbs the wavelengths of interest, the site is arguably the best ground-based location for submillimeter observations due to its thin, ultradry atmosphere. Once complete, it will be the second highest observatory in the world.

The submillimeter (submm) regime, defined as wavelengths from 1.0 to 0.2 mm, or frequencies from 300 to 1,500 GHz, offers a unique window into astrophysics. The mapping speed of FYST, along with first generation focal plane instruments, will enable new large-scale surveys of the sky. CCAT will reveal the trail from interstellar clouds to star formation in the Milky Way; the process of galaxy assembly and evolution; the process of reionization of the universe from the first galaxies; the growth of large-scale structure in the universe and massive clusters of galaxies; and transient events from the growth of protostars to the most luminous explosive events in the universe. In addition, CCAT submm maps of the cosmic microwave background are critical to the search for primordial gravitational waves – the required signature of the inflationary epoch at the origin of the universe.

To achieve these goals, CCAT is building FYST, with a six-meter clear aperture primary mirror. The aperture is modest by today's standards, but due to its low emissivity, low cross-polarization and large field of view that can illuminate several hundred thousand detectors, its mapping speed is enormous. Mechanically, FYST is unconventional, as the elevation axis can go from nadir (EL = -90°), to horizon (EL = 0°), zenith (EL = +90°), and then opposite horizon (EL = +180°). Also, the optics are fully contained within the elevation superstructure, which diminishes the wind loading, and combined with a retractable shutter, provides environmental protection for maintenance and stowing for inclement weather. The design of FYST is so compelling that the Simons Observatory chose to produce a copy with reduced tolerances for its large aperture telescope operating in the millimeter-wavelength regime, and it serves as the baseline design for the Chilean large aperture telescopes of the fourth generation, ground-based cosmic microwave background experiment (CMB-S4).

Any telescope, of course, is just a machine that collects and focuses light. Focal plane instruments are needed to enable the broad range of science topics outlined above, and there are two planned for FYST's first light: Prime-Cam and the CCAT Heterodyne Array Instrument (CHAI). Both instruments use pulse tube cryocoolers to lower the instrument background and enable the superconducting detectors to collect the weak astrophysical signals. Liquid cryogens were ruled out early in the planning stage due to their expense and the remoteness of the site.

For CHAI, two cryostats are planned, one for low frequency (~475 GHz) and one for high frequency (~810 GHz). Each CHAI cryostat uses two cryocoolers running in parallel to achieve a 50 K thermal shield and a 4 K focal plane array. From an operations standpoint, a key feature of the CHAI cryostats is their ability to go into a standby mode where only one cryocooler is required to maintain system temperatures when the instrument is not observing. This is especially important for the power budget of the observatory and to help reduce its carbon footprint.

Prime-Cam will have multiple optics modules within a single large cryostat (roughly 1.8 m in diameter), also utilizing multiple cryocoolers for 80, 40 and 4 K thermal intercepts, as well as a dilution refrigerator providing a 100 mK bath for the microwave kinetic inductance detector arrays. The optics modules will encompass both continuum cameras and imaging spectrometers. The modular design of Prime-Cam allows for optics modules to be developed in parallel at member institutions, as well as provide a framework for staged deployment and upgrades.

Progress on the observatory is well underway. The telescope's foundation is complete, as well as the installation of 8 km of power and fiber optic cables and hundreds of meters of grounding grid. The steel structure of the telescope is complete as well, and the FeNi36 alloy elevation superstructure is currently in fabrication. All bearing, drive, and servo components have passed their initial factory acceptance testing. The mirror backup structure, made of carbon-fiber-reinforced plastic, is nearly finished for the primary mirror and the secondary is in progress, and all the 146 lightweight aluminum mirror tiles have reached completion. CPI Vertex Antennentechnik GmbH, the prime contractor handling the detailed design and construction of FYST, is conducting a full trial assembly this year in Germany prior to shipping to Chile in 2024. We look forward to declaring first light in early 2025 and commencing upon our early science program.

Carbon fiber-reinforced plastic truss assembly for the primary mirror backup structure of FYST. *Credit: CCAT Observatory, Inc.*

Milling of the gearbox and main bearing interfaces on the central section of the telescope traverse welded assembly. *Credit: CCAT Observatory, Inc.*

Welding of the FYST support cone base assembly. *Credit: CCAT Observatory, Inc.*

Principal technician Billy Keim installs a cover plate over the detectors for NASA's Nancy Grace Roman Space Telescope. *Credit: NASA/Chris Gunn*

NASA Completes Heart of Roman Space Telescope's Primary Instrument

by Ashley Balzer, NASA's Goddard Space Flight Center, Greenbelt, Md.

The heart of NASA's Nancy Grace Roman Space Telescope was recently delivered to Ball Aerospace in Boulder, Colo., for integration into the Wide Field Instrument (WFI). Called the Focal Plane System (FPS), it serves as the core of Roman's camera. When the mission launches by May 2027, astronomers will use this system to gather exquisite images to help unravel the secrets of dark energy and dark matter, discover exoplanets and explore many topics in infrared astrophysics.

The FPS is made up of a large detector array and its associated electronics. The detectors were developed by engineers at NASA's Goddard Space Flight Center in Greenbelt, Md., and Teledyne Scientific & Imaging in Camarillo, Calif. The Goddard team also developed the electronics and assembled the FPS. Each of Roman's 18 detectors has 16.8 million tiny pixels, which will provide the mission with remarkable image resolution. Through these "eyes," we will be able to peer through dust and across vast stretches of the cosmos, creating high-resolution panoramas of the universe.

"Roman's focal plane array is one of the biggest that has ever flown onboard a space-based observatory," said Mary Walker, the Roman WFI manager. "Its creation is the product of many years of innovation from a very dedicated team – one that is eagerly anticipating the incredible science Roman will yield."

Once the FPS is installed in the spacecraft's WFI – its camera – technicians will continue the build by integrating the instrument's radiators.

"For optimal performance, the detectors must be operated at -288 °F, or -178 °C," said Greg Mosby, a research astrophysicist and Roman detector scientist. "Roman's detectors are so sensitive that nearby components in the Wide Field Instrument must also be cooled, otherwise their heat would saturate the detectors, effectively blinding the observatory." The radiators will redirect waste heat from the instrument's components away from the detectors out into cold space, ensuring that Roman will be sensitive to faint signals from distant galaxies and other cosmic objects.

After the radiators are installed, Roman's camera will be complete and ready for thermal vacuum tests this summer. The team expects the entire WFI to return to Goddard in spring of 2024, where it will ultimately be integrated into the rest of the observatory.

For more information about the Roman Space Telescope, visit: **roman.gsfc.nasa.gov** or **www.nasa.gov/roman**. To virtually tour an interactive version of the telescope, visit: **https://roman.gsfc.nasa.gov/interactive**.

Scorpius Space Launch Company Showcases Composite Liner-less Tanks for 2023 Lunar Mission

by Markus Rufer, President and CEO, Scorpius Space Launch Company

Scorpius Space Launch Company (SSLC), an all-composite pressure vessels manufacturer based in Torrance, Calif., announced its flight-qualified PRESSURMAXX composite liner-less propulsion tanks are integrated and preparing for launch on Houston-based Intuitive Machines' lunar lander, Nova-C. Intuitive Machines, a space exploration, infrastructure, and services company, is preparing for Nova-C to be shipped to Cape Canaveral, Fla., where it will launch on a SpaceX Falcon 9 Rocket. Nova-C utilizes a liquid methane and liquid oxygen pressure-fed engine. Both propulsion tanks are PRESSURMAXX composite liner-less tanks manufactured by SSLC.

The completely wrapped composite tank which will be inserted in the landing module for the upcoming mission. *Credit: Intuitive Machines*

Wrapping and preparing the Scorpius Composite Pressure Maxx tank prior to next steps. *Credit: Intuitive Machines*

"Years ago, aerospace industry leaders said cryogenic all-composite, liner-less pressure vessels were not achievable, now the same technology, made by SSLC, is supporting Intuitive Machines' mission to the moon," says Markus Rufer, chief executive officer of SSLC. "The rigorous testing and validation affirms the SSLC team's dedication to changing the space launch industry."

Intuitive Machines performed more than 150 different tests on the composite liner-less tanks as part of the development and certification process. "SSLC's PRESSURMAXX composite liner-less tanks have optimized performance on Intuitive Machines' first mission to the moon," says Trent Martin, Intuitive Machines' vice president of lunar access. "The tanks SSLC created weigh significantly less than traditional options, enabling Intuitive Machines to deliver more mass to the lunar surface that will pave the path for humanity's sustainable return to the moon."

SSLC specializes in rocket propulsion components for pressure-fed launch vehicles, including all-composite pressure vessels that have application for spacecraft and rockets as well as many other non-aerospace applications that demand lightweight and very robust pressure vessels. SSLC has sold its PRESSURMAXX cryogenic pressure vessels to more than 20 commercial aerospace customers. As a supplier to aerospace and defense companies, SSLC attained supplier-performance ratings at the highest levels, with its award-winning technology widely recognized throughout the aerospace industry. For customers seeking a broader system solution, such as launching specific payloads into space, SSLC offers full turnkey launch and mission engineering/system design solutions tailored to specific concepts. Its sister company, Microcosm, Inc., specializes in reducing space mission costs and provides end-to-end mission support. Intuitive Machines supplies space products and services to support sustained robotic and human exploration to the moon, Mars and beyond. Intuitive Machines' products and services are offered through its four business units: Lunar Access Services, Orbital Services, Lunar Data Services, and Space Products and Infrastructure. **www.scorpius.com** and **intuitivemachines.com**.


ACME
CRYOGENICS
PART OF OPW | a DOVER company
H2
Hydrogen
HYDROGEN
ENERGY
STORAGE
A ONE-STOP-SHOP FOR MISSION CRITICAL CRYOGENIC SOLUTIONS
Multi-Gas Blenders
Vacuum Jacketed Pipe & Flex Hose
Vaporizers
Final Line Manifold Assemblies
www.acmecryo.com
Copyright © 2022 Acme Cryogenics

Air Gases Can Benefit the Environment

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

Overview

The commercial production of oxygen and nitrogen supported the industrial revolution in the late 19th century and up to the mid-20th. Oxy-acetylene cutting and welding were important for projects like the Eiffel Tower, the Panama Canal and the Central Valley Project Corporation hydropower plants. Oxygen, nitrogen and argon refined steelmaking and metal heat treatment, from Bessemer steel converters to cryogenic tempering. Food conservation has benefited from nitrogen, argon and CO_2 with the controlled atmosphere conservation of produce.

Since the 1980s, higher purities and lower power consumption have been sought, challenging the conventional designs of air separation units (ASUs). Air gases have transformed the paper industry, ore smelting, glass plants, medical and oil refineries. With the increasing demand across industry sectors, oxygen and nitrogen have become commoditized and are now commonly used in home care, welding, food, and, for a while, water treatment.

Over the last 30 years, the pharmaceutical and semiconductor industries pushed the envelope for producing ultrahigh purity gas requirements further. Gas analyzers could not even keep up with the new air separation plants producing at the part-per-billion purity level. Simultaneously, extra-large air separation plants with capacities above 2,000 tons of oxygen per day were developed to serve the energy and chemical industries, such as coal-to-liquid, gas-to-liquid, and various gasification processes for producing liquid fuels, chemicals and electricity. The world's largest air separation plant in the world today was commissioned in 2016 and produces 5,000 metric tons per day of oxygen.[1] Restraints to the cryogenic oxygen and nitrogen market entail small on-site vacuum and pressure swing adsorption plants, membrane generators, and oxygen concentrators for home care.

500-ton-per-day, 1981 cryogenic oxygen plant with reversing exchangers. *Credit: Nils Tellier*

The global market growth valuation for air gases[2] is:

	2020-2022	2027-2029	CAGR (approx.)
Oxygen	US$35.5 billion	US$55 billion	11.4%
Nitrogen	US$35 billion	US$57.8 billion	10.4%
Argon	US$387.6 million	US$577.9 million	5.12%

Killing a Gentle Giant

Air separation plants, particularly cryogenic plants, are large power and energy consumers. A cryogenic plant producing 1,000 tons of oxygen per day can consume the same monthly energy as 8,000 homes and uses the same power as 2,400 homes. However, the power consumption of cryogenic plants is very steady, with a capacity factor upwards of 95%, meaning that they operate at a nearly constant power level around the clock. They are an ideal load on an electric grid because they guarantee a constant utilization of the transmission network and provide a steady and predictable base load for electric generators.

Cryogenic ASUs require steady-state operations, 24/7 year-round, because of the fractional distillation process. Although ASUs can turn down their production and power consumption to some limited extent, it can take hours to ramp up and stabilize the plant. If attempting to reduce power below a certain threshold, typically around 60% of the design production, the distillation columns will suddenly dump their liquid inventory and the plant will shut down on a fault. Another cause for a plant trip is a power blackout, however short. Restarting the plant, attaining product purity and resuming production takes several hours to a day, significantly stressing the operators on shift. On the contrary, gas liquefiers are fast to start and shut down because they do not have distillation columns.

The cost to produce oxygen is largely based on electricity, and the steady operation and high capacity factor were advantageous to electric utilities. With the deregulation of electricity and the transition to regional transmission operators and independent system operators such as MISO and CAISO, the cost of market electricity has become variable, even volatile.

The surge of intermittent renewable generation, such as wind and photovoltaic solar, has lessened the grid's ability to maintain capacity (frequency and voltage firming) by displacing conventional power generation. Grid operators and state regulators have addressed this issue by allowing market electricity prices to vary widely and by encouraging electric loads to follow the pricing trends: when electricity is cheap, increase your consumption, and when it is expensive, reduce it. Figure 1 (on the next page) exemplifies this price volatility with California's Trading Hub NP15 on the Day-Ahead Market between August 29 and September 12, 2022 (divide the price by 10 to obtain cents/kWh).

Unfortunately, this leaves ASUs vulnerable to high energy prices, particularly during evening hours when the sun sets and gas turbines ramp up, since they have very limited turndown capabilities and much operational inertia. Figure 1 shows that oxygen or nitrogen production costs can fluctuate as much as 800% from hour to hour. Consequently, air gas costs become more volatile, affecting many industry sectors. Coincidental factors affecting the air gas industry include the cost of bulk transportation and current supply chain issues for parts.

ASUs do not generate CO_2 except for the carbon footprint of the plant's electricity. So, is the current regulatory approach to energy decarbonization, a nail in the coffin of air separation plants and the industries they serve? Or does it matter, since manufacturing has been offshored since the 1990s anyway?

A New Challenge

Are ASUs bad for the environment? Or are they collateral damage by environmental regulations? From Antofagasta, Chile, to Eureka, CA and across the globe, air gases have performed environmental miracles with the paper, glass, and mining industries. Oxygen has successfully displaced or mitigated chlorine and sulfur emissions and reduced NOx from furnaces while allowing client industries to improve recoveries, improve air quality and reduce emissions. Even liquid nitrogen converts piles of used tires into shoes and road-silencing substrates. Strawberries, pears, and green beans are available year-round in the supermarkets. Lithium, which combusts spontaneously in the air, can be safely recycled from used electric vehicle batteries under argon blanketing.

Today, the air separation industry is at a new crossroads. It is not the time to look back and ask for recognition. That ship has sailed with the commoditization of gases. The new challenge going forward is to partner with energy decarbonization while evolving into nimble operations that can absorb the volatility of energy prices and availability. This is a tall order because nothing is cheap in cryogenic equipment.

What is the future of air separation, of ASUs capable of fast operation flexibility, participating in demand response without affecting production, and even perhaps running off the electric grid? Is the time ripe for scaling up Sterling acoustic liquefiers and expecting more from adsorbents? RIX Industries (CSA CSM, Benicia, Calif.) must think so with their advanced liquid oxygen plant producing LOX within 20 minutes of a warm start. This small air separation plant no longer uses fractional distillation. Still, the flexibility of operation and fast start comes

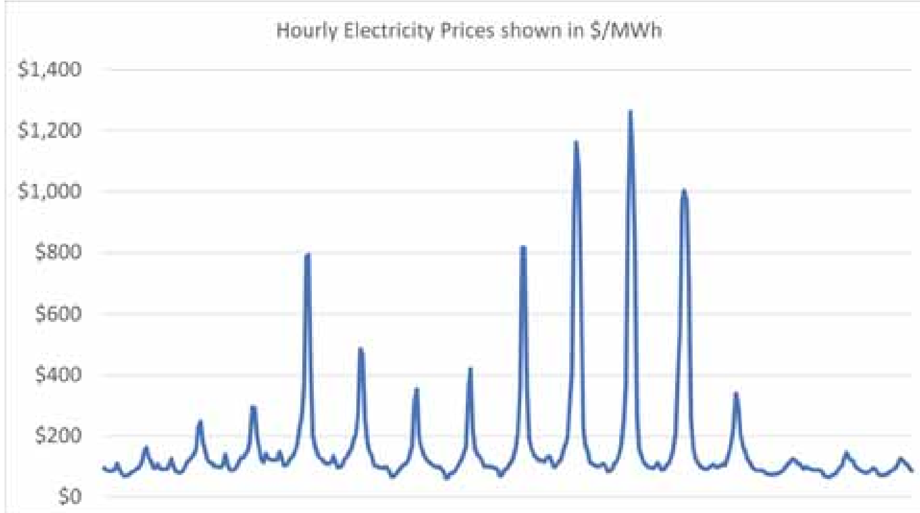


Figure 1: California TH_NP15 hourly price of electricity between August 28 and September 12, 2022. *Credit: EPSIM Corp.*

Removing an ASU cold box. *Credit: Nils Tellier*

Advanced LOX plant. *Credit: RIX Industries*

at the cost of product purity and production capacity.

NET Power is developing its serial number 1 (SN1) utility-scale project, which combusts fuel with oxygen instead of air and uses supercritical carbon dioxide as a working fluid to drive a turbine instead of steam. This eliminates nearly all emissions, including air pollution and CO_2, and inherently produces pipeline-quality CO_2 that can be sequestered, all while operating at competitive costs and efficiencies compared to traditional gas power plants.[3]

We are not talking about painting the plants green and adding a few solar panels for PR. Turning the PURPA-1978 adage of "combined heat and power" to "combined cooling and power," Liquid Air Energy Storage (LAES) shows the promise of storing significant amounts of energy in a small footprint with a roundtrip efficiency near 50% when accounting for the massive cooling potential for server farms, cold storage facilities, and even small river streams. Despite three years of drought in California, hydropower plants had to be bypassed for river temperature control for two months in 2022. The price to pay was 15,000 MWh of carbon-free hydroelectric generation forfeited, US$1.4 million of electricity revenues not realized, and 11,760 tons of additional CO_2 emissions from replacement generation. Is this a shining opportunity for LAES? Absolutely! But who should take the initiative? Not the national labs, which are focused on lithium-ion battery technology. 2023 is a wet year, and all the reservoirs had filled up in California by March. The Bureau of Reclamation and the Department of Energy lost interest in LAES as early as April 2023. Still, the opportunity is real for the cryogenic industry, and the Inflation Reduction Act may provide financial feasibility to what used to be just great ideas.

References

[1] Air Liquide Sasol T17 plant.

[2] GlobeNewswire's Market Study Report

[3] www.netpower.com.

Electrifying Space: Zenno's Fuel-Free Satellite Pointing System Achieves Milestone

by Sandra Lukey, Zenno Public Relations

New Zealand headquartered spaceflight systems company Zenno Astronautics (Zenno) announced that it reached a production milestone for its world-first superconducting magnetorquer for spacecraft attitude control, the Z01™. Zenno is building life in space, revolutionizing space movement through the untapped energy of super magnets. This flagship satellite control system super torquer technology enables fully autonomous and fuel-free satellite positioning and precision interactions between satellites. Built on Zenno's proprietary superconducting magnet technology, Z01™ radically changes how spacecraft navigate space and their impact on our planet at a fraction of the size and weight of traditional technology. With sales surpassing 48 million US dollars, Zenno reached a major milestone in sales in under a year. This revolutionary satellite pointing system is designed to significantly increase the range of capabilities for attitude control in space, including fully autonomous satellite positioning and extended satellite orbit time.

Zenno CEO and Co-Founder Max Arshavsky (left) and Chief Revenue Officer Erica Lloyd with Z01™, the world's first superconducting magnetorquer for spacecraft attitude control. *Credit: Zenno*

Zenno CEO and co-founder Max Arshavsky says achieving the sales milestone for Z01 in under a year "demonstrates that the global space industry is embracing innovative technology that solves a real problem." The Zenno invention enables higher performance in satellite design and function, offering benefits well beyond the constraints of existing technologies. Alarming in its simplicity, the Z01's pointing capabilities unlock new opportunities and new services in orbit by enabling better imagery and communications and offering the benefit of more time in space.

"Z01 is the world's most advanced spacecraft pointing technology and operates like a sustainable magnetic sail or electric vehicle in space – addressing the challenges of moving objects in space while reducing the impact on the planet. Z01 radically enhances sustainability, reliability, and accuracy as it is fuel-free, harnessing magnetic forces and solar for spacecraft control," says Arshavsky.

Zenno is planning to launch its first full-scale Z01 attitude control system in late 2023. The innovation is the first of several that the six-year-old company is bringing to market to support its mission to build life in space.

Getting an ever-increasing number of satellites into orbit is only half of the equation; satellites require persistent shifts to ensure their antenna, sensors, solar panels and more are facing the correct directions. Zenno's breakthrough Z01 super torquer consumes electricity only and does not require on-satellite fuel consumption for satellite control in orbit. In contrast, existing propulsion systems that enable these movements require fuel until a satellite's mission ends. Powered by solar panels, Zenno's Z01 on-satellite hardware uses cryogenically cooled high temperature superconductors to generate strong magnetic fields, which interact with the Earth's geomagnetic field, allowing the satellite to rotate and shift.

Attitude control systems are one of the largest and heaviest subsystems on a satellite. Yet, Z01 is significantly smaller and lighter than existing attitude control technologies. "Small is significant when it comes to satellites, as it reduces launch costs and creates radical new possibilities for spacecraft design and deployment. With a mass of around 4 kg, Z01 is around one-tenth of the weight of traditional torquers that perform similarly," Arshavsky adds.

"As we can control and maneuver spacecraft, additional services can also be provided that will open up new opportunities in the future, such as debris removal, construction and servicing in space. We are working on a range of innovations that use Z01 as a base technology and will together form solutions to enable the space industry to thrive in the long term." **www.zenno.space**.

Lake Shore CRYOTRONICS

CryoComplete

Everything you need to make temperature-dependent, low-level electrical measurements from **77 K to 500 K**

- Complete measurement system
- Optimized full signal path
- Quick lead time

LN_2 cryostat

The Environment by Janis VPF-100 sample-in-vacuum cryostat provides a variable-temperature sample environment from 77 K to 500 K. The pour-fill design allows quick and easy LN_2 refills.

PC with MeasureLINK™

Enables a wide range of capabilities, including data charting, instrumentation control, and system monitoring with a cryostat-specific process view.

Source + measure + lock-in

Run ultra-low-noise AC/DC measurements with the MeasureReady® M81-SSM synchronous source measure system. It includes a balanced current source module and a DC/AC/lock-in voltmeter module with a combined noise performance (differential) of 4.1 nV/√Hz.

Temperature controller + sensor

Control temperature within 50 mK with our Model 335 temperature controller, precision calibrated diode, and a pre-wired heater. Default cryostat tuning enables fast setup and operation.

1+ 614.891.2243

lakeshore.com/cryocomplete

Analyzing Transcritical CO_2 Compression and Pumping Pathways

by Matt Taher, P.E., Bechtel Energy Inc., Houston, USA

Supercritical carbon dioxide exhibits anomalous behavior in the vicinity above the critical point. The Irish physical chemist Thomas Andrews (1863) was the first who studied the supercritical behavior of carbon dioxide. He explained his observations of the fluid state above the critical point as follows:

"...the surface of demarcation between the liquid and gas became fainter, lost its curvature, and at last disappeared, the tube being then filled with a fluid which, from its optical and other properties, appeared to be perfectly homogeneous [T. Andrews, Jan. 1870]".

Unlike what was perceived by Andrews, thermodynamic properties of a supercritical fluid are not homogeneous as confirmed by inelastic X-ray scattering measurements and molecular dynamics simulations, so that liquid- or gas-like regions can be further extended beyond the critical point to the supercritical region. As shown in Figure 1, the transition from gas-like to liquid-like in a supercritical fluid occurs during passing through the coexistence frontier in a so-called "Widom region,"[1] which was first identified experimentally by Nishikawa and Tanaka.[2]

Another salient feature of supercritical CO_2 is that its response functions (i.e., change of isobaric heat capacity, to change in temperature or pressure) increase sharply in magnitude in the neighborhood above the critical point. As shown in Figure 2, the isobaric heat capacity of pure CO_2 at 79.25 bara and 35 °C changes by approximately 29.6% as pressure increases by only 0.5 bar.[3]

The carbon dioxide compression process that involves compressing CO_2 in the gas phase to the supercritical phase is 'transcritical,' for example, with subcritical low-side and supercritical high-side pressure. Similarly, transcritical CO_2 pumping involves pumping subcooled liquid CO_2 to high-pressure dense fluid CO_2.

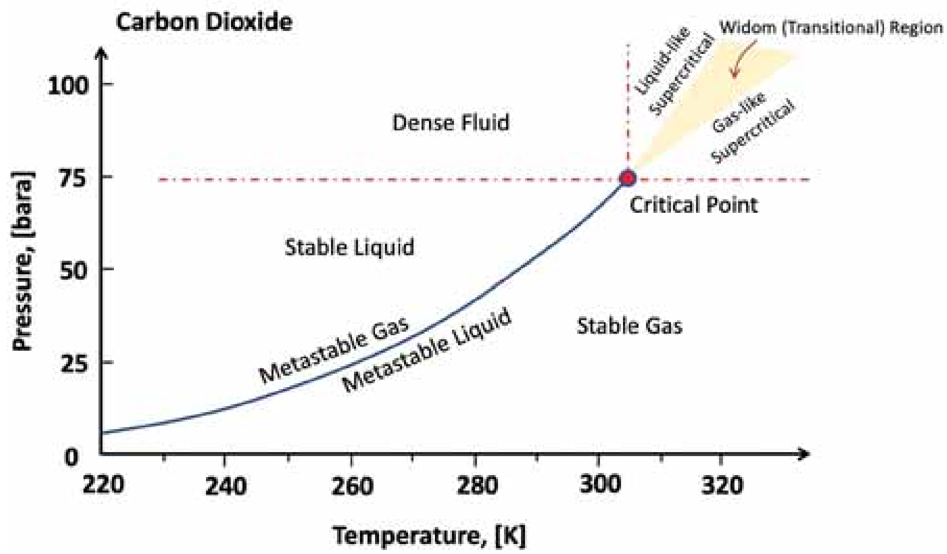


Figure 1: Phase diagram of carbon dioxide above and in the vicinity of the critical point showing the dense fluid, liquid-, gas-like supercritical and the transitional (Widom) region. *Credit: Matt Taher, P.E.*

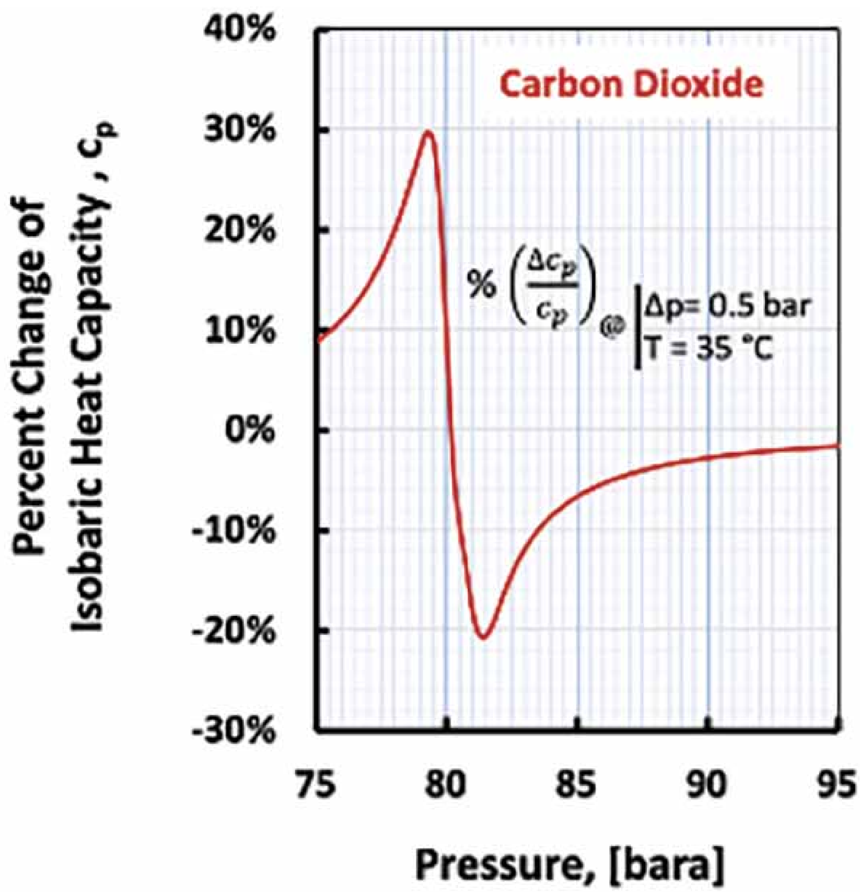


Figure 2: Sensitivity of isobaric heat capacity, c_p is examined for 0.5 bar change of pressure at a constant temperature of 35 °C across a range of pressures above the critical point of pure CO_2[3]. *Credit: Matt Taher, P.E.*

As shown in Figure 3, three different pathways can be considered for a transcritical carbon dioxide compression. The choice of these different pathways impacts on the selection of compression equipment, plant layout, operational flexibilities, control methods and the overall efficiency of the transcritical CO_2 compression process.

The Pathway A: Transcritical Compression Only

The Pathway A includes multiple stages of compression, from a low pressure in the gas phase to a high pressure in the supercritical phase and followed by the supercritical after-cooling to dense fluid conditions. This method of transcritical CO_2 compression can be achieved using inline (between bearing) multistage centrifugal compressors, integrally geared centrifugal compressors or reciprocating compressors. The heat of compression in the gas phase is removed using interstage coolers.

The maximum flow rate of a low speed, lubricated reciprocating compressor in a transcritical CO_2 compression service is limited to approximately 270 am^3/min [9,500 ACFM] with two manifolded cylinders at the inlet. Centrifugal compressors may be utilized at higher flowrates. The Pathway A in Figure 3 is based on using an 8-stage integrally geared centrifugal compressor that elevates CO_2 pressure from 1 bara to 150 bara. Five intercoolers are used in the subcritical region to keep the inlet temperature of the first six stages at 40° C. An aftercooler is used to cool down the supercritical CO_2 at 150 bara and 165° C to the final dense fluid temperature at 40° C.

The Pathway B: Transcritical Compression and Dense Fluid Pumping

The Pathway B utilizes a similar process as The Pathway A does until the CO_2 pressure is elevated above the critical point; then the supercritical CO_2 is cooled down to a dense fluid state and is pumped to the final pressure using a multistage centrifugal pump.

Thermophysical and transport properties of CO_2 abruptly change at thermodynamic conditions slightly above the critical

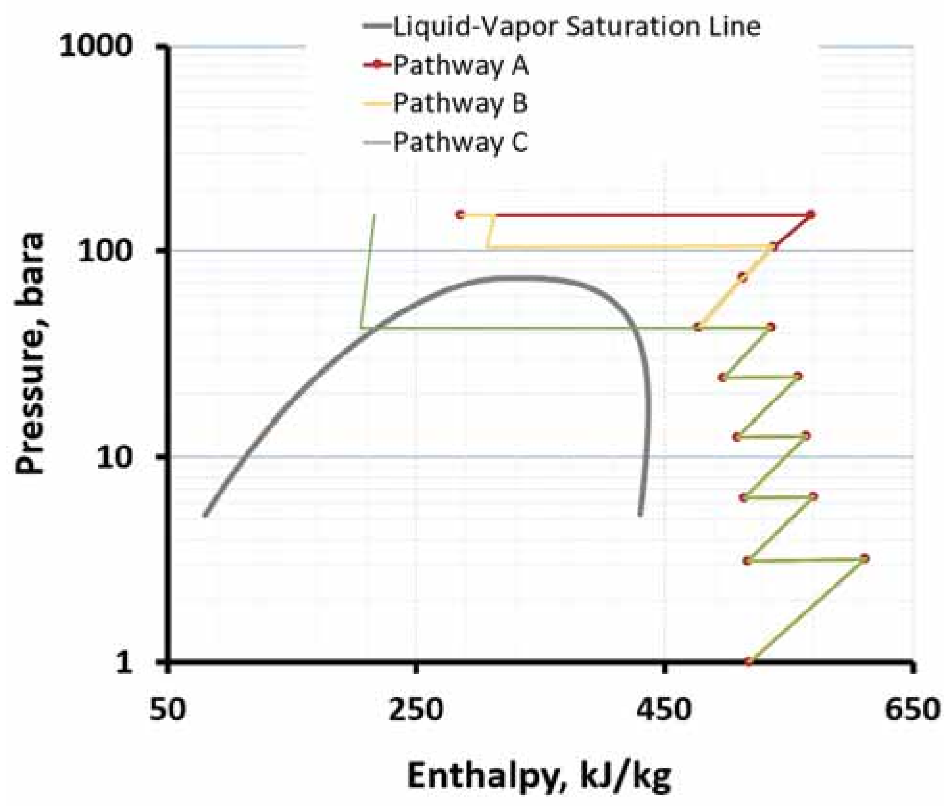


***Figure 3: Three possible transcritical CO_2 compression pathways from 1 bara to 150 bara.**[3] Credit: Matt Taher, P.E.*

point. Therefore, a proper margin must always be maintained from the critical point in the supercritical region.

The Pathway B in Figure 3 is based on using the same first seven stages of the integrally geared compressor of The Pathway A to reach the discharge pressure of 105 bara. After cooling down the supercritical CO_2 to 40 °C, a multistage centrifugal pump is used to increase the pressure of dense CO_2 fluid to 150 bara. Over 50% saving in the compression work of the last stage can be achieved by replacing the last supercritical stage of the integrally geared compressor in The Pathway A with a multistage centrifugal pump in The Pathway B, which accounts for approximately 4% of the overall compression work in this example case.

A large differential pressure (e.g., >80 bar) for the pump is usually required to achieve a meaningful saving in the overall compression power. However, a large differential pressure in the CO_2 dense phase results in a high change of density (i.e., large compressibility) and impacts on the hydraulics and selection of dense fluid CO_2 pumps. The selection of pump inlet conditions, which defines the inlet density, impacts on the hydraulic performance and rotordynamic behavior of CO_2 pumps in The Pathway B applications.

The Pathway C: Subcritical Compression, Liquefaction and Transcritical Pumping

The Pathway C involves subcritical CO_2 compression in the gas phase followed by CO_2 liquefaction and then pumping subcooled liquid CO_2 to a final pressure as a dense fluid. The CO_2 liquefaction can be performed either by employing an external refrigeration process using ammonia or light hydrocarbons as refrigerants or by an internal refrigeration process using the CO_2 feed as the refrigerant. Unlike The Pathway B, centrifugal pump hydraulics design for The Pathway C is very similar to that of conventional centrifugal pumps, as pumping of subcooled liquid CO_2 follows a quasi-isochoric process. For instance, the change of density in the liquid phase of CO_2 from 42 bara at -20 °C to 150 bara at -15 °C is approximately 0.5%.

▶ *continues on page 20*

 Continued from page 19

The Pathway C shown in Figure 3 is based on using the same first five stages of the integrally geared compressor of The Pathway A to reach the subcritical pressure of 42 bara. Using a liquefaction system, CO_2 is liquefied and then subcooled liquid CO_2 is pumped using a multistage centrifugal pump to the final discharge pressure of 150 bara as a dense fluid. Over 70% savings in the compression work can be achieved by replacing the last three transcritical stages of the integrally geared compressor in The Pathway A with a multistage centrifugal pump in The Pathway C, which accounts for approximately 19% of the overall compression work in this example case. To evaluate the overall energy consumption of The Pathway C, the energy consumption for the CO_2 liquefaction process must be added to the compression work. CO_2 liquefaction is an energy-intensive process, and lowering energy consumption is a key factor in system design.

Matt Taher is a Bechtel distinguished technical specialist, who works as a turbomachinery advisor for the LNG technology center of Bechtel Energy Inc. in Houston, Texas. His experience covers various applications and types of turbomachinery in carbon Capture and LNG processing operations. Mr. Taher is a registered professional engineer in the state of Texas and is a Fellow of the American Society of Mechanical Engineers.

REFERENCES

[1] Widom, B., 1972, “Phase Transitions and Critical Phenomena,, Vol. 2 (eds Domb, C. & Green, M. S.).

[2] Nishikawa, K., Tanaka, I., 1995, “Correlation lengths and density fluctuations in supercritical states of carbon dioxide.” Chem. Phys. Lett. 1995, 244, 149-152.

[3] Taher, M., 2022. “Carbon Capture: CO_2 Compression Challenges and Design Options,” Proceedings of the ASME Turbo Expo 2022, Rotterdam, the Netherlands, Paper number: GT2022-82209.

Emerson Launches Industry's First Transcritical CO_2 Solution

by Michelle Crawley, Michelle.Crawley@TriComB2B.com

Emerson, a global technology and software company, announced an expansion of its CO_2 compression portfolio with the development of the company's first transcritical CO_2 screw compressor, purpose-built for the rigors of high-pressure industrial CO_2 refrigeration. The new Vilter transcritical CO_2 compressor — developed in response to increasing industry demand for sustainable, safe and reliable CO_2 refrigeration technologies — will complement the new Vilter subcritical CO_2 compressor to comprise a full transcritical CO_2 compression solution. The subcritical CO_2 compressor is available for sale today; the transcritical CO_2 compressor will be available for sale later this year.

The new CO_2 portfolio is designed to answer the industry's call for industrial-grade CO_2 refrigeration solutions. Hydrofluorocarbon (HFC) refrigerants continue to be phased down by global regulatory efforts, while increasing occupational safety requirements are impeding the use of ammonia. As a result, industrial operators are exploring eco-friendly alternatives to legacy HFCs and seeking safer, ammonia replacements. Although CO_2 offers an ideal combination of sustainability, high-performance and safety, the industrial refrigeration market has lacked a suitable CO_2 compression solution. To date, CO_2 refrigeration technologies have been based on commercial-grade, multi-compressor strategies, which have been proven overly complex and less reliable under harsh industrial conditions.

"Building on our legacy of innovation, we have engineered the industry's first transcritical CO_2 screw compressor – built for heavy-duty industrial requirements and rated for CO_2 transcritical pressures," said Gary Chafee, business development manager – industrial CO_2 solutions, for Emerson's climate technologies business. "The new Vilter Transcritical CO_2 compressor is based on proven single-screw compression technology and features a complete packaged solution, including an on-board controller, suction valve/strainer,

Vilter transcritical CO_2 skid with screw compressor. *Credit: Emerson*

inverter duty motor and an oil management system. In addition, the transcritical CO_2 compressor is built for maximum flexibility, capable of scaling from single-, dual- and tri-compressor configurations per capacity requirements, all while utilizing the same oil management system and controller."

The new transcritical CO_2 compressor is designed for the high stage of a CO_2 transcritical system and is engineered and rated to withstand CO_2's high pressures in transcritical mode. It will be available in seven displacements with a power range from 100 to 800 horsepower per compressor, up to 1600 HP in dual configuration and 2400 in tri-configuration. The subcritical CO_2 compressor is designed for the low side of CO_2 transcritical or cascade systems and is available in 11 displacements with a power range from 100 to 800 horsepower per compressor. **www.emerson.com**

A Closer Look at Large-Scale Helium Systems, Comparing Refrigeration and Liquefiers

by Maria Barba, Cryogenic Engineer, Fermilab

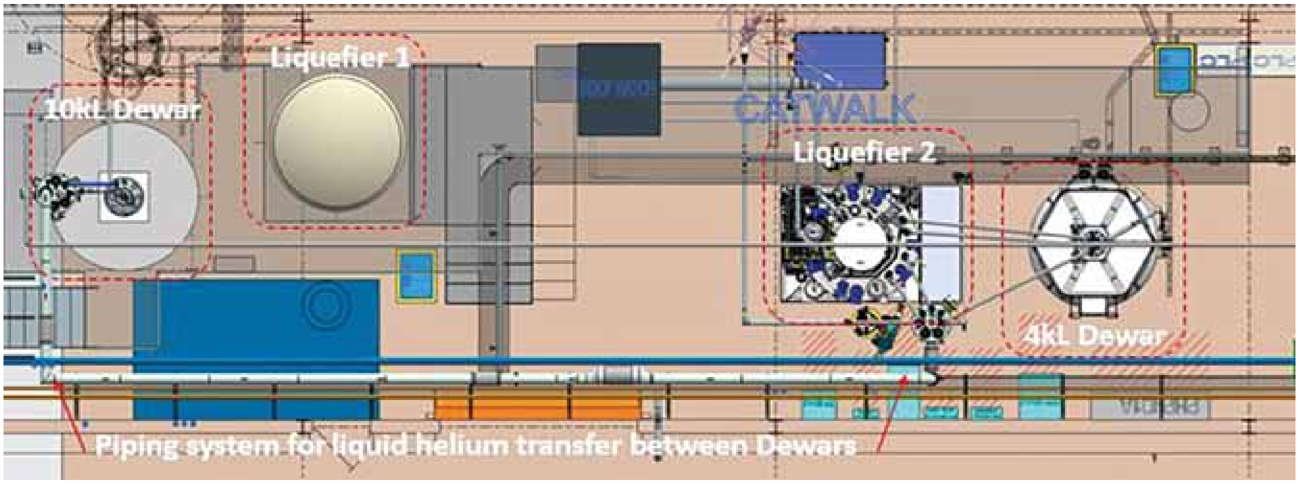


Illustration courtesy of Maria Barba, Fermilab.

Cryogenics is the area of physics covering the production of low temperature environment and the study of physical effects at these temperatures. Its use covers a wide range of applications, such as electronics, medicine, physics and rocketry. It is indispensable to take advantage of the superconducting properties of certain materials, only attainable at cryogenic temperatures.

This large variety of applications is due to the different available cryogenic fluids, such as helium, hydrogen, nitrogen, oxygen, argon, etc., reaching their liquid state at different temperatures. Due to the different properties of the mentioned fluids, the technology necessary to liquefy these fluids can vary from one to another. This article focuses on large-scale helium systems, as an example of a cryogenic system.

Large-scale helium systems can be used as refrigeration systems, a closed system where the same amount of helium constantly circulates, or they can be used as liquefiers, where helium is liquefied and then distributed to be used in other systems. The required low temperature cooling is made by at least two gas-bearing expansion turbines and is often enhanced by a precooling step at 80 K with liquid nitrogen.

A good example of a large-scale helium system is the helium cryogenic plant operating at the IB-1 Cryogenic Test Facility at Fermilab. The plant is composed of two cryogenic liquefiers able to provide more than 300 L/h each. Each liquefier is linked to a compressor station for high pressure helium supply (two Mycom compressors providing up to 120 g/s for one liquefier and one Sullair compressor providing up to 200 g/s for the other liquefier). Each liquefier also has its own dewar for liquid helium storage, providing a total storage capacity of 14,000 l. Furthermore, both liquid helium dewars are connected through a piping system to the different test stands to provide liquid helium and support testing activities involving superconducting magnets and cavities. In addition, the two liquid helium dewars are connected together through a secondary piping system that allows the transfer of liquid helium from one dewar to the other by just setting a pressure difference between both dewars higher than 0.2 bar. This allows the refill or empty of one or the other dewar at any moment and easily adapts to the helium needs of the test stands. Finally, the entire cryogenic facility is handled by a single common inventory control system, composed of three regulatory valves (high pressure valve, low pressure valve and bypass valve), and nine storage tanks, giving a total buffer volume of more than 1,000 m^3. All the mentioned components are connected in a closed loop where the gas helium is initially compressed at the compressors, then liquefied in the coldboxes and transferred to the liquid helium storage dewars from where it is distributed among the different test stands and finally vaporized again. Then the gas helium is either sent to the buffer tanks for storage or sent back to the compressors, closing the loop and avoiding helium losses as much as is possible.

Adding a second coldbox to the IB-1 Cryogenic Test Facility, as well as connecting both liquid helium dewars for operations, has been part of a recent upgrade of the IB-1 Cryogenic Test Facility necessary due to the exponential increase over the last years of the testing activities related to superconducting quantum materials, SRF cavities for the PIP-II and the LCLS-II projects, as well as superconducting magnets for the HL-LHC project and fusion research activities.

Adding a second coldbox to the IB-1 Cryogenic Test Facility, as well as connecting both liquid helium dewars for operations, has been part of a recent upgrade of the IB-1 Cryogenic Test Facility necessary due to the exponential increase over the last years of the testing activities related to superconducting quantum materials, SRF cavities for the PIP-II and the LCLS-II projects, as well as superconducting magnets for the HL-LHC project and fusion research activities.

Skyroot Aims to Make Space More Accessible with Revolutionary Engine, Lower Costs

Skyroot has been working on a more powerful model, unveiling to the public the new and improved Dhawan-II, which is said to have successfully completed testing.
Credit: Skyroot Aerospace

Skyroot Aerospace, an Indian company, is dedicated to democratizing access to space by pushing the boundaries of technology. It aims to integrate space into our daily lives, which will have transformative effects on humanity. In 2020, Skyroot Aerospace introduced the 3D-printed cryogenic engine, Dhawan-I. Now they have unveiled the improved Dhawan-II, which has successfully completed testing. The engine, like its predecessor, is 3D printed and utilizes liquid natural gas and liquid oxygen as propellants. The tests took place at Solar Industries' propulsion test facility in Nagpur, India. This development comes amidst a surge in 3D printing projects in the aerospace sector, including Relativity Space's 3D-printed rocket and NASA's RDRE, a full-scale rotating detonation rocket engine. Skyroot Aerospace's engine will be used in the Vikram-II spacecraft, enhancing its payload capacity. The Dhawan-II engine boasts a maximum thrust of 3.5 kN and endured 200 seconds of testing.

Pawan Kumar Chandana, co-founder and CEO of Skyroot Aerospace, expressed pride in the company's achievements and the potential of advanced technologies such as 3D printing and green thrusters. "The successful testing of the Dhawan-II engine is a landmark achievement for Skyroot and the Indian private space sector," said Chandana. "We are proud to be at the forefront of developing advanced cryogenic technologies and pushing the envelope with technologies such as 3D printing and green thrusters." Skyroot Aerospace aims to conduct its first orbital flight with the Vikram-I rocket by the end of the year, followed by the launch of Vikram-II with the 3D-printed cryogenic engine in 2024.

Skyroot's ambitions extend to a satellite launch in 2023, aiming to reduce launch costs by 50% compared to its competitors. Skyroot has raised $68 million to fund its next two launches and has engaged 400-plus potential customers. The demand for small satellite launches is expected to increase in the coming years as companies seek to expand broadband services and enhance various applications. Skyroot faces competition from other rocket launch rivals in countries like China and Japan, but the company's cost-effective approach and government backing have garnered investor confidence. The Indian government's support, along with regulatory reforms and the establishment of a new agency, has enabled private space companies like Skyroot to emerge. The company aims to build rockets at a fraction of the current industry costs by leveraging carbon fiber components, 3D-printed parts and efficient engineering practices. With a focus on cost efficiency and technological innovation, Skyroot is inspired by the success of SpaceX and envisions a future where space commerce is economically viable for all. **https://skyroot.in**
Source: Skyroot

Linde's Sustainability Initiatives Advance Carbon Reduction, Clean Energy Solutions

Linde's FLEXASU plant in Denmark, designed to operate and store products when wind energy is abundant and less costly, meets the entire demand for Denmark. *Credit: Linde*

The MF Hydra, powered by fuel cells, has successfully completed sea trials and is now in commercial operation. *Credit: Norled*

Linde, a global industrial gases and engineering company, has recently made significant progress with various decarbonization-focused projects. As a prominent player in the industrial gases and engineering industry, Linde is actively driving the clean energy transition. The company's focus on hydrogen technologies and infrastructure allows Linde to support customers across various sectors in decarbonizing their operations. Linde's commitment to sustainability is evident in its projects, technology developments and efforts to expand its hydrogen business.

In Beaumont, Texas, Linde will build, own and operate an on-site complex which will include autothermal reforming with carbon capture, plus a large air separation plant to be integrated into Linde's extensive Gulf Coast industrial gas infrastructure. It will supply clean hydrogen and nitrogen to OCI's 1.1 million ton-per-annum blue ammonia plant, the first greenfield blue ammonia facility of this scale to come onstream in the US. Linde will supply OCI with clean hydrogen by sequestering more than 1.7 million metric tons of carbon dioxide emissions each year.

Linde has also signed an agreement with Heidelberg Materials, one of the largest building materials companies worldwide, to jointly build, own and operate a large-scale carbon capture and liquefaction facility. The project aims to reduce carbon emissions at Heidelberg's Lengfurt plant in Germany. The new facility will capture, liquefy and purify about 70,000 tons of CO_2 per year. Linde will market the resulting liquid CO_2 as feedstock for the chemicals and food and beverage industries.

In Norway, Linde has commenced the supply of liquid hydrogen to Norled, a ferry operator, for the world's first operational hydrogen-powered ferry called *MF Hydra*. Linde not only provides clean hydrogen but also developed, built and installed the fuel containment system, onshore truck-to-ship bunkering facility, onboard storage tank and fuel processing equipment. The MF Hydra, powered by fuel cells, has successfully completed sea trials and is now in commercial operation. This project marks an important milestone in the maritime sector's transition to zero-emission fuels, showcasing the potential of hydrogen in decarbonizing shipping.

In contrast to traditional ASUs, which are designed for continuous output, Linde has developed a new generation of air separation units (ASUs), FLEXASU®. The designs allow operation and storage of gases when energy is abundant and less costly, and turndown of production when energy is less abundant and more costly. The company's FLEXASU plant in Denmark has a daily output of 470 tons of industrial and liquid oxygen, medical oxygen and liquid nitrogen – enough for Linde to meet the entire demand of the Danish market. While making best use of wind energy, this design has also dramatically reduced the transport emissions previously released to source these products from Sweden and Germany.

By providing high-quality solutions, technologies and services, Linde is making its customers more successful and helping to sustain, decarbonize and protect the planet. The company serves a variety of end markets such as chemicals and energy, food and beverage, electronics, healthcare, manufacturing, metals and mining. Linde's industrial gases and technologies are used in countless applications including production of clean hydrogen and carbon capture systems critical to the energy transition, life-saving medical oxygen, and high-purity and specialty gases for electronics. **www.linde.com** *Source: Linde*

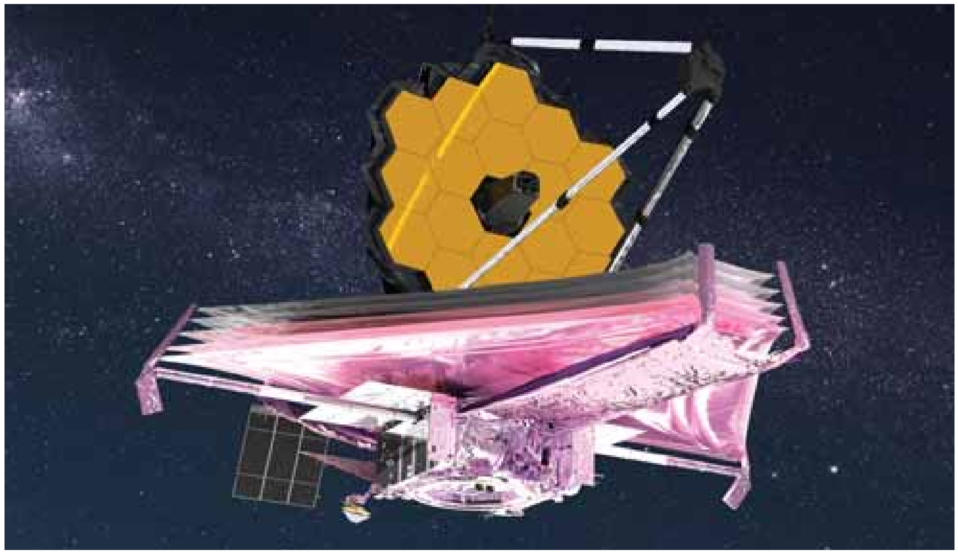
Space Cryogenics

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

Goddard Goings: Insight Into Its Past, Present and Future

James Webb Space Telescope

"I'm Back in the Saddle Again!" – It's likely anyone reading this article has heard about the James Webb Space Telescope (JWST). The telescope launched on December 25, 2021 (EST) with much fanfare. Over the next month, it traveled to its observation location at the L2 Lagrange point in the earth-sun gravitational system. It has been sitting comfortably at this saddle point for well over a year. Cooling of the instrument didn't wait until reaching this point. Oh no, this began shortly after the launch from the spaceport in French Guiana because the majority of the telescope was cooled passively via thermal radiation to outer space.

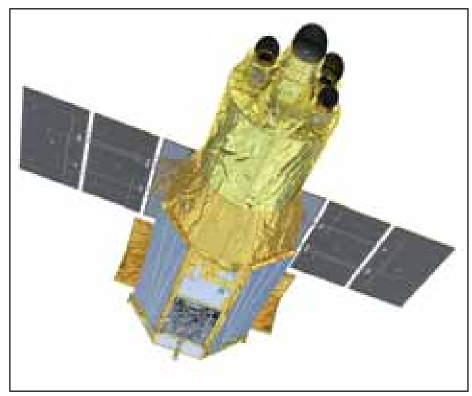


The slow cooldown of JWST's MIRI was intentional because it enabled efficient scheduling of the deployment tasks and ensured the cleanliness of the optics by preventing water and molecular contamination transport. *Credit: NASA GSFC*

By the time JWST reached L2, the coldest part of the observatory was near its ultimate temperature of 30 K. However, the most cryogenic of all instruments on the telescope—the Mid-Infrared Instrument (MIRI)—had only cooled to 155 K. Cooldown to reach the rest of the observatory took another 70 days or so. This slow cooldown was intentional for a variety of reasons. "The cooldown duration and sequencing happened almost exactly to plan, which enabled efficient scheduling of the deployment tasks and ensured the cleanliness of the optics by preventing water and molecular contamination transport," states Brian Comber, a key thermal engineer on the mission.

The thermal model of the telescope was quite accurate. According to Shaun Thomson, the thermal engineering lead for JWST at Goddard Space Flight Center (GSFC), "The time to complete cooldown was only two days longer than predicted (162 vs 160 days)." He goes on to say, "At final steady-state condition, 96% (three-sigma) of all temperature sensors fell within the confidence interval of predicted temperatures." Shaun sums up how well the cooldown of the instrument went: "We staffed to be ready for any contingencies or deviations which may have arisen and that would have pulled off people, potentially leaving us unable to properly monitor the observatory. However, things went so well to plan that we were able to reduce the number of staff. Hard to add people, easy to release people." Brian's summation is a little more colloquial: "We planned for things to go wrong and to need more thermal engineers, but we ended up just watching paint dry by the second half of the cooldown."

About 100 days after launch, the MIRI cooler reached its steady-state operating temperature. MIRI is unique among the instruments on the telescope since it needs to operate near 6 K to achieve its required sensitivity. The whole of the Integrated Science Instrument Module (ISIM) resides near 40 K, and a multistage pulse tube cooler provides the initial cooling below this while a Joule-Thomson cooler completes the task. Regarding performance of the MIRI cooling system, I'll let Kimberly Banks, the GSFC MIRI cryocooler systems engineering lead, have the final say: "A little over a year later and the cryocooler is matching its initial on-orbit performance baseline, allowing MIRI and JWST to continue its amazing science discoveries." Enough said.



After one final round of pre-flight checks and tests, the XRISM satellite will be loaded into the fairing of the rocket; the long-anticipated launch occurs in late August 2023. *Credit: NASA GSFC*

X-ray Imaging and Spectroscopy Mission

"She packed my bags last night, pre-flight. Zero-hour 9 AM." – The satellite that is the X-ray Imaging and Spectroscopy Mission (XRISM) is waiting to be tucked away in the fairing of an H-IIA rocket at the Tanegashima Space Center on the southeast coast of Tanegashima Island, Japan. XRISM is comprised of two X-ray instruments, the Resolve spectrometer and the Xtend CCD wide-field imager. This mission is a multi-national collaboration with major inputs from ESA, JAXA, and NASA.

NASA Goddard contributed the Resolve instrument since the microcalorimeter inside was developed here. It also needs to be cooled to 0.050 K to achieve the sensitivity necessary to detect single soft X-ray photons. This ultralow temperature is provided by a multistage adiabatic demagnetization refrigerator, known colloquially as an ADR. GSFC is a world leader in the design, production and testing of spaceflight ADRs. So the marriage of these two technologies at Goddard is perfect.

The Resolve instrument saw more than ten test campaigns that, when added up, total many months of detector operation at 0.050 K. "Its performance is even better than the precursor, the Soft X-ray Spectrometer on Hitomi." states Michael DiPirro, cryogenics subject-matter expert on XRISM. It also saw vibration tests at the instrument, cryogenic dewar and spacecraft levels of assembly. This testing spanned two continents and a global pandemic; it was not painless. Mike again adds: "We made it through a very harrowing time of finding and fixing a low temperature leak during the height of COVID. Teamwork, logistical support and remote access kept us going through this one -year-plus critical period from March 2020 through April 2021."

There is one more round of pre-flight checks and tests before the satellite is loaded into the fairing of the rocket. After that, the long-anticipated launch will occur in late August 2023. Safe Travels XRISM!

Dragonfly

"Fly me to the moon ..." – Dragonfly, a collaboration between NASA GSFC and Johns Hopkins Applied Physics Laboratory, aims to put a rotorcraft on Titan, Saturn's largest moon. After the craft touches down, it will fly from one location to another, sampling the atmosphere and surface land and seas. This is the first time a science vehicle will fly the entire payload from location to location on another world as it gathers data.

Figure 1: Cartoon representation of oxygen liquefaction test system. *Credit: NASA*

The Dragonfly Mass Spectrometer (DraMS) is currently being developed to identify different kinds of organic material that comprise Titan's surface. The cryogenic engineering team on DraMS is developing an interface between the room temperature rotorcraft body and the near-cryogenic temperatures of an onboard sample chamber, while minimizing the thermal leak to the Titan environment. Pete Barfknecht (GSFC), the cryogenic lead on DraMS, sums it up this way: "The Wonderwall has a bunch of conflicting requirements that have pushed the design to the edges of what's physically possible to manufacture. We're using a lot of 3D printing to make ultralight, dimensionally stable structures while still being able to dump excess heat overboard." This hasn't been easy. "Typically, cryogenic experiments are done in a vacuum environment to avoid convective parasitic heat loads. Operating on Titan gives us the challenge of working in a pressure environment that is 1.5 times that of Earth at 1/7th the gravity along with the difficulty of having to simulate these conditions here on Earth," continues Richard Ottens (GFSC), deputy cryogenic lead on DraMS.

Other instruments aboard Dragonfly include: DraGNS, a gamma-ray and neutron spectrometer to help identify surface composition; DraGMet, a suite of geophysical and meteorological sensors; and DragonCam, a camera that will image Titan's terrain and help guide navigation of the craft. Currently, engineering models of the instruments are being developed alongside the finalization of the rotorcraft design. Dragonfly has a scheduled launch date in 2027 and a touchdown on Titan in 2034.

Cryogenic spaceflight missions are not Goddard's only focus. In fact, you will find a feature article about the Roman Space Telescope in this very issue. Check it out, and thanks for reading!

Cool Cryo Guests

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

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

Tips for Cryogenic Air Separation Units: Safety Aspects of the Condenser/Reboiler

This series of articles aims to provide tips for cryogenic air separation units, particularly in the context of increasing energy costs. This article continues the discussion of the condenser/reboiler of an ASU, focusing here on safety aspects.

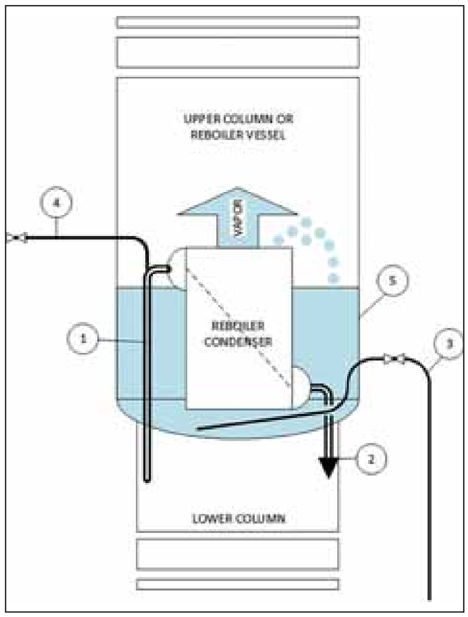


Figure 1: Bath-type Reboiler/Condenser. *Credit: EPSIM Corp.*

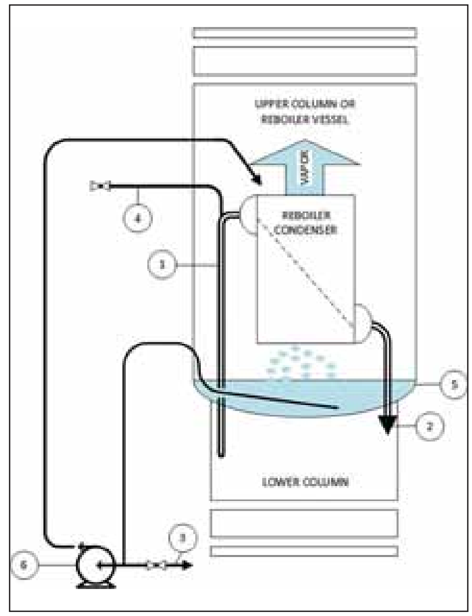


Figure 2: Example of film vaporizer. *Credit: EPSIM Corp.*

Two Types of Reboiler/ Condensers

The reboiler/condenser is a two-stream heat exchanger with the high pressure circuit acting as a thermosiphon and the low pressure side open to the boiling fluid in the column sump. There are two types of reboiler configurations: bath-type and falling film.

Bath-Type Reboilers

In the case of high purity nitrogen generators, argon columns, and pre-1990s oxygen plants, the reboiler is typically immersed in a boiling liquid bath as shown in Figure 1. The exchanger type is either aluminum plate or stainless steel vertical tubes. Heat input from the high pressure condensing fluid boils the liquid bath on the low pressure side.

Numbered items are:

1. High pressure vapor intake to reboiler
2. High pressure liquid discharge from the reboiler
3. Low pressure liquid sump purge (self-draining valve)
4. Non-condensable vent
5. Upper column sump and boiling liquid bath

Falling Film Reboilers

Film reboilers entail locating the exchanger above the liquid bath, with a pump recirculating the low pressure liquid into the reboiler. This type of reboiler/condenser has been deployed in larger air separation plants since the 1990s. It provides superior heat exchange because the low pressure liquid (liquid oxygen) flow is turbulent.

The upper column sump holds just enough liquid oxygen inventory to feed the recirculation pump, but the reboiler exchanger is located above the liquid and does not contact it directly. The recirculation pump takes liquid oxygen from the column sump and pushes it back into the exchanger to condense the high pressure vapor. Falling film reboilers provide superior operational flexibility to bath-type, particularly during plant start-up and production turndown.

Numbered items are:

1: High pressure vapor intake to reboiler
2: High pressure liquid discharge from the reboiler
3: Drain/purge
4: Non-condensable vent
5: Upper column sump and liquid bath
6: Recirculation pump

Reboiler Safety

Most reboiler applications use an oxygen-rich liquid as the low pressure vaporizing fluid. Hydrocarbon accumulation is the highest risk. Fortunately, it can be easily averted.

Hydrocarbons are present in ambient air at a trace level. Although most are removed by the front-end purification or silica gel guard adsorption, as commonly used with reversing heat exchangers, there is always a minute fraction of hydrocarbons that will enter the ASU's lower column and get pushed up to the low-pressure column. Taking acetylene as an example, its freezing temperature is -82 ºC (-116 ºF). It is warmer than the cold box process temperatures, including that of liquid oxygen in the sump of the upper column. Acetylene is brought to the column sump from the falling liquid. The sump of the upper column is the final dead-end destination for hydrocarbons because liquid oxygen is vaporized back up the column. Absent simple safety measures, acetylene and other hydrocarbons can concentrate to dangerous levels in the liquid oxygen.

Hydrocarbon saturation must be considered as a global risk in the liquid oxygen sump and as a localized risk inside the reboiler exchanger. The mechanics are similar, but the circumstances and mitigation methods are different.

To prevent the saturation of hydrocarbons in the liquid oxygen sump, it is necessary to withdraw some liquid oxygen from the column sump by using the purge line illustrated as item 3 in Figures 1 and 2. Liquid supply from the column to maintain the sump level will ensure proper hydrocarbon dilution. Unfortunately, purging some liquid oxygen means losing some production. This is a compromise necessary for the safety of the plant. There may be instances where the purged liquid can be sent to storage, so long as it does not become the point of hydrocarbon concentration. Along with a constant purge, it is critical to monitor the liquid oxygen continuously for hydrocarbons. Likewise, it is necessary to drain the low pressure column sump completely when the ASU is shut down for several days, even if it means a longer restart. These are cardinal rules of ASU operation safety.

At the local level, hydrocarbon saturation can happen from dry vaporization,

Figure 3: Dirt rings in a saucepan, visualizing dry vaporization and hydrocarbon concentration. *Credit: Nils Tellier*

even if the liquid oxygen sump is at a safe level of hydrocarbon dilution. If liquid oxygen vaporizes at a fixed location, hydrocarbons will concentrate gradually at that location. The process is similar to dirt rings accumulating on the perimeter of a saucepan when boiling potatoes, where the dirt impersonates hydrocarbon deposits. Once liquid oxygen comes back in contact with the deposits, a spontaneous explosion can occur.

To mitigate this risk, it is paramount to respect the minimum immersion level for a bath-type reboiler. Figure 1 illustrates the benefit of sufficient immersion with excess liquid droplets overspilling back into the sump. The excess liquid spillover ensures that the exchanger is continuously rinsed.

For film reboilers, a minimum recirculation flow ensures that all exchanger parts are continuously wetted and rinsed, as illustrated in Figure 2 by the excess liquid falling back into the column sump.

These process parameters, minimum immersion or minimum recirculation flow, should be available from the ASU manufacturer or vendor. For further reference, EIGA IGC Doc 65/13E provides detailed guidelines on the safe operation of reboilers and condensers in air separation units.

All valves on oxygen service must be self-draining, as illustrated by item 3 in Figure 1, to prevent the formation of a meniscus and dry vaporization after closing the valve.

On a different note, running a bath-type vaporizer fully submerged in liquid oxygen risks critical or catastrophic mechanical damage to the column trays if the boil-off is strong enough to push liquid upward. It is important to run the bath-type vaporizer at the proper level of immersion.

One more risk worth mentioning is the scarring of aluminum equipment in liquid oxygen service. Aluminum builds a protective layer of oxidation naturally. A loose object, such as a weld bead, can expose a streak of "fresh" aluminum on impact, and liquid oxygen will re-oxidize the exposed aluminum so violently that it can result in combustion/explosion. This concern is particularly valid with film reboilers due to the velocity of the recirculating liquid and the kinetic energy of a foreign particle. Mitigation includes proper cleaning and blowdown after any maintenance activity on the ASU cold box and installing a fine-mesh screen downstream of the recirculation pump. Further references can be found in ASTM G88 and G94 publications.

Feedback and questions to the author are always welcome by emailing nils@epsim.us.

References:

[1] European Industrial Gases Association

Clean Energy Future

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

LH2 for Transportation – Tank Boiloff vs. Transfer Losses

Liquid Hydrogen onboard is moving into transportation for heavy-duty trucks, aircraft, and other vehicles. As a long-time specialist in cryogenic insulation, you'd think I'd be interested in talking about evaporation losses, aka "boiloff." I'm still somewhat interested, but there are bigger problems to solve. In the laboratory, I've built cryogenic thermal insulation systems that give effective thermal conductivity of around 0.015 mW/m-K (or R-value 10,000). This system would be, of course, a type of multilayered radiation shielding operating in high vacuum (below 0.01 millitorr). This same system, at a thickness of only about 25 mm, could limit the heat transmission to nearly 0.5 W per square meter of area. The books are replete with the data.[1] However, great systems design for LH_2 storage and transfer is the starting place and essential ingredient in minimizing heat transmission, while insulation is still an important subingredient to the great design that is necessary for a functional and effective system.

The clean energy future depends on liquid hydrogen – and the moving around, transferring, distributing, servicing and dispensing of that liquid hydrogen. (The vent gas recovery and reuse will also be required at scale.) The liquid hydrogen will be made onsite or trucked in from large-scale centralized plants, as is currently done. For a hydrogen economy in motion, storage is not the problem and boiloff from the tanks is certainly not the main problem. Transfer is the problem at every step of the infrastructure-to-vehicle process.

Tank boiloff depends on the tank size, but let's say it is 1% for a medium-sized 18,000-gallon (68 m³) tank (high-vacuum multilayer insulation system, of course). Transfer losses, on the other hand, start at 10% and just go up from there. A 16,000-gallon (61 m³) tanker that builds pressure up to 20 psig during transit absorbs about 150 MJ of heat. This heat and the corresponding pressure increase translates into venting/losses in the end. Tanker offloads make for net losses of about 13%, according to the history of running thousands of LH_2 tankers from the Gulf Coast plants to NASA Kennedy Space Center for the 30 years of the space shuttle program.[2]

Liquid hydrogen transfer operation showing transition from vacuum jacketed line to uninsulated vent line. *Credit: J. Fesmire*

This situation represents the best-case scenario, as the receiving tanks are always kept vented to atmosphere (0 psig) and do not require blowdown before taking on the liquid. If a receiver tank blowdown is necessary, an additional loss in the range of 10% could be typical. For example, consider a 16,000-gallon tanker offload to an 18,000-gallon receiving tank: the blowdown from 150 psig to 110 psig will waste 337 kg of hydrogen, and the final blowdown of the tanker (assuming 40 K ullage temperature) will waste approximately 571 kg of hydrogen. The total loss is 908 kg, or 21% of the tanker load.

And that is just the beginning–there are more transfers to be made: tank pressurized and transferred to the vehicle; purging of the system after transfer; blowdown of the vehicle tanks and so on. Altogether, these losses could stack up to nearly 50%.[3] In the end, for the perhaps $40,000 tanker load you paid for, half of it went up in smoke. But it doesn't have to be this way any longer.

Technologies and techniques are here today to dramatically mitigate these losses. In fact, the potential exists to create closed-loop infrastructure architectures, eliminating losses across the entire process. The energy-carrier nature of hydrogen (electric power or combustion) makes these ideas practical and economical. The way transfer was done in 1965 is the way it is being done in 2023. But now we have the motivation and need that did not exist before: closed-loop, zero-loss systems for the end-to-end servicing of aircraft and heavy trucks with sporadic schedules and on/off-duty cycles. These types of 24/7 demands are just emerging, and modern servicing systems and methodologies are needed. At the heart of all it will be great designs for storage and transfer that are integral with active refrigeration systems to control the pressures. (And yes, facilitating zero boiloff for the tanks will be a nice bonus!)

References:

[1] Demko J, Fesmire J, and Shu Q, *Cryogenic Heat Management*, CRC Press Taylor, & Francis Group (2022).

[2] Swanger A, "LH_2 Storage and Handling Demonstrations Using Active Refrigeration," DOE/NASA Advances in Liquid Hydrogen Storage Workshop, August 2021.

[3] Partridge J, "Fractional consumption of liquid hydrogen and liquid oxygen during the space shuttle program," *Advances in Cryogenic Engineering*, AIP 143 (2012).

Cryo Bios

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

William F. Vinen

William Vinen was a pioneer in the field of quantized vortices and quantum turbulence in He II (superfluid helium). His accomplishments, both experimental and theoretical, ranged from the first direct detection of a quantized vortex to a broad understanding of quantum turbulence and its relationship to classical turbulence.

William Frank Vinen (known to all his friends and colleagues as Joe Vinen) was born in Watford, England. After attending the Watford Grammar School, he entered Cambridge University where he earned a First Class Honors Degree in Physics in 1953. Vinen stayed on in Cambridge for his Ph.D., conducting research in cryogenics in the Mond Laboratory. He finished his doctorate in 1956 and remained at Cambridge in a variety of teaching and research positions until 1962.

It was at Cambridge that Vinen made his first important discovery, one that set the stage for much of his work during the rest of his career. Vinen's thesis advisor was D.V. Osborne. In 1950, Osborne published the results of a classic experiment involving the rotation of He II (the so-called rotating bucket experiment). The results of this experiment showed that He II acted more like an ordinary fluid than a superfluid under rotation. The explanation for this discrepancy, developed mainly by Richard Feynman, was the existence of quantized vortices within the superfluid component of the He II. These microscopic vortices would have a unit circulation of h/m (where h is Planck's constant and m is the mass of the helium atom) and their presence would explain the results of Osborne's experiment in a manner consistent with the current understanding of He II. In 1956, Vinen, working together with H.E. Hall at Cambridge, indirectly detected these vortices via attenuation of second sound. In 1961, Vinen published the results of a very clever experiment using a vibrating wire in a rotating vessel of He II that could trap vortices and allow measurement of circulation down to values of h/m. This experiment directly detected vortices of circulation h/m consistent with the theory's prediction (Figure 1). Vinen and Hall were jointly awarded the Simon Memorial Prize in 1963 for their work on this topic.

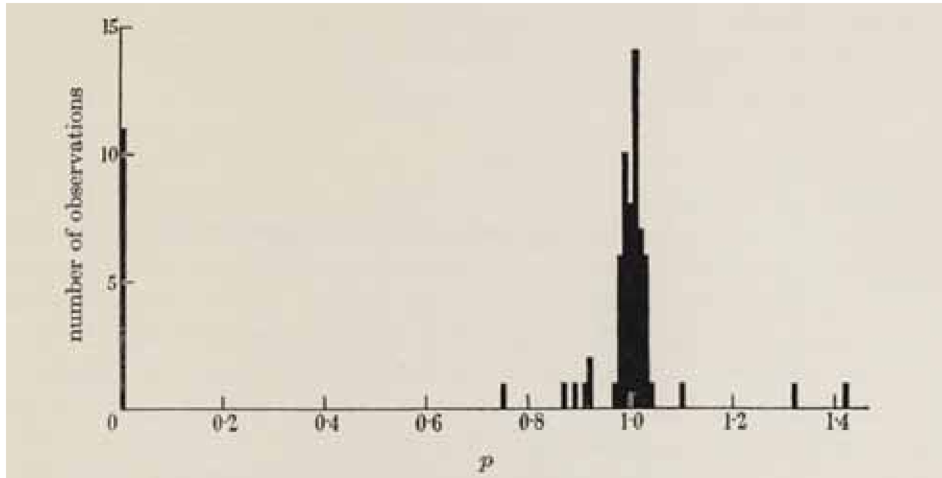


Figure 1: Results of Vinen's Vibrating Wire Experiment, showing detection of quantized vortices with a circulation of h/m.
Credit: W. F. Vinen, "The Detection of Single Quanta of Circulation in Liquid Helium II," Proc. Roy. Soc., A260, 218 (1961).

Quantized vortices are created by any movement of the superfluid component of He II above a critical velocity, including the movement found in internal convection heat transfer within He II. These vortices interact with the normal fluid component of He II via mutual friction, and this interaction helps explain the heat transfer within He II for most large-scale applications. The quantized vortices represent turbulence in the superfluid component. This quantum turbulence frequently acts like turbulence in ordinary fluids but can differ from it under certain conditions. Vinen investigated and became an expert in quantum turbulence during his career, producing many important experimental and theoretical results.

In 1962, Vinen moved to the University of Birmingham where he became a Professor of Physics and led the condensed matter physics group. He eventually became the chair of the physics department. During his long career at Birmingham, Professor Vinen conducted research on He II, including the transition from He I to He II and on the interactions of ions and light with He II. He also conducted research on Type-II superconductors and high temperature superconductors. Upon retirement, he continued research on quantum turbulence, visiting and collaborating with institutions in the USA, Czechia (Czech Republic), Japan and Finland. He was very interested in the development of physics education, chairing the education committees of the Institute of Physics and the Royal Society. He also played an important role in the establishment of a four-year master's program for physics in the United Kingdom.

Professor Vinen received numerous awards during his career, such as Fellow of the Royal Society, the Rumford medal from the Royal Society and an honorary doctorate from the Charles University in Czechia. The 2023 International Conference on Quantum Fluid and Solids (https://qfs2023.org) includes a memorial session in honor of Henry Hall and Joe Vinen. Professor Vinen produced many publications during his career. A nice overview of his work on quantum turbulence and its relationship to classical turbulence can be found in: "An Introduction to Quantum Turbulence," W. F. Vinen, *Journal of Low Temperature Physics*, Vol. 45, Issue 1-4 (November 2006). He also wrote "Fifty Years of Superfluid Helium," published in *Advances in Cryogenic Engineering*, Vol 35 (1990).

SPOTLIGHT ON A CORPORATE SUSTAINING MEMBER (CSA CSM) : Alloy Valves and Controls (AVCO)

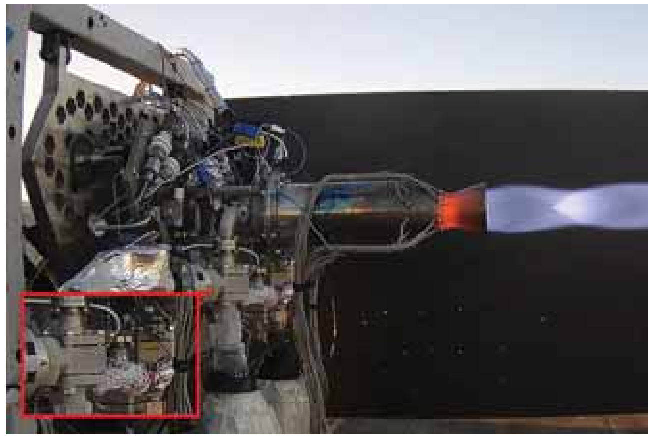
AVCO Sets its Sights on Mars

by Gregory Parra, AVCO Vice President

"You're Going to The Moon" should now be quoted as "You're Going to Mars." From the 1990s downturn in the aerospace industry to today's exponential growth, the demand for precision flow control and flow measurement has continued to follow the same growth trajectory. The focus of Alloy Valves and Control (AVCO) has been on the need to fulfill the requirements of research and development for rocket engine design, test stands, rocket propellant and life support systems for space travel in both unmanned and manned space vehicles.

AVCO valves are designed to meet or exceed industry standards. The standards include but are not limited to American Society of Mechanical Engineers, American Society for Testing and Material and Fluid Control Institute. Valves are devices that control the flow of liquids or gases. The control of the media is to start/stop the flow or control the flow rate of media. In the environment of space, valves must seal the media externally and internally at high pressure, vacuum pressure, cryogenic temperatures and high temperatures. AVCO accomplishes this task by employing fundamental engineering concepts. These concepts are concentricity, perpendicularity, parallelism, symmetry and tangential contact. Having design concepts in place and the ability to deliver products in a timely manner will work to land mankind on Mars.

Alloy Valves and Control's flagship valve is the ball valve. In simple terms, a ball valve is a sphere in a cylinder. Ball valves are also known as quarter-turn valves, on/off valves, flow control valves, servo valves and diverter valves, just to name a few. With our tagline "Engineered for Engineers" in mind, our team listens to our clients' requirements and collaborates with our engineering staff to craft customized ball valves that precisely fulfill customer needs. The applications could entail rocket engine fuel valves or life support system valves with various media. Examples include LOX, GOX, LN_2, GN_2 and H_2 from vacuum to 400 bar. Our ability to transverse space to Mars becomes a reality when we provide the best engineered product. AVCO delivers products in a timely manner by employing the concept of utilizing interchangeable parts to build control valves like building a LEGO® set. Our on-time delivery for all AVCO products is over 92%, and we are constantly working to achieve even better results. We accomplish delivery goals by using AVCO-designed valve components across a wide range of our ball valve series. For example, the AVCO on/off valves (1100 Series) share the same components as a LOX valve (1500 Series), a servo valve (1700 Series) or a throttling control valve (1900 Series). Alloy Valves and Control builds valves to meet clients' flow control requirements.



Launcher space test with AVCO valves. *Credit: Andre at Launcher Space*

NASA Morpheus lander using AVCO Valves. *Credit: NASA®*

Take for example some recent application inquiries AVCO received and the solution offered:

Client Objective: design servo diverter valve with Cv over 35, maximum temperature 120 ºF, pressure from 100 psi to 1 Torr, total weight at 5.50 pounds, minimum envelope space, end connection SAE AS-1656, power consumption 24VDC at 1.6 amp.

AVCO Solution: 1-1/2" 1700 series valve, 6051 Aluminum body and ends, 316SS ball and stem, TFM 1600 seats, mounted with closed coupled with motor operator. Product shipped in six weeks.

Client Objective: design flow control fuel valve with Cv range from 1 to 15, media RP-1, LOX.

AVCO Solution: ¾" AVCO 1900 series valve, 316SS body, ends, stem and 316SS 90 degree vee ball, PTFE seats. Product shipped in two weeks.

The commonality between the two sets of valves listed above is that many of the components are commercially off-the-shelf items. These components include valve bodies, ball, stems, valve seats, valve body seals and stem packing. Our ability to have valve parts readily available, whether a full port ball or a vee ported ball, fluoropolymer valve seats to thermoplastic seats, allows AVCO to configure a valve for various applications.

To land and establish living modules on Mars by 2029 and beyond will require suppliers to adapt and overcome the logistic and various environmental conditions to transport and support astronauts in space, on the moon and Mars. AVCO has been, and will continue, to forge a path forward to meet the challenges brought to our company. By adhering to our belief that "Not all ball valves are created equal," AVCO will meet the flow control needs of the aerospace industry by delivering, in a timely manner, equipment to establishing a living facility on Mars. **www.avcovalve.com**.

Research Leads to Innovations in Space Cryogenics Technology

by Benjamin Hayes, Ed Fong, Gopinath Warrier, Matthew Harrison, Trevor Bright (All authors represent The Aerospace Corporation.)

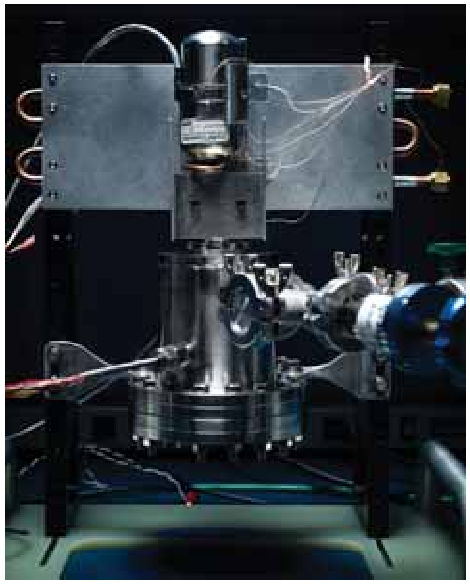
Introduction

Cryogenic technology is a robust field of research that plays a significant role in future space missions. Technology development for cryogenic fluid management and cooling of sensors takes many forms. The Aerospace Corporation (Aerospace) houses experts in thermal management, optics and sensor development to inform the space industry of current state-of-the-art and future mission-enabling technologies.

One such key technology is the lightweight mechanical cryocooler, which began development in the 1960s but did not receive wider adoption for use in space until the 1990s. Since then, cryocoolers have been integrated in numerous missions with cryogenic payloads, with Aerospace often playing a key role in the design and mission assurance. Maintaining expertise, leading research and tracking the development of critical technologies for use by the space community are core tenets of Aerospace, serving both government and commercial customers.

Cryocooler Vendor Survey

To gauge the state of the technology, Aerospace surveys industry leaders in state-of-the-art spaceflight-relevant cryocoolers, gathering performance metrics and program maturity levels. This vendor survey was initially conducted in 2007 with follow-ups in 2013 and 2015. Since then, the industry has seen continued developments to adapt to the rapidly evolving space architectures and missions. Aerospace is currently reaching out to industry partners to update the vendor survey for the next generation of cryocoolers. (Survey results will be available to the industry this fall.)



Inside the test facility to characterize the thermal performance of a mini-cryocooler for future small satellite applications. *Credit: Aerospace*

Developing In-House Capability on Cryocooler Performance Evaluation

To maintain technical expertise in space cryogenics, Aerospace regularly invests in its internal research and development program to research and advance new high-priority capabilities. One such project is developing in-house expertise on cryocooler integration into small-satellite systems, such as CubeSats or payloads with severe size, weight and power (SwaP) constraints. The miniaturization of cryocooler thermomechanical units and control electronics will enable some future missions to fit into these smaller platforms. The IR&D effort is helping grow Aerospace's expertise and modeling tools by characterizing the thermal performance metrics, such as cold tip and reject temperatures, cooling capacity and power consumption. These continually developing tools will keep Aerospace ready to support future trade studies and anomaly investigations.

Mineral and gas identifier (MAGI) is a wide-swath moderate spectral resolution thermal-infrared imaging spectrometer detector cooled to 55 K. *Credit: Aerospace*

Increasing trends for programs are toward lower cost cryocoolers, multiple payload instruments on a single space platform and/or secondary coolers to provide redundancy. All these trends have manifested in designs incorporating multiple cryocoolers to share a single load, provide stage cooling (e.g., optics) or provide a lower cost alternative to a larger single cryocooler. The integration of multiple cryocoolers may result in structural dynamics crosstalk between the cryocoolers sharing a single mounting structure, which in turn may result in anomalous behavior. Mission examples were identified by Aerospace and resulted in an internal research program to characterize all exported forces and torques of a single cryocooler. Follow-up work included attaching a secondary vibration source to mimic a second cryocooler. The results from these tests showed that when the secondary frequency was nearly equal to that of the operational frequency and out of phase, a low "beat" frequency appeared in the structure which reduced the effectiveness of both passive and active vibration control mechanisms. Proposed solutions have been investigated through both the IR&D and program involvement with promising results. (This is still an ongoing research topic.)

In addition to unit-level analysis, research and optimization, Aerospace provides systems engineering support for customers on cryogenic payloads. Often these systems involve complex designs to minimize thermal parasitics and dynamic loads of sensitive detectors that require stable operating environments. Whether these spacecraft designs used cryoradiators, cryogenic dewars or mechanical cryocoolers, Aerospace's experience in detectors and optics has ensured customers can optimize available resources to meet mission requirements, typically through detailed architecture studies, implementation of our robust mission assurance process and test support.

Zero-Boiloff Cryogenic Fluid Management

Aerospace provides technology development of cryogenic fluid management for space and launch vehicles in all stages from launch to on-orbit operation. Cutting-edge technologies for preconditioning, storage of cryogenic fluids and safe loading of cryogens through the payload fairing are actively being evaluated for potential issues that would affect safe implementation. Investigation of state-of-the-art technology for launching large cryogenic propellant tanks without a payload fairing is ongoing, with preliminary results indicating that structural multilayer insulation, needed for propellant storage in space, can protect the tanks from thermal and structural loads during liftoff.

In-space servicing, assembly, and manufacturing (ISAM) is going to require an increase in the technology-readiness level in cryogenic fluid management to enable future space architectures and missions. Being able to accurately mass gauge in low-g environments remains a key enabling technology. Aerospace is involved in assessing existing and new approaches for future ISAM operations and providing unbiased feedback of their pros, cons and overall maturity level. Promising low-g mass gauging technologies, such as radio frequency mass gauging, model propellant gauging and spectral mass gauging, have been assessed. These assessments help inform future research funding for both internal and external programs.

Currently in development is a set of liquid hydrogen mass gauging requirements for a nuclear thermal propulsion vehicle. Evaluation of the onboard propellant inventory at all stages of this multiyear mission includes quantifying propellant mass utilized during burns; mass lost due to tank wall diffusion; leakage and boiloff between burns; boiloff during tank or line chilldown and transfer processes; and mass remaining in empty tanks when jettisoned.

For access to Aerospace's expertise in spacecraft and launch vehicle cryogenic systems, contact Matthew Harrison (matthew.harrison@aero.org) or Benjamin Hayes (benjamin.z.hayes@aero.org). **www.aerospace.org**

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

Advanced Cooling Technologies, Inc.

A premier thermal management solutions company, focusing on custom applications of two-phase heat transfer technology, including custom cryogenic heat pipes, loop heat pipes (LHPs), thermal straps, and pulsating (oscillating) heat pipes (PHPs and OHPs).

Bhiwadi Cylinders Pvt. Ltd.*

Bhiwadi Cylinders is a leading manufacturer of static and transportable cryogenic pressure vessels and cylinders, along with vaporizers ranging from 200 to 100,000 liters.

Meiji Rubber & Chemical Co., Ltd.

Meiji's cryogenic hoses in a variety of sizes preserve high flexibility and high pressure at the extremely low temperatures used when handling cryogenic fluids such as LNG, LN_2, LPG, etc. Hose for LNG is available in 1 and 2 inch diameter only.

Photon Spot Inc.*

Photon Spot manufactures compact sub-Kelvin cryogenic systems, superconducting single-photon detectors, and systems with very low temperature oscillations at 4 Kelvin. The company's products are carefully designed for quantum applications.

Suntronic Inc.

With expertise in complex designs for mission critical environments, Suntronic offers full-range custom manufacturing services which include PCB assembly, cable and wire harness assembly, new product introduction, box builds and aftermarket services.

Willets Midstream Services, LLC

Willets Midstream Services is a trusted provider of cryogenic gas processing solutions. Built on commissioning and troubleshooting, WMS offers Certification/Inspection, Consulting/Engineering, Education/Training, and Operations/Field Services.

*CSA CSM

Mirroring the James Webb

by Bob Wells, DMP CryoSystems

DMP CryoSystems received a request for qualifications in 2005 to custom design a CryoTemper, specifically to thermal-cycle large discs. In the specifications, horizontal airflow was required due to the solid geometry and mandatory loading of two units at a time. Temperature uniformity would have to be within +/- 5 °C even during the ramps from -155 °C and +150 °C. The design was further complicated by the need to monitor 26 T/C's attached to the load. DMP decided to use a Yokogawa temperature controller and Eurotherm Recorder with math capability and 30 T/C channels. It wasn't until later and deep into production that DMP found out that its efforts would be used for the James Webb Space Telescope's mirrors.

DMP CryoSystems Inc., originally known as Durable Metal Products Co., Inc. was founded in 1994 as a manufacturer of cryogenic tempering equipment and continues to lead the industry in product innovations and services. Some of its current customers include Pratt & Whitney, Parker, SKF Bearing, Dana Corporation, Raytheon, Gleason, and Hamilton Sunstrand Aerospace. However, DMP CryoSystems was particularly proud to announce that it was selected by a NASA subcontractor to supply temperature cycling equipment for the James Webb Space Telescope (JWST).

From its inception, the DMP CryoTemper™ has set itself apart. Designed from the ground up, it has always been intended for use in rigorous environments, delivering efficient, trouble-free operation. Utilizing ever-evolving technologies in insulation, construction and control systems, CryoTemper processors should not be confused with converted deep freezers.

For JWST, DMP designed, built, and delivered two CryoTempers to SSG-Tinsley in Richmond, Calif. (Tinsley is a subsidiary of SSG Precision Optronics, Inc., a developer of major telescope and other opto-mechanical systems for spaceflight environments for both defense and civil applications.) The

The state-of-the-art DMP CryoTemper™ technology was used in the James Webb Space Telescope for its mirrors.
Credit: DMP CryoSystems

front-loading guillotine-style doors allowed clear access to operators loading the transport frame, which secured up to two mirrors each. Although the mirrors are very light (less than 30 pounds each), they are hexagonal and almost five feet in diameter. The process called for 13 T/C's to be taped to each mirror, with the temperatures monitored and recorded. A port led from inside the chamber to a junction box where each T/C landed on a terminal strip. The operator then selected upper/lower/both on a switch to indicate the mirror positions for the recorder. The process also called for the door to be closed and the thermal cycle started. The recorder then monitored the T/C's, and if any fell outside the +/-5 °C range, in either group, the controller was put into a hold condition, which would automatically clear as the T/C came back inside the range and allowed the controller to continue the ramp. This would continue throughout the entire temperature cycle, down to -155 °C and up to +150 °C and back to ambient.

Each of the 18 mirrors, plus spares, were put through the same thermal cycle after every process step of manufacture. Whether after machining, scraping, polishing, or coatings, etc., each mirror underwent another thermal cycle, each one fully controlled and each with a single data report.

Alternatively, the CryoFurnace™ is the first and only cryogenic furnace available with a temperature range of -300 °F to 1,200 °F in a controlled nitrogen atmosphere. The CryoTemper continues to set the standard for all other systems with a temperature range of -300 °F to 550 °F. It remains the most efficient and versatile cryoprocessor on the market. All processors are available as top- and front-loading batch systems.

Both equipment lines, CryoTemper and CryoFurnace, are manufactured for the difficult commercial heat treating environment. The CryoFurnace has become a favorite of the vacuum and aerospace heat treating community for its ability to satisfy the AMS-2750 pyrometry specification. By utilizing the full temperature range of the CryoFurnace, users have been able to minimize product handling and cut cycle times in half. **www.cryosystems.com**

Cryospain's First-of-its-Kind Project Focuses on LOX for Standardized Rocket Launch Bases

by Pierre Meurgey, Sales and Marketing Director, Cryospain

Set to begin in the fall of 2023, Cryospain's latest project will see it build key liquid oxygen supply modules for a groundbreaking new system developed by French startup SpaceDreamS. The revolutionary idea is to standardize launch bases for rockets, making them interoperable as well as being transportable. Today there are 20 to 25 rocket launch programs in Europe alone. Huge amounts of spaceflight budgets disappear into one-shot launch bases that are also incompatible with others. So this revolution of mobile and standardized bases is one Cryospain is excited to be a part of.

This isn't the first time we've taken part in space-travel-related initiatives. For example, Cryospain's experts provided cutting-edge, pipe-in-pipe technology for a revolutionary UK SABRE (Synergistic Air-Breathing Rocket Engine) project.

Courtesy of CryoSpain

State-of-the-Art Equipment for a Space Exploration Revolution

Our engineers will be designing two liquid oxygen (LOX) supply systems within skid modules. Their purpose is to inject the launch base's motors with LOX at extremely high flow rates and pressures. We'll add pneumatic actuator fail close valves with limit switches and solenoids to our state-of-the-art piping system, and we'll also design the entire system for optimal flow between the skids and the LOX tank.

Our team will also install one skid connected to "bundles" (300 bar nitrogen blocks) and to a liquid oxygen (LN_2) tank. SpaceDreamS calls this area the Lox-Box. The other skid will be located within an area they call a launcher mockup, along with a high-pressure LOX tank of just under a cubic meter, designed and manufactured by Cryospain for liquid oxygen supply. This compact size allows for the high performance tank to fit perfectly within these modular systems. Cryospain's designers will ensure the piping system is adaptable to any base, anywhere in the world. The potential improvements, both in terms of time and money spent on rocket launches, are huge.

Work will start in our very own workshops here in Spain, where we'll carry out the engineering, as well as the manufacture of every element in the skid modules and the compact LOX tank. Our team will then travel to a military facility in Bordeaux to carry out installation and activation of the prototype.

www.cryospain.com

Success in Harsh Environments: Signaling the Future of Cryogenic Communications

by Del Pierson, Product Line Manager for Quantum and Space, XMA Corporation, mpierson@xmacorp.com

XMA, with its space heritage spanning from low-Earth orbit (LEO) to deep space exploration units, embarked on a journey to enter the supply chain for quantum computing more than 10 years ago. The driving force behind this industry expansion was XMA's success in cryogenic temperatures down to approximately 4 K in space environments. XMA managed to strike the perfect balance between rugged materials that remained non-superconductive at cold temperatures and low-mass products. When quantum technologists cooled these components to millikelvin temperatures, the specifications remained unchanged. This consistent performance from ambient to cryogenic conditions has become XMA's baseline for success. With the cross-pollination of knowledge between the space and quantum industries, XMA has experienced steady growth in both sectors, thanks to its novel designs and successful environmental testing. As space exploration and quantum computing continue to advance, XMA leverages the newfound knowledge from each industry to improve the other.

The needs of the space and quantum computing industries bear striking similarities. Space requires low-mass, mechanically rugged and cryogenic components. On the other hand, quantum computing emphasizes reducing the mechanical footprint rather than mass. Additionally, quantum computing components must not only function flawlessly in cryogenic environments but also contribute to maintaining these environments by effectively thermalizing and redirecting the heat generated by the signals. In both industries, addressing these challenges revolves around one overarching necessity: clean radio frequency (RF).

XMA finds itself in a unique position to deliver disruptive, cutting-edge products to these industries. The company's journey begins with its thin film lab where vertical integration and adherence to the AS9100 risk reduction standards ensure a smooth yet highly regulated transition from design engineering to full-rate production. XMA's engineers enjoy complete access to an in-house thin film resistor lab, driving the development of new products and process updates. This includes terminations with smaller chips and attenuators with new chip substrates. Direct access to the lab, combined with close industry partnerships, serves as the driving force behind XMA's innovation.

Thin film technician processing a resistor board.
Credit: XMA Corporation

XMA directional coupler under test.
Credit: XMA Corporation

Over the past two years, XMA has introduced myriad new products tailored to the space and quantum industries. These innovations encompass components in traditional coaxial packages, as well as those that deviate from the traditional product line, aiming for the future of embedded attenuation, new interconnect types and flex cabling. Although each new component is designed to fulfill a multitude of objectives, they never compromise on delivering high quality RF signals. This commitment to excellence in RF remains at the forefront of XMA's designs.

XMA's latest coaxial components boast redesigned mechanical interfacing, modern connectors, refreshed materials that enhance thermalization and advanced capabilities to prevent interruptions caused by high energy signals. For instance, XMA's new cryogenic directional coupler leverages updated mechanical interfacing and materials to fit within a smaller package size. Couplers designed for space applications utilize a lighter-weight aluminum housing, while those intended for quantum computing employ a well-thermalized gold-plated copper housing. Although these designs share numerous features that produce reliable and clean RF, XMA's deep industry knowledge enables seemingly minute changes that ultimately lead to superior system performance.

In parallel to its dedication to coaxial products, XMA is boldly venturing into the development of non-coaxial components, marking a significant shift in the company's innovative approach. For example, XMA is developing a revolutionary flexible cable focused on low crosstalk, high signal line density and minimal heat load. Although the current market demand for these cables comes from the quantum community, the space community is following close behind. XMA is eager to implement the nuanced requirements from the space community and continue to develop high performance cryogenic cables with clean RF. Leveraging space heritage, thin film innovation and industry collaborations, XMA is signaling the future of cryogenic communication. **www.xmacorp.com**

SPOTLIGHT ON A CORPORATE SUSTAINING MEMBER (CSA CSM) : ZeroAvia

ZeroAvia's Zero-Emission Aircraft Engines Target Liquid Hydrogen

by Dominic Weeks, ZeroAvia

Zero-emission aviation pioneer ZeroAvia recently reached an important milestone, which was celebrated at an event held at ZeroAvia's Paine Field research and development site in Washington state when Governor Jay Inslee, Congresswoman Suzan DelBene (WA-01) and Alaska Airlines CEO Ben Minicucci watched as ZeroAvia CEO Val Miftakhov unveiled a 76-seat Q400 aircraft, ready to be retrofitted with a prototype hydrogen-electric engine.

Alaska Airlines has provided ZeroAvia with a Dash 8 Q400 regional turboprop to test its hydrogen-powered electric propulsion system. The plane is now emblazoned with ZeroAvia navy- and sky-blue graphics and Alaska Airlines' name on the tail. *Credit: GeekWire Photo / Lisa Stiffler*

"Demonstrating this size of aircraft in flight, powered entirely by novel propulsion, would have been unthinkable a few years ago," said Val Miftakhov. "Launching this program puts us on track for a test flight next year and accelerates our progress toward the future of zero-emission flight for Alaska Airlines and for the world at large."

Alaska Airlines CEO Ben Minicucci speaking at the event at Paine Field in Everett, Wash., when the airline gave the keys to a Dash 8 Q400 to ZeroAvia. Behind Minicucci, from left: Snohomish County Executive Dave Somers; Washington Congresswoman Suzan DelBene; Governor Jay Inslee; ZeroAvia CEO Val Miftakhov; and Diana Birkett Rakow, Alaska Airlines' sustainability lead. *Credit: GeekWire Photo / Lisa Stiffler*

When Alaska Airlines' regional carrier Horizon Air retired its Q400 fleet, it reserved one of the aircraft for research and development purposes to further advance zero-emissions technology for the aviation industry. For the 40- to 80-seat segment and beyond, LH_2 fuel storage is required due to improved energy density when compared to gaseous systems. Therefore, LH_2 is one of three key building blocks, alongside advanced electric motor technology and higher temperature fuel cells, for zero-emissions applications for larger aircraft.

"This is a great step forward in aviation innovation, to help create a new future of flight – right here at home," says Ben Minicucci. "Alaska Airlines has defined a five-part journey to achieve net-zero carbon emissions long-term, but we can't get there alone. New technologies are required to make that future possible, and we're thrilled to partner with industry leader ZeroAvia to make new zero-emissions options a reality."

Aligning ZeroAvia's powertrain with the Dash 8-400 airframe will represent a commercially viable zero-emission aircraft with fuel cell engine technology – around five times more powerful than what has been demonstrated anywhere to date. ZeroAvia's recent advancements clear the way for a potential flight of the Q400, but also demonstrate rapid progress toward certification of the ZA2000 propulsion system. This advancement is in accordance with similar recent accomplishments of ZeroAvia. In January, it flew a retrofitted 19-seat aircraft with its prototype 600 kW hydrogen-electric engine (ZA600). This followed the demonstration flight of a 250 kW system in 2020, which, at the time of flight, was the world's largest aircraft flown using a novel zero-emission power source.

ZeroAvia's hydrogen-electric engine uses fuel cells to generate electricity from hydrogen fuel before using that electricity to power electric motors that turn the aircraft propellers. The certifiable ZA2000 system will include ZeroAvia's High Temperature PEM fuel cells and liquid hydrogen fuel storage, integral to delivering the necessary energy density for commercial operations of large regional turboprops. The company has already established an engineering partnership with De Havilland of Canada, the original manufacturer of the Dash 8 family of aircraft, to enable exchange of data and expertise with the airframe.

Congresswoman DelBene adds to the importance of the impact ZeroAvia's milestone has on the planet. "As we work to meet our emissions-reduction goals, we must prioritize decarbonizing the commercial transportation sector. The Alaska Airlines-ZeroAvia partnership is a prime example. This collaboration could revolutionize the aviation industry to make our planes greener and our skies cleaner."

HyperCore

At the same event in Washington State, ZeroAvia also debuted its breakthrough multi-megawatt modular electric motor system in a 1.8 MW prototype configuration at the event – demonstrated with a propeller spin aboard the ZeroAvia's 15-ton HyperTruck ground-test rig. Over the last few weeks at its Hollister location in California, ZeroAvia has been testing its 1.8 MW electric propulsion system configuration with the stock Dash 8-400 engine gearbox and propeller. This configuration consists of two "HyperCore" motor modules, each a high-power, high-speed 900 kW permanent magnet radial flux machine which operates at 20,000 rpm, matching the typical turbine engine speeds, and providing an unprecedented 15 kW/kg motor power density.

Crucially, HyperCore's modular design enables the technology to address applications ranging from 900 kW up to 5.4 MW,

ZeroAvia's ground-test truck outfitted with two of its 900-kW (kilowatt) engines and a Q400 propeller.
Credit: GeekWire Photo / Lisa Stiffler

ZeroAvia CEO Val Miftakhov in front of a massive ground-test truck with two of its 900-kW engines and a Q400 propeller. The startup gave a demonstration of its engine at Paine Field. *Credit: GeekWire Photo / Lisa Stiffler*

meeting a number of regional turboprop and regional jet requirements. The development and testing program will enable the understanding and measurement of system dynamics, calibration of physical and electrical models, and validation of thermal management systems. The company is concurrently developing world-class silicone-carbide power electronics and the matching hydrogen fuel cell systems, which convert hydrogen to electricity, powering the electric propulsion system. These systems will be brought together to create the full hydrogen-electric propulsion system, tested on the ground and then in the air. **www.zeroavia.com**

Product Showcase

This Product Showcase is open to all companies and related manufacturers offering new or improved products for cryogenic applications. We invite companies to send us short releases (150 words or fewer) and one high-resolution JPEG of the product to http://2csa.us/psc.

Cryogenic Pump and Vaporizer Skids

Cryopump Asia

These cryogenic pump and vaporizer skids are compact and easily movable. The skid can be transported with a forklift and installed in different locations, making it ideal for both mobile and stationary filling stations. Perfect for various industries, the skid is a versatile solution that can be used for filling gas buffet and cylinders in industrial, medical and food industries. The skid comes with all interconnecting piping and electrical wiring connections that can be easily set up by the user on-site. The Cryopump Asia skid package ensures efficient pumping of cryogenic liquids at high pressure, providing a reliable and cost effective solution for cryogenic liquid pumping needs. **www.didwania.com/vaporizer-skids.html**

High-Lift Relief Valves

Mack Valves

Typically used to safeguard boilers, vessels and pipework from the risks of higher than desired pressures protecting valuable resources and avoiding costly downtime, the high lift relief and full lift nozzle valves are designed for large vessels that require higher relieving capacity including applications across building services, cryogenics, pharmaceuticals, mining and food and beverage. The specs include bronze/stainless steel materials; flanged, 15-150mm and screwed, 15-50mm sizes; pressures up to 9,000k Pa, 1,305 psi and 90 bar; and temperatures from -196° C to +190° C. **https://mackvalves.com/high-lift-relief-valves**

DRY ICE 3K ION

ICEOxford

The DRY ICE 3K ION is a closed cycle system designed for ion trap and cold atom quantum computing research. The 3 K base temperature system achieves ±100nm at the sample in an ultrahigh vacuum environment, providing the best possible levels of stability to the sample space. The system also offers excellent optical access options and the integration of high homogeneity, high stability, and low current magnet. Other key features include 8 optical ports and 8 ports for customer wiring. **www.iceoxford.com**

DeTech Solution LN2 Monitoring System

DeTech

DeTech has developed a patented solution overcoming the challenges that have plagued the LN_2 containment monitoring industry for decades. It provides predictive analytics, multilevel fault tolerant protection and early warning systems down to the sensor level, resulting in a quintessential asset protection system. Its end devices report sensor data in real time to an on-site gateway which, in turn, reports to the cloud-based user interface. There are three status levels that are tank-specific and customizable with notifications and alerts so that technicians can proactively and easily manage each tank's liquid nitrogen level. DeTech's patent is exclusive and has unmatched features, such as reduced labor and component costs, exclusive patented telemetry predictive analytics, automated customizable fill notification, self-supervising protection down to the sensor level, patented cloud communication loss watchdog and patented app-based fill interface. **https://detechus.com**

ALPHA OMEGA INSTRUMENTS™ Series 1300™

Alpha Omega

The Alpha Omega Instruments™ Series 1300™ oxygen deficiency monitor is a digitally controlled instrument with a measuring range of 0-30%. Oxygen values are displayed to the nearest tenth of a percent on a high contrast front panel LCD. The monitor is housed in a resilient polycarbonate, wall-mountable general purpose enclosure. Standard input power to the Series 1300 is 90-264 VAC, 47-63 Hz, and 18-36 VDC powered systems are available. The eloquence of the Series 1300 is its simple operation as well as its ease of expandability. Included are four individually adjustable Form C alarm relays, each rated at 10 amps (250 VAC). The Series 1300 can be programmed to provide a maximum of nine individual alarm events. Two scalable analog outputs (4-20 mADC and 0-20 mADC) are standard, as is RS-232 serial communications. Each Series 1300 includes an internally mounted audible alarm rated at 85 decibels (nominal) as well as visual alarm indicators. The Oxygen Deficiency Monitor Series 1000 has been replaced with the Series 1300 Oxygen Deficiency Monitor. **www.process-insights.com**

PolarSafe® Cryogenic Storage Dewars with Racks

Cole-Parmer

Facilitating cryogenic management, the PolarSafe® storage dewars from Cole-Parmer® come with stainless steel racks to accommodate boxes or canisters (depending on model). With high thermal efficiency, each unit provides long term storage in liquid nitrogen for up to 200 days without refill, under normal operating conditions (may vary by model). The 95L and 115L models feature a lockable lid with temperature and fluid level display. The dewars safely store samples for up to 200 days without liquid nitrogen refill and are available in sizes from 2L to 115L. The ultralow evaporation loss enhances cryogen protection, and they are made with durable aluminum construction with dual handles that aid mobility and a five-year vacuum warranty. **www.coleparmer.com**

ECL502 Series

RegO

ECL Series

RegO® cryogenic and industrial gas products are 100% tested and packed with innovations to maximize flow control, reduce the need for service and lower the cost of ownership. Backed by its industry-leading 10-year warranty, 25-year regulator service life, and global network of technical and sales support, RegO delivers trouble-free performance and peace of mind. The ECL502 series cryogenic economizers are designed to be used as pressure-reducing valves to automatically maintain a constant inlet or back pressure, normally closed at pressures below its set point and open at pressures above its set point. The ECL502 is primarily designed to assist in maintaining a desired system pressure ideal for nitrogen, oxygen, argon and other cryogenic cylinder applications with a 100% performance improvement over RegO's ECL series. The ECL502 series offers outstanding performance for maintaining LNG fuel line pressure. **www.regoproducts.com**

MVE Vapor Shippers

Linde

MVE vapor shippers are designed for the safe transportation of biological samples at temperatures -150 °C or colder. Manufactured from durable, lightweight aluminum, they employ a hydrophobic compound that absorbs liquid nitrogen to ensure spill-free shipping. They also repel moisture and humidity, assuring maximum holding time and eliminating the necessity to dry units between uses. **www.lindedirect.com/specialty-gas-electronic-solutions/cryogenic-products**

People & Companies in Cryogenics

Cryogenic measurement systems manufacturer **Bluefors** (CSA CSM) has acquired **Rockgate**, a Japan-based distributor of cryogenic equipment. Based in Finland, Bluefors said the purchase will help establish direct sales and service presence in the Japanese cryogenics technology market and expand its global footprint beyond Finland, Germany, the Netherlands and in the US. Following the completion of the acquisition, **Tsuyoshi Ohta** will take the lead of the Bluefors business in Japan. The transaction is estimated to be completed by the end of June 2023. Earlier this year, Bluefors completed the acquisition of **Cryomech** (CSA CSM), a US-based cryocooler technology and manufacturing firm.

……………………………………

Renaissance Fusion announced the addition of two world-class technical leaders to its team: Head of HTS Film Deposition **Alexander Usoskin** and Head of Magnets, Vacuum, and Cryogenics **Carlo Sborchia**. Located in Grenoble, France, Renaissance Fusion builds stellarators, the most efficient, steady, and stable fusion reactors on earth.

Alexander Usoskin and Carlo Sborchia.
Credit: Renaissance Fusion

……………………………………

With its third company acquisition in just over two years, marine pump specialist **Svanehøj** continued to expand its service solution business by taking over California-based **Complete Cryogenic Services (CCS)**, a specialist in service and overhaul of submerged pumps on LNG tankers. CCS becomes an independent part of Svanehøj Service Solutions and will be named Svanehøj CCS – Complete Cryogenic Services. The company's nine employees will continue to work in their current roles with Henry Smith IV as director. Following the acquisition of CCS, Svanehøj employs 320 people and has activities in Denmark, the UK, France, Singapore, China, Japan and the US.

……………………………………

FuelCell Energy, Inc., and **Chart (CSA CSM)** signed a memorandum of understanding to develop opportunities to combine the companies' complementary strengths in delivering reliable and efficient carbon dioxide capture for use or sequestration, as well as generation and storage of gaseous or liquefied hydrogen. FuelCell Energy brings its expertise in manufacturing two high temperature electrochemical fuel cell energy platforms for decarbonizing power and producing hydrogen, while Chart is a leading global manufacturer of highly engineered equipment in the Nexus of Clean, which includes carbon dioxide and hydrogen compression and liquefaction, and equipment for the entire supply chains of both molecules.

……………………………………

The President of the Republic of the Congo, Denis Sassou Nguesso, and the Chief Executive Officer of Eni, Claudio Descalzi, laid a foundation stone for **Congo LNG**, the country's first natural gas liquefaction project and one of Eni's core supply diversification initiatives. The project is expected to reach an overall liquefied natural gas (LNG) production capacity of 3 million tons per year (approximately 4.5 billion cubic meters/year) from 2025. The project will see the installation of two floating natural gas liquefaction plants (FLNG) at the Nenè and Litchendjili fields, an aspect of the project already in production, and at the fields yet to be developed. The first FLNG plant, currently under conversion and with a capacity of 0.6 million tonnes per year (MTPA), will begin production in 2023. The second FLNG plant–already under construction–will become operative in 2025 with a capacity of 2.4 MTPA.

……………………………………

On May 11, 2023, Maestro Piotr Gajewski conducted the National Philharmonic in the world premiere performance of Henry Dehlinger's *Cosmic Cycles. "Cosmic Cycles: A Space Symphony"* is a collaboration between composer **Henry Dehlinger, NASA's Goddard Space Flight Center**, and the **National Philharmonic** that features a fusion of music and video in seven multimedia works on the sun, earth, moon, planets and cosmos.

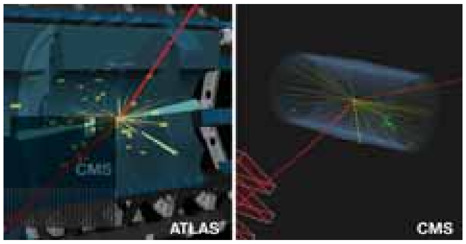
An enhanced color image of Jupiter.
Credit: NASA/Joel Kowsky

……………………………………

Meyer Tool & Mfg. (CSA CSM), a HURCO PRO shop, is beta testing the new HURCO VMX30UDi. The VMX30UDi is a five-axis trunnion style mill with a 10-inch diameter rotary table. Outfitted with a 15,000-rpm direct drive spindle, the mill allows Meyer to run a client's parts faster than ever. The machine is also fitted with a 60-pot tool changer for increased efficiency. During lights-out, the probing system can check for wear on a tool and automatically change over to its sister tool. Meyer released a video of the new HURCO at **www.mtm-inc.com/our-new-hurco-v8203mx30udi.html**.

……………………………………

The discovery of the Higgs boson at **CERN's Large Hadron Collider (LHC)** in 2012 was a major milestone in particle physics. ATLAS (a general-purpose particle physics experiment at LHC) and CMS (the compact muon solenoid, a general-purpose detector at the LHC) have been studying its properties and exploring its various decay



Candidate events from ATLAS (left) and CMS (right) for a Higgs boson decaying into a Z boson and a photon, with the Z boson decaying into a pair of muons.
Credit: CERN

processes. At the recent Large Hadron Collider Physics conference, they presented the first evidence of the Higgs boson decaying into a Z boson and a photon, which could suggest the existence of particles beyond the Standard Model. These decays occur through "virtual" particles that cannot be directly observed, possibly including undiscovered particles interacting with the Higgs boson. By combining their data sets, ATLAS and CMS improved the statistical precision of their search, resulting in a significant measurement above the Standard Model prediction. This study sheds light on the nature of the Higgs boson and provides a test for physics beyond the Standard Model, with future experiments expected to further enhance our understanding of rare Higgs decays.

....

Four stunning composite images have been created using data from **NASA's Chandra X-ray Observatory** and **James Webb Space Telescope**. These images combine Chandra's X-rays, which are high-energy light, with infrared data from Webb to create breathtaking views of two galaxies, a nebula, and a star cluster. Additional data from NASA's Hubble Space Telescope, Spitzer Space Telescope, the European Space Agency's XMM-Newton, and the European Southern Observatory's New Technology Telescope is also incorporated. The colors in the images are mapped to make the data visible to human eyes. The images showcase various cosmic phenomena, including a star cluster in the Small Magellanic Cloud, a barred spiral galaxy, the Eagle Nebula, and the Phantom Galaxy. These extraordinary images provide insights into star formation, remnants of exploded stars, and high energy activity from stars. The Chandra and Webb

Clockwise from top left: NGC 346 (star cluster); NGC 1672 (spiral galaxy); M16 (Eagle Nebula); and M74 (spiral galaxy)*. Credits: X-ray: Chandra: NASA/CXC/SAO, XMM: ESA/XMM-Newton; IR: JWST: NASA/ESA/CSA/STScI, Spitzer: NASA/JPL/CalTech; Optical: Hubble: NASA/ESA/STScI, ESO; Image Processing: L. Frattare, J. Major, and K. Arcand*

telescopes, along with their supporting observatories, offer a captivating glimpse into the wonders of our universe.

....

Scientists at **Ecole Polytechnique Federale de Lausanne** have developed a groundbreaking research instrument called the **CryoNanoSIMS** machine, which allows for the analysis of the chemical and isotopic composition of vitrified tissue samples. The instrument is the only one of its kind in the world and opens up new avenues of research. By utilizing a sample preparation process developed by Nobel Prize winner **Jacques Dubochet**, the CryoNanoSIMS machine enables scientists to observe the precise distribution of nutrients, drugs, trace elements, and contaminants at a subcellular level in biological tissue samples. This breakthrough technology has the potential to advance various fields, including the treatment of bacterial infections and cancer, plant growth, crop production and environmental analysis. The instrument's development required nearly a decade of work and collaboration with Swiss firms to achieve the necessary precision. The researchers have successfully tested the CryoNanoSIMS method on samples of Green Hydra and plan to apply it to studying coral symbiosis and coral bleaching in future research.

Meetings & Events

CSA Short Courses at CEC/ICMC
July 9, 2023
Honolulu, Hawaii
www.cryogenicsociety.org

Cryogenic Engineering Conference/ International Cryogenic Materials Conference (CEC/ICMC)
July 9-13, 2023
Honolulu, Hawaii
www.cec-icmc.org/2023

Space Cryogenics Workshop
July 16-18, 2023
Kailua-Kona, Hawaii
spacecryogenicsworkshop.org

BCC Advanced Cryogenics Course
July 18-20, 2023
Abingdon, Oxfordshire
bcryo.org.uk/bcc-advanced-cryogenics-course-july-2023-oxfordshire

Society for Cryobiology: CRYO2023
July 25-27, 2023
Minneapolis, Minnesota
cryo2023.com

Cryogenic Engineering and Safety Annual 5-day Course
July 31 - August 4, 2023
Golden, Colorado
www.cryocourses.com

EUCAS 2023: 16th European Conference on Applied Superconductivity
September 3-7, 2023
Bologna, Italy
eucas2023.esas.org

MT-28: International Conference on Magnet Technology
September 10-15, 2023
Aix-en-Provence, France
mt28.aoscongres.com/home!en

International Workshop On Emissions Free Air Transport Through Superconductivity
October 4-5, 2023
Bristol, UK
efats.info

Index of Advertisers

Join CSA and start receiving Cold Facts!

Rates: circle $ amount

In US: Individual $80 • Student or retiree: $35

Outside US: Individual $120 • Student or retiree $75

Corporate, in US, number of employees:
1-10, $470 • 11-25, $660 • 16-50, $870 • 51-100, $1,290
101-500, $2,340 • 501-1,000, $5,250 • 1,000+, $7,350

Corporate, outside of US, number of employees:
1-10, $525 • 11-25, $725 • 16-50, $940 • 51-100, $1,330
101-500, $2,455 • 501-1,000, $5,450 • 1,000+, $7,615

Government/Non-profit: $450

Outside the US, please remit in US $ on US bank. No bank transfers.

Charge your membership

__Discovery __Visa __MasterCard __AmEx

Account number ______ Expiration ______ Security code ______

Signature ______

Please print

Name ______ Title ______

Company ______

Address ______

City ______ State/Country ______ Zip + 4 ______

Email ______ Website ______

Phone ______ Fax ______

Send to:

New Memberships • Cryogenic Society of America
800 Roosevelt Rd. Suite 312-C • Glen Ellyn, IL 60137
Fax: 630-790-3095

Join CSA online! http://2csa.us/member

***Cold Facts* is the official technical magazine of The Cryogenic Society of America, Inc.** 800 Roosevelt Rd. Suite 312-C • Glen Ellyn, IL 60137
Phone: 630-858-7337 Ext. 8765 • Fax: 630-790-3095
Email: membership@cryogenicsociety.org • Web: cryogenicsociety.org
A non-profit technical society serving all those interested in any phase of cryogenics
SSN 1085-5262 • July 2023
Printed in USA

OmegaFlex®

Cryogenic / Vacuum Jacketed Hose Assemblies

Keep Cryogenic Liquids Cold • Safety Containment

Omegaflex Cryogenic / Vacuum Jacketed Hose Assemblies

- Superior insulation properties
- Multi-layer insulation creates a low heat transfer rate
- Minimizes cryogenic liquid boil-off
- Containment of the media in case of inner hose rupture

Metal Hose

- Allows for the transfer of liquids or gases, usually at high pressure and high or cryogenic temperature

Cryogenics Applications

- Nitrogen
- Hydrogen
- Oxygen
- Carbon Dioxide
- Helium
- Argon
- Other Natural Gases

Omegaflex welders and Omegaflex welding procedures are qualified to Section IX of the ASME Boiler and Pressure Vessel Code. Omegaflex hose assemblies are qualified to ISO-10380:2012.

Cryogenic and Vacuum Jacketed Assemblies are oven dried and purged with Argon to a moisture content of 2 PPM and verified with a moisture analyzer. Hose assemblies can be charged with Helium to maintain dryness during shipping and storage.

Cryogenics and Vacuum Jacketed Assemblies are Helium Leak checked to 1 x 10-9 std. cc/sec.

Contact OmegaFlex with your specification and we will engineer a custom jacketed hose assembly for you.

omegaflex.com

OmegaFlex®
OmegaFlex, Inc.
451 Creamery Way • Exton, PA 19341
ISO 9001 Registered Company
IND-156 09/21