TURBOMACHINERY INTERNATIONAL

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COVER STORY
Carbon Capture and Storage is on the Rise

COMPONENTS & AUXILIARIES
Curbing CO_2: Technological Efforts to Reduce Carbon Emissions

SHOW REPORT
WTUI 2024 Highlights Challenges with Running GE Aeroderivatives

TURBO TOUR
GE Vernova's Gas Turbine Manufacturing Facility


Flawless Execution

FROM 1959 *to* 2024…

In 1959, founders G. Renfrew Brighton and R. Tom Sawyer started the publication entitled *Gas Turbine International*, which would later become *Turbomachinery International*. After 65 years, the magazine continues to focus on turbines, centrifugal compressors, and related ancillary equipment, including maintenance and repairs and software and controls.

But the world has changed many times over since the start of our publication, and now the race toward decarbonization is pushing turbomachinery in new ways so that it can adapt and support new climate goals, newer fuels, and new means of lowering the industry's carbon footprint while reliably powering the world.

Each issue we aim to tackle the evolution of turbomachines, their intricacies, and the many means to decarbonize. To this effort, our cover story, written by the Global CCS Institute, gives an exact view of carbon capture and storage (CCS) facilities in the pipeline, as well as insights into deployment, the creation of networks and hubs, and what's needed to propel CCS forward. A cousin piece to our cover story tackles CO_2 at the component and software levels to offer readers a snapshot of technologies designed to reduce carbon emissions.

In tandem with a recently posted podcast, this issue's Q&A is with Emerson, who addresses digital ecosystems' role in plant safety, cybersecurity, and plant efficiency and maintenance. Guest coverage from WTUI 2024 and CERAWeek 2024 discuss challenges and best practices when running aeroderivatives; and energy and power markets, supply chains, net zero, and beyond, respectively.

In April, part of our team traveled to Greenville, SC to visit GE Vernova's facility. Assistant Editor James Cook walks readers through the center and gives insight into the company's processes, principles, and more. A big thanks to the GE Vernova team in South Carolina for hosting us.

Klaus Brun and Rainer Kurz tackle the myth that coatings last forever while Amin Almasi explains why root-cause analysis is important for turbomachines.

This issue is jam-packed with information and resources. We hope you enjoy it and are always open to hearing your feedback.

Thank you for your continued readership.

Alissa Marrapodi
Assistant Managing Editor

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> "According to scenarios by IPCC and IEA, carbon-capture and storage deployment must scale up to gigatons of stored CO_2 per annum to mitigate climate change and reach net-zero emissions by mid-century."
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> — The Global CCS Institute

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NEW PRODUCTS

The latest turbomachinery industry innovations

Atlas Copco Industrial Air: GA 11-30 FLX Compressor

The GA 11-30 FLX dual-speed compressor reduces start-up peak, unload power, and transient losses compared to other fixed-speed compressors and requires up to 20% less energy during usage. The compressor's compact footprint allows users to place the drive train set vertically to save space.

▲ **GA 11-30 FLX dual-speed compressor. Credit: Atlas Copco Industrial Air**

SpaceX: MethaneSAT Emissions Monitor

MethaneSAT will orbit the Earth 15 times a day to detect methane emissions from oil and gas operations across wide regions of the planet's surface. High sensitivity, high resolution, and a wide field of view will enable the satellite to measure changes in methane concentrations as small as three parts per billion.

▼ **MethaneSAT emissions monitor. Credit: Business Wire**

H2SITE: Palladium-Alloy Membrane Separator

This palladium-alloy membrane separator has been validated for separating hydrogen blends ranging from 5-20% concentration. The separators reached a 97% hydrogen recovery rate at 99% purity within the gas stream during validation. The technology produces high-purity hydrogen for fuel-cell applications.

Teledyne FLIR: Si2-Pro, Si2-LD, Si2-PD

The expanded Si2-Series of acoustic imaging cameras detects compressed air leaks, specialty gas leaks, mechanical faults, and partial discharges. Improvements include a 12 MP color camera, 8x digital zoom, LED illumination for dark areas, and increased battery life. A new "mech mode" enhances site safety by quickly detecting mechanical issues.

▲ **Si2-LD acoustic imager. Credit: Business Wire**

MAN Energy: Cluster 5 Double Layer SCR Converter

The Cluster 5 Double Layer SCR catalytic converter has a diameter of 3,900 mm, weighs 28 metric tons, and is ammonia ready with an integrated control system. The exhaust gas after-treatment system is typically used on cruise ships and cargo ships to reduce NOx emissions by up to 90%.

◀ **Cluster 5 Double Layer SCR. Credit: MAN Energy Solutions**

Mitsubishi Power to Supply GTCC Equipment

Mitsubishi Power is manufacturing an M701F gas turbine, a steam turbine, a heat recovery steam generator, and a selective catalytic reduction system for installation on Lamma Power Station's 380 MW Unit 13 near Hong Kong.

▶Lamma Power Station. Credit: HK Electric

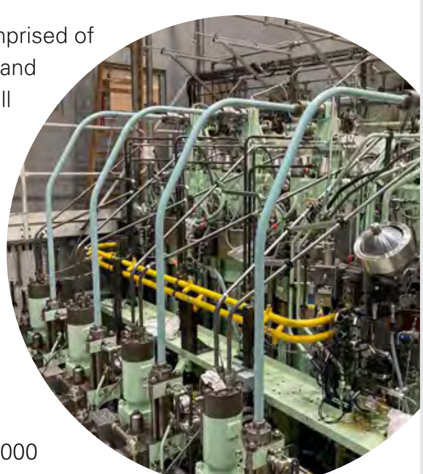
NZT Power Project Enters Execution Phase

bp's upcoming gas-fired Net-Zero Teesside Power station, equipped with carbon capture, entered the execution phase. Balfour Beatty will head up construction of the U.K. combined-cycle plant; GE Vernova will supply a 9HA.02 gas turbine, steam turbine, generator, and HRSG; and the assets will be integrated into the carbon-capture plant using Technip Energies' solution powered by Shell CANSOLV CO_2 capture technology.

◀ Rendering of NZT Power station. Credit: bp

MAN Energy Installs 7S60ME Ammonia Engine

A joint venture comprised of K Line, NS United, and the Itochu Corp. will explore the use of MAN Energy's 60-bore ammonia engine in a bulk carrier new build. Imabari Shipbuilding will install an SCR-connected B&W 7S60ME-ammonia engine for the 200,000 dwt-class bulk carrier.



▲ 7S60ME-ammonia engine. Credit: MAN Energy Solutions

Ansaldo Energia Parallels GT36 Turbine at Power Plant

Ansaldo completed the first parallel operation of its gas turbine in a new 800 MW combined-cycle unit at EP Produzione's Tavazzano and Montanaso power plant in Italy. The unit is comprised of a GT36 H-class gas turbine coupled to a steam turbine and two generators.

Why is Root-Cause Analysis Important for Turbomachines?

After a failure or unscheduled shutdown, if the root cause is not found and eliminated, it can happen again.

BY AMIN ALMASI

Root cause analysis (RCA) plays a major role in the reliability, maintenance, operation, and performance of a turbomachine. It is a problem-solving method used to identify the root causes of faults and identify corrective actions to prevent the problem/failures/faults from reoccurring—simply repairing or replacing a part is not enough.

For example, if a bolt is broken, there may be an incorrect bolt torque at installation, wrong bolt selection, inappropriate bolt material, etc. Any failed or damaged part should not necessarily be replaced with the same bolt. Based on RCA, a different part with superior material or a stronger structure might be used. Fixing the root cause usually prevents the whole sequence of events that led to a failure (or trip). In many cases, the failure is because of two or multiple deviations. All should be addressed.

CONSIDERATIONS FOR MAJOR OVERHAUL & REPAIRS

An important milestone for turbomachinery is a major overhaul (major shutdown), which is ideally planned every 5 or 6 years. Major overhauls are planned due to fouling, excessive vibration, misalignment issues, chronic problems, or malfunctions. During repair and maintenance, it is necessary to keep track of the tasks hour-by-hour. Before shutting down, take note of the final set of operational key parameters, such as hot alignment data. For failures or damaged parts, proper RCA should be completed, and root causes should be properly dealt with.

Special care is needed for the disassembly, inspection, and repair of key parts, such as lubrication systems and seal systems. Delicate or tiny parts including small valves, instruments, sensors, small orifices, etc. in turbomachinery systems or associated subsystems can be easily missed or damaged. Dirt or foreign materials can be introduced in lubrication oil or seal systems at major maintenance works that later cause serious problems at start-up.

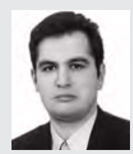
It is useful to get a sample of fouling and deposits on internal parts to determine how they formed and necessary to conduct a proper analysis to eliminate them. Rubs can be identified at major overhauls when turbomachinery is disassembled and could indicate a problem or

Some details or data, such as clearances, matches, etc., at disassembly are lost, and it is sometimes difficult to re-construct events and properly re-assemble the turbo-machinery package. Hour-to-hour notes, proper match marks, and neat/orderly writing can help to avoid such difficulties.

malfunction. For example, operation at critical speeds at high vibration amplitudes can result in some rubs. Too often some details or data, such as clearances, matches, etc., at disassembly are lost, and it is sometimes difficult to re-construct events and properly re-assemble the turbomachinery package. Hour-to-hour notes, proper match marks, and neat/orderly writing can help to avoid such difficulties. Component clearances, such as bearing clearances, are important to check and report during re-assembly. Bow check of the rotor is also important.

KEY CHALLENGES IN RCA

Several conditions can make RCA more time-consuming. Important information is often missing because it is generally not possible, in practice, to monitor everything and store all data for a long time. Secondly, gathering data and evidence and classifying them along a timeline of events can be difficult and time-consuming. Thirdly, there may be more than one root cause for a given problem/failure, and this multiplicity can make the conclusion difficult to establish. Fourth, the root causes often have several levels. Looking at many examples of turbomachinery RCAs, a deeper investigation could reveal that specification at the design stage, the operational procedure, or the maintenance procedure might be the root cause. ■



Amin Almasi is a Chartered Professional Engineer in Australia and the U.K. (M.Sc. and B.Sc. in mechanical engineering). He is a senior consultant specializing in rotating equipment, condition monitoring and reliability.

Carbon Capture and Storage is on the Rise

The number of carbon capture and storage (CCS) facilities in the pipeline is at an all-time high, with accelerating momentum for deployment and application across industries.

BY SPENCER SCHECHT, HONOR IOSIF, AND JOEY MINERVINI

CCS in operation at Chevron Australia's Gorgon natural gas plant, Western Australia. Credit: The Global CCS Institute

CCS is on the rise globally, as governments, industry, and communities grapple with the increasing urgency of addressing climate change. Data from the Global CCS Institute indicates a period of unprecedented growth, with the number and capacity of CCS facilities in the project pipeline at an all-time high. The Institute's *2023 Global Status of CCS Report* noted a 102% increase in CCS facilities in the pipeline compared to 2022: As of April 2024, there are 564 commercial CCS facilities in the project pipeline.

The Institute also noted accelerating momentum for CCS in industries beyond the lower-cost applications of gas processing, ethanol, and ammonia production. CCS is being integrated into industries such as cement, steel, chemical plants, power plants, and even carbon-removal technologies, such as direct air capture (DAC), bioenergy with CCS (BECCS), and waste-to-energy plants.

Despite this rise in CCS, the data show more efforts are needed to be on track with the scale of deployment required to meet global climate goals. According to scenarios by the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA), CCS deployment must scale up to gigatons of stored CO_2 per annum to mitigate climate change and reach net-zero emissions by mid-century.

NORTH AMERICA IS LEADING THE WAY

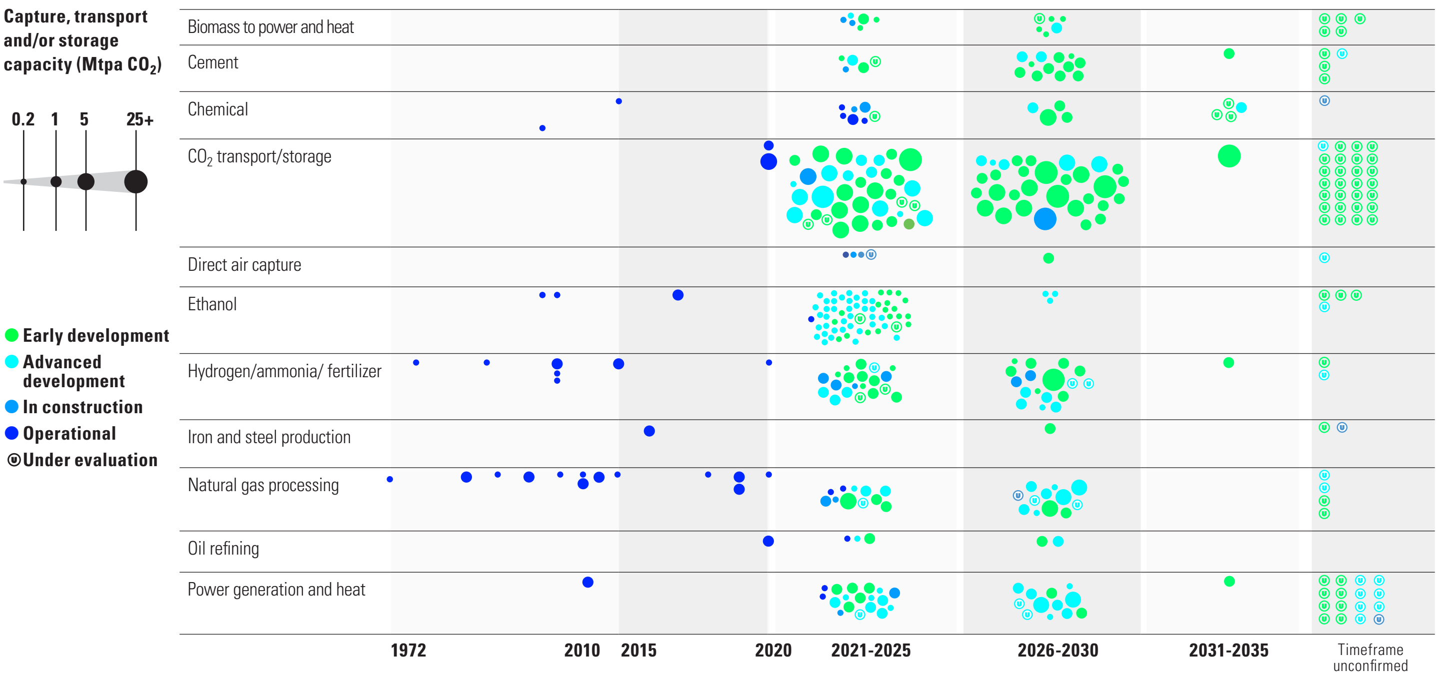
Scale-up of CCS project capacity is being driven mostly by North America, where the United States leads in deployment with 73 new CCS facilities entering the pipeline in 2023. The top applications for carbon capture in the United States are ethanol, ammonia, hydrogen, and fertilizer production, as well as power generation and heat.

U.S. CCS scale-up is supported by policies and clear regulatory frameworks, which have significantly improved the business case. Economic incentives include the enhancement of the 45Q tax credit for stored CO_2, now set at US$85 per ton, through the Inflation Reduction Act. Additional federal funding for CCS projects is accessible through initiatives such as the CHIPS & Science Act (2022) and the Bipartisan Infrastructure Law (2021).

The United States' goal of carbon-free electricity by 2035 has also turned attention to the potential to scale up CCS at fossil-fuel power plants. Projects at various stages of development continue at 23 power/heat facilities, with more than half planning to be operational in the late 2020s.

Considerable geological storage resource development is also underway in the United States, with the Environmental Protection Agency (EPA) receiving an unprecedented number of Class VI permit applications. As of March 15, 2024, 130 well permit applications for 44 projects were under review and an additional 69 well permit applications for 33 projects were being reviewed in states that have Class VI primary enforcement authority (Louisiana, Wyoming, and North Dakota).

In Canada, the federal government released its Carbon Management Strategy, setting out a vision for carbon-management technologies to be deployed to help achieve



CCS project pipeline by industry and year of operational commencement. Credit: The Global CCS Institute's 2023 Global Status of CCS Report.

the country's climate objectives. The 2023 federal budget also included significant support for CCS deployment, including an investment tax credit to cover up to 50% of the capital cost of CO_2 capture projects until 2030.

In Alberta, 25 storage hubs were proposed through the provincial Technology Innovation and Emissions Reduction Regulation (TIER). The province also announced that the Alberta Carbon Capture Incentive Program would provide a grant of 12% for new eligible CCUS capital costs to developers.

CARBON PRICE AND GOVERNMENT SUPPORT DRIVE DEPLOYMENT IN EUROPE

In Europe, the business case for CCS deployment is boosted through the Innovation Fund and Connecting Europe Facility as well as individual national subsidy programs. The carbon price of the EU Emissions Trading System (ETS) also provides an important incentive for hard-to-abate industries to consider CCS in their sustainability strategies.

Additionally, as part of the Green Deal Industrial Plan, the European Commission proposed the Net-Zero Industry Act in 2023, which seeks to scale up technologies that will drive decarbonization. The Act proposes an injection target of 50 million tonnes per annum (Mtpa) of CO_2 stored within the EU by 2030.

There are now more than 100 CCS projects in various stages of development in Europe, representing more than a 60% increase since 2022.

Denmark continues to develop CCS regulations and move toward implementation at speed, aiming to become a European CCS Hub by 2032.

The U.K. government in its Spring 2023 Budget announced it will invest £20 billion in CCS with a target of capturing 20-30 Mtpa of CO_2 by 2030.

The Dutch government has continued to reward deployment of CCS in 2023 through its SDE++ subsidy. In October 2023, the Porthos project reached a final investment decision. The Aramis project, which will offer CO_2 transport infrastructure from Rotterdam to multiple storage fields in the high North Sea, appears to be fully subscribed for the first 5 Mtpa of CO_2 capacity.

Progress on Norway's full-scale CCS project Longship continues, and Norway is awarding other exploration and storage licenses to expand its CO_2 storage capacity to meet growing demand.

BRAZIL'S PETROBRAS LARGEST OPERATING CCS PROJECT IN 2023

Although North America and Europe took the lead in 2023 for projects in the pipeline, Brazil's Petrobras was the largest operating CCS project. Petrobras reported it injected 10.6 $MtCO_2$ in 2022, increasing the total CO_2 injected to 40.8 Mt since operations began. Petrobras projects will reinject 80 $MtCO_2$ cumulatively by 2025.

MIDDLE EAST ON CUSP OF UPTREND

Both the United Arab Emirates (UAE) and Saudi Arabia have announced net-zero targets for 2050 and 2060, respectively. With abundant natural gas, geological storage resources, and existing expertise, oil producers in the Middle East are positioning to become major suppliers to the low-emissions hydrogen and ammonia export markets.

In the UAE, Abu Dhabi National Oil Company's (ADNOC) CCS projects are being implemented in stages, with 5 Mtpa of CO_2 capture expected by 2030.

In Saudi Arabia, the Al Jubail CCUS industrial hub will capture and store 44 Mtpa of CO_2 from industrial facilities by 2035.

NETWORKS AND HUBS CREATE EFFICIENCIES

In addition to vertically integrated CCS projects, the Institute has seen a rise in CCS networks and hubs, tracking approximately 115 networks globally in 2023.

These are becoming dominant modes of CCS deployment as they deliver the advantage of shared common infrastructure, which can provide economies of scale and allow several operators to leverage synergies between point-source carbon capture and CO_2 removal—all of which can shorten permitting timelines and create efficiencies during both development and operation.

NEW INDUSTRY CCS MODEL RECOGNIZED

With the rise of networks and hubs, the Institute has recognized a new CCS industry model developing in standalone CO_2 transport and storage facilities. These facilities are multi-user, multi-industry CO_2 facilities and are not limited to a single dedicated CO_2 capture source. In 2023, 101 of these facilities were identified globally.

DEVELOPING ECONOMIES NEED SUPPORT

Despite the robust growth in the CCS project pipeline, that growth is not distributed equally across the globe. Most CCS projects are being developed in advanced economies, with projects in developing economies far less common. More support is needed across the global south if climate targets are to be met.

By way of support, the Global CCS Institute created the Southeast Asia CCS Accelerator (SEACA) initiative to work with governments, multilateral organizations, and the private sector to help accelerate investment in CCS as an essential component of the region's broader efforts to mitigate climate change.

Scale-up of CCS project capacity is being driven mostly by North America, where the United States leads in deployment with 73 new CCS facilities entering the pipeline in 2023.

Countries such as Malaysia, Indonesia, Thailand, Brunei, and Timor-Leste are seeking to leverage oil and gas production expertise and infrastructure to establish CO_2 storage facility projects to both manage their own emissions and generate revenue from the storage of third-party CO_2.

Success can only be achieved through active collaboration between the public and private sectors. Waiting for the market to deliver CCS without a strategy, cooperation between governments and project developers, or the necessary policy interventions will not achieve the scale of deployment required to meet climate goals.

PROJECT FINANCING CRITICAL

Similarly, project financing needs to gain momentum. CCS facilities are capital-intensive, and the availability of finance is critical.

Currently, CCS projects are generally financed by corporate balance sheets, as project finance is not yet widely available. Recently, financing prospects have improved due to increased policy support and price signals. It is worth noting though that this increase is mostly in equity funding in developed economies benefiting from multiple revenue streams. There has also been an uptick in merger-and-acquisition activity and some consolidation of CCS service providers.

To reach the rates of CCS deployment required to support climate ambitions, project debt finance will need to be as common for CCS projects as it currently is for general infrastructure projects.

SCALING TO 2030 AND BEYOND

While there has been encouraging progress in CCS with good reason to be optimistic, there is still more work that needs to be done.

Achieving global climate targets will require annual CO_2 storage rates of approximately 1 billion tonnes per annum (Gtpa) by 2030 and multiple Gtpa by 2050. Reaching this gigaton scale globally requires significantly increasing CCS deployment, particularly in developing economies. Support in the form of capacity building, legal and regulatory framework development, and storage mapping will be essential to accelerate deployment.

Facilitating CO_2 transport and storage hubs to attract more capture projects would also help maximize the number of CCS projects deployed.

There is also a need to shorten project lead times without compromising the highest levels of safety, environmental stewardship, accountability, and community engagement.

With further collaboration among governments, industry, investors, and communities, the CCS industry can accelerate deployment and continue its dynamic path for scaling up through 2030 and beyond. ■

The lead author is Spencer Schecht, Senior Business Development Lead at the Global CCS Institute, an international think tank whose mission is to accelerate the deployment of CCS. Co-authors are Honor Iosif, Public Affairs Manager - APAC, and Joey Minervini, Public Affairs Manager – Americas.

Curbing CO_2: Technological Efforts to Reduce Carbon Emissions

Technology designed to reduce carbon emissions is supporting the power generation industry's move toward decarbonization.

BY JAMES COOK

In 2022, total annual U.S. electricity net generation by utility-scale electric power plants (at least 1 MW of electric generation capacity) of about 4.23 trillion kWh from all energy sources resulted in the emission of about 1.65 billion metric tons of CO_2, according to the U.S. Energy Information Administration.

With a continued emphasis on emissions reduction for the power generation and industrial markets, particularly in carbon and methane mitigation, companies are executing initiatives to address environmental concerns and meet sustainability goals. They are investing in upgrading equipment to reduce emissions and optimizing processes to streamline efficiency, thus minimizing the chance of excess CO_2 leakage.

COMPONENTS TO REDUCE CO_2

Companies like John Crane, MTU, and Siemens Energy are just a few participants in the carbon-reduction trend. Each has developed modified processes or new technologies to eliminate carbon output within their operations.

John Crane

John Crane retrofitted dry gas seals on oil and gas assets at a natural gas liquid extraction plant in the United Arab Emirates that wanted to lower emissions and operation/maintenance costs. The company replaced floating oil ring wet seals with dry gas seals on four centrifugal compressors. To accommodate the new dry gas seal cartridge, new seal housings for the low-pressure (LP) compressor were required.

Two Type 28XP seals were installed on the high-pressure (HP) compressors and two Type 28AT seals were installed for the LP tandem seal for the HP and LP compressors. Each unit was fitted with a Type 83 barrier, backed up by one seal gas support system with a nitrogen generator for each compressor. Following the retrofit, a rotor-dynamic study revealed a rotor instability issue. Thus, tilting pad journal bearings with squeeze film dampers were installed on the LP compressors.

The results of the retrofit are as follows:

- 97% reduction in CO_2 emissions
- Reduced upgraded bearing-type rotor vibration
- Successful startup and commissioning of compressor trains one and two
- Increased compressor reliability

At a pipeline station in Oman, John Crane performed a turnkey retrofit of two large compressor trains from oil seals to Type 28 dry gas seals, with the addition of the following assets and work: a gas seal system with a gas conditioning unit, filters, and a heater; separation seals; rotor dynamic analysis and modifications; and installation and commissioning support. The dry gas seals required a unique design to fit into the seal cavities. The LP and HP compressors were disassembled so their rotor and compressor casings could be modified to fit the new seals cartridges.

The pipeline station experienced the following benefits:

- 98% reduction in CO_2 emissions
- 2% less gas consumption during gas turbine combustion
- Eliminated process gas contamination and reduced oil removal costs
- Significantly reduced maintenance and energy costs
- Increased compressor reliability

MTU Maintenance Hannover

In December 2022, MTU Maintenance Hannover completed an energy project for a new office building and a nearby production facility. A heat pump was installed to provide both heating and cooling for the sites, supporting two gas-powered boilers by releasing and drawing ambient heat with the help of a compressor. Heating or cooling is released into the surrounding area through a water distribution system.

The heat pump produces different water temperatures throughout the seasons, cooling in the summer and heating in the winter. The cooling and distribution process generates 50°C warm water to be stored in buffer tanks, which is then heated further for varying production applications that require hot water. Considerable amounts of gas are saved by heating the water an extra 20°C instead of 40°C.

In the winter, cold water is transported back to the maintenance, repair, and operations plant to cool down its production machines. In the remaining seasons, spring and fall, the heat pump system lowers the temperature of warm water from the cooling network to 10°C. The cooling units' electricity usage is lowered during this process. Annual carbon emissions can now be cut, as for every unit of electricity consumed, the system generates four combined heat and cold units. For 2023, MTU Maintenance Hannover was able to save 219 tons of CO_2.

Thermal water approximately 2 km underground is set to largely replace MTU's current gas-based heat supply at the Munich HQ. Credit: MTU

Sigrid Huber, Director of Work Safety and Corporate Environmental Sustainability at MTU Aero Engines, said the company's increased use of photovoltaic installations through the MTU network has also supported reduced emissions. Currently, MTU Aero Engines is implementing geothermal technology at its Munich location to further decouple its operations from traditional energy sources. Once construction of the geothermal power plant is complete (the projected date is mid-2025), the site's heat supply will be largely independent of fossil fuels, thereby significantly mitigating its carbon emissions.

SOFTWARE FOR CO_2 REDUCTION

In addition to using physical components to minimize CO_2 output, companies often create software solutions to monitor and record emissions data for operators to take the next step in mitigation. The software often incorporates artificial intelligence and IoT to enhance efficiency and accuracy in data reporting, allowing end-users to develop comprehensive strategies or technologies to abate recorded emissions.

Siemens Energy's Predictive Emissions Monitoring System (PEMS) enables operators to make informed decisions and develop strategies to cut back on carbon output. PEMS is a digital solution that can predict exhaust emissions with internal system engine parameters, as well as use data from the gas turbine to create an algorithm that generates precise emissions signatures.

In addition to the PEMS variant, Siemens Energy also produces a physical version of the technology: the Continuous Emissions Monitoring System (CEMS). The CEMS product relies on physical sensors to analyze gas extracted from the exhaust; however, the system uses calibration gases that demand consistent maintenance. Both solutions are highly adaptable, allowing customers in the energy industry to view the emissions footprint for NOx, CO, and CO_2, and PEMS additionally reduces capital and operational expenditures.

PEMS is integrated with the Omnivise digital platform and is currently installed on several combustors around the world. Siemens Energy reports more than eight successful installations on dry low emission (DLE) and non-DLE combustors.

THE PATH FORWARD

As industries like power generation and oil and gas seek to curb their carbon emissions, a concerted effort is underway to adopt innovative technologies and strategies. Companies are investing in equipment upgrades and process optimizations to minimize CO_2 leaks, aligning with global sustainability goals.

With continued collaboration between private companies, government agencies, and international organizations, the path to a greener future in the power generation and industrial sectors becomes clearer. As these initiatives progress, the industry is poised to achieve significant reductions in carbon emissions, paving the way for a more sustainable and efficient energy landscape. ■

GE Vernova's Gas Turbine Manufacturing Facility

GE Vernova's center in Greenville, SC operates as a validation testing facility, technology laboratory, and repair shop for the company's gas turbine portfolio.

BY JAMES COOK

Greenville, South Carolina, rooted in the manufacturing industry and home to approximately 60,500 manufacturing employees across numerous companies, is the headquarters of GE Vernova's Gas Turbine Manufacturing and Technology Center. Built on 413 acres of land with over 1.7 million square feet of manufacturing space and laboratories, the facility has been a gas turbine manufacturing plant since 1968. Currently, the grounds contain a gas turbine technology center, a repair center, combustion manufacturing, an outage simulator, a variety of test stands, and the gas turbine technology, combustion, and static load labs.

In early spring 2024, *Turbomachinery International* toured GE Vernova's facility, which employs thousands of local residents, contributing to the region's long-standing history of manufacturing.

THE SHOP FLOOR

The tour began on the manufacturing shop floor with Ed Stefanik, Greenville Plant Manager, leading the charge. Originally established as a gas turbine manufacturing facility and later expanded, this segment of the campus is operated according to GE Vernova's "lean" manufacturing principles.

The goal of lean is to eliminate waste across the board: eliminating redundant work, tracking goals in a centralized meeting space, reducing the physical footprint of each machine, and more. This lean idea even extends to reducing the distance that a part may travel while on the shop floor: The company reduced the average distance of buckets traveled from 3.1 miles to just over 300 feet.

The fourth gas turbine assembly bay, cleverly dubbed "D Bay," gave insight into the assembly process and sheer number of machines that flow through the area. According to Stefanik, GE Vernova shipped out 3,300 gas turbines from Greenville since the start of operations, all of which came through D Bay.

Turbine casings are lifted on vertical assembly stands in D Bay for drilling, alignment, and bolting processes that take approximately five days. In the next step, "The [assembled casing] is laid down horizontally. It then goes into one of these build stands, we take off the upper half casings, and then we load all the internal components including the rotor," said Stefanik. "That process takes between seven and 14 days."

The manufacturing space also conducts maintenance, repairs, and overhaul work on turbines that have met their maximum operating hours in the field. Many of the models in this area have been operating since the late 1990s and early 2000s.

"Our engineering team brings the older turbines in to do a full inspection, make some repairs, and replace components, and can recertify them for approximately 80,000 hours of extended life," said Stefanik. "A lot of the upgrades and expansions in the next steps of our lean journey are heavily focused on rotor repair."

TEST STAND 7

Our team's next stop was Test Stand 7. It contains six critical components: a starter motor, drive motor, torque converter, gearbox, load compressor, and the gas turbine being tested.

A One Field Services employee demonstrates field technologies in the gas turbine outage simulator. Credit: GE Vernova

"It's a 50-meter drive train—we start with an 88SM motor for initial acceleration and a drive motor for acceleration to full speed. Then a torque converter and gearbox allow both 50 Hz and 60 Hz operation," explained Cody Ford, Senior Engineering Manager. "We use a load compressor to simulate being on the grid."

Air is fed into the test rig via large ducts that span the ceiling and connect to the drive train's compressor section. Throttling valves help transport the load through a shaft to the gas turbine. The model currently hooked up is the company's advanced 7HA.03 gas turbine—one of the many since 2011 to come through the facility for full-speed, full-load validation.

The entire testing process typically takes several months before shipping out via rail, and the facility can test either natural gas or liquid fuel based on a customer's needs.

GAS TURBINE OUTAGE SIMULATOR

We discovered on our walkthrough of the outage simulator—hosted by Karen Maud, Senior Engineering Manager; Tom Mogle, Technical Leader; and Dave Runkel, Lead Tooling Engineer—that the facility is home to a space for GE Vernova's engineers to brainstorm and develop tools to make the millwrights' work more efficient and pain-free. Parts and tools are 3D-printed to prototype their use in the field before final development and implementation.

Runkel highlighted a recent tooling development that helped millwrights access the lower section of the gas turbine, reducing physical exertion and assisting in nozzle extraction and component installation. "We came up with a temporary gantry crane that we mount to the horizontal joint that goes down [to the lower half of the turbine]. We also designed additional tooling that allows us to attach components to the lower half and pull those components without needing to send someone down there—that saves a lot of time and is much safer for our teams."

During the Live Outage tour, Jeremiah Smedra of Value Stream Programs explained

Cody Ford gets a bird's eye view of Test Stand 7. Credit: GE Vernova

that the field procedure documents started as an onsite paper-based program and developed into a fully integrated, digital information and reporting system. Multiple routers provide Wi-Fi and site data directly to devices, such as tablets and large screen monitors, for a field procedure app used by the onsite team. The app offers a centralized hub with access to work tasks, technical documents, lists of parts, images, and demonstration videos.

"Historically, the shift turnover notes were done in Word documents by the field engineers. Now, we can start to aggregate what was done from the tablets and auto-populate lists," said Smedra. "Then, when the field engineers put their open items in, we can aggregate those at a regional level. Our ability to see things, understand things, and bring resources to bear—that's a game changer."

THE TESTING LABORATORIES

Combustion testing is a vital aspect of GE Vernova's services in Greenville, using a variety of fuels and operating conditions to allow experts to assess the performance of a gas turbine in real-time. Diana Setzer, Senior Engineering Manager; Will Moore, Technical Leader in Testing; Will York, Technical Leader in Combustion Design; and Fabien Codron, Senior Product Manager, guided the tour through its Combustion Lab Control Center and Testing Lab. The control center is manned by the engineering team and the data recording team, examining live video images of the combustor during full-speed, full-load tests.

The lab conducts early developmental testing with renewable fuels, such as hydrogen, to assess combustion performance, component durability, and levels of emissions within GE Vernova's emerging technologies. Dry low NOx (DLN) technology is currently a heavy focus of the combustion lab.

"GE Vernova is testing DLN technology, which employs lean pre-mix combustion," said York. "The reason we use lean pre-mix combustion is if we pre-mix the fuel and air well, then we can have lower emissions than our diffusion flame combustors. Instead of maybe 200 - 300 parts per million of NOx, we're able to get some of our F-class combustion systems down to single digits."

The testing lab displayed a variety of parts for one of GE Vernova's combustors, and York explained how the company's developed technology can work with hydrogen-natural gas blends while avoiding roadblocks presented by hydrogen's inherent characteristics. Controlling the hydrogen flame and flashback requires special consideration with a DLN system.

"We designed our micro-mixer fuel nozzle, which consists of a bunch of small tubes that air flows through, into which fuel is injected. These are made with additive manufacturing and produce small jet flames," said York. "The advantage now is that the flow goes straight through and it's aerodynamically clean—you use turbulent diffusion and jet in crossflow mixing and get compact flames. This runs much better on hydrogen without flashback than earlier DLN systems."

GE Vernova's 9F.05 gas turbine assembly area. Credit: GE Vernova

The micro-mixer technology was tested to run up to 100% hydrogen at the lab but was later retrofitted to include the use of natural gas to create the DLN2.6e combustor, which can burn on blends of natural gas and up to 50% hydrogen. According to York, many operators want the ability to switch between fuels based on available supply and a variety of operational factors.

WHAT'S NEXT?

GE Vernova spun off from GE as a standalone entity on April 2, 2024. It will now comprise three operating segments—power, wind, and electrification—and is supported by its accelerator businesses. The company continues to focus on providing a multitude of power solutions for its worldwide customer base to help them power economies and deliver electricity. The standalone will continue to conduct research and product development with emerging fuels and technologies, all the while working in tandem with federal regulations to ensure a cleaner future.

Innovations such as advanced manufacturing techniques, combustion testing with renewable fuels, and large-scale project data aggregation are tools GE Vernova is using to achieve its overarching goals. A lean approach is ingrained within every facility, process, and piece of machinery put out by GE Vernova, eliminating waste to accelerate the company's future growth.

"In Japanese, 'kaizen' means continuous improvement," said Chris White, Communications Leader, GE Vernova's Gas Power Business. "When you come in as a cross-functional team on a Monday, you leave on Friday with a different process. That's how we accelerate GE Vernova's growth and improvement. Kaizen is a key part of the lean methodology and central to who we are as a company." ■

Go to turbomachinerymag.com/videos for more coverage from our onsite visit.

Digital Ecosystems Optimize Plant Efficiency & Safety

Digital tools can extend a turbomachine's life, optimize plant efficiency and maintenance, and more.

JAMES NYENHUIS
Performance Consultant
Emerson Power and Water
Solutions Business

Jim Nyenhuis, the Performance Consultant at Emerson's Power and Water Solutions Business, spoke with *Turbomachinery International* about the various benefits and uses of software, including artificial intelligence (AI) and machine learning (ML) in a power plant.

Q How does a digital ecosystem improve operational efficiency, plant safety, etc.?

Nyenhuis: Digital technologies allow us to address all those issues. We work with customers to understand what operational efficiency means to them based on their objectives. Plant safety is without question built into everything we do. We want to understand and leverage what the underlying technology can tell us and let that information feed up through the digital ecosystem—how do we understand what's working well at the plant level, how do we identify if there are control problems or if individual pieces of equipment are having issues? A lot of that information is lying within the automation infrastructure, and I don't think we've leveraged that to the degree we want to. We find many customers do not understand the performance characteristics of their closed-loop controls or areas to drive additional improvement, efficiencies, etc.

Performance and control management is another big area that we look at. Our information, such as the automation system, will oftentimes track what operators are doing within the system. In the past, that information was stored in text-based logs, but there's a lot of valuable information stored in those log files that if we expose it, we can understand how operators are interfacing with the system during different periods of operation, be it startup, shut down, various operating modes, etc., and based on that we can determine where operators are spending a lot of their time.

Q How do intelligent detection and monitoring technologies increase a turbomachine's lifecycle?

Nyenhuis: We want to ensure that we're monitoring the right things and keeping the operations within the OEM limits of that asset—gas turbine, steam turbine critical pumps, etc. We want to coordinate with our customers on how to provide the right guidelines and additional levels of automation to ensure that those assets are not operated outside their design specifications and parameters. In many cases, this means determining what additional levels of monitoring we can deploy to track things that may not be necessary for control but could tie into the larger picture of the evolving life expenditure and the amount of critical stress being put on that asset. These additional levels of monitoring can be deployed and then folded back into technologies to understand the operational impact of the asset's long-term life.

Q What about cybersecurity—what kinds of risks are power plants exposed to?

Nyenhuis: That's a critical issue, and it comes up in everything we're doing—and certainly within this digital ecosystem. There is an expectation from our customers that cybersecurity is thought of at all levels of deployment, even individual things driving valve positioning. Those risks are real in the plants and critical infrastructure assets that we deal with. As solution providers, we're looking to build cybersecurity capabilities all along that chain—from the lowest-level field device implementation to software that manages those devices with real-time control systems and the cloud. This capability becomes a bit more efficient and streamlined when we have a seamlessly integrated digital ecosystem where we can share some of the expectations of what is running and how we manage security throughout.

Q Cost and integration are two barriers that can keep an organization from upgrading or implementing new digital tools. How does Emerson address these and other concerns?

Nyenhuis: We primarily want to ensure that the current solutions are functioning as they should. As we engage with our customers, it's very common that we are not fully deploying and realizing the benefits of the solutions already there.

As new solutions in monitoring, AI, and ML come out, there are two components we are seeing: On the one hand, we need to have templated solutions that we can drop in—a standard and automated approach to develop models and deploy solutions against critical templated assets. This gives us an efficiency of deployment from a cost and value perspective to the end users. On the other hand, customers need a level of customization. Whatever solution platforms we deploy, there needs to be a component that allows a customer to, when they find situations that are specific to them, have the means to step outside those templated deployed solutions that cover 80 - 90% of the situations and be able to customize things to meet their needs.

Q How does Emerson see the future of AI-based software and envision the role of cloud-based analytics in shaping the future?

Nyenhuis: As we continue to evolve toward the future, AI and ML will become an inherent part of what we are already deploying. They are the enabling technologies that allow us to take the vast amount of information available and encapsulate and interpret the relationships that those things tell us. As we actively work in this area, we see the need for overarching contextualization of the various data. In a traditional plant scenario, we might organize things at an asset level in our ERP and computer maintenance management systems or folks only maintain individual parts and assets. But we want to work toward a consistent frame of reference that allows the data from these disparate pieces, pieces of that digital ecosystem, to efficiently flow together so these enabling technologies allow us to pull the right information from different systems and aggregate them together and put them in the right context to make decisions. ■

Visit turmachinerymag.com/podcast to hear the full interview with Emerson.

WTUI 2024

Highlights, Challenges, and Best Practices in Running GE Aeroderivatives

User communities benefit from WTUI's "hands-on" maintenance-and-repair approach for LM units.

BY DREW ROBB

The 33rd annual Western Turbine Users Inc. (WTUI) conference took place in late March 2024 in Palm Springs, CA. Almost 1,100 attendees were welcomed by WTUI President Ed Jackson, Plant Manager at Missouri River Energy Services' Exira Generating Station in Brayton, Iowa.

"A strong user group like WTUI challenges OEMs and equipment suppliers to improve their products as we demand new uses and extend the lives of our equipment," said Jackson.

He introduced the authorized service providers for LM turbines: IHI Power Services Corp., MTU Maintenance, and TransCanada Turbines—each briefed the audience on their service offerings. Clive Nickolay, CEO of GE Vernova's Aero Business Line, then addressed various deficiencies in the supply chain for vital components and repairs. He laid out a few details of ongoing reorganization efforts that are taking place to speed up delivery, debug parts availability, and reduce the time taken to return a unit to the customer.

"Demand for materials, components, and engines is exceeding supply across the aero-engine space," said Nickolay. "We are maximizing the reuse of existing materials and components, beefing up our supply-chain options, and working out ways to increase the repairability of parts. We are also lowering lead times by placing stock in the right places within the supply chain, so they are closer to our depots and end users."

Jim Vono, President and CEO of FieldCore and One Field Services Leader at GE Vernova, followed up by explaining the top factors being worked on to further upgrade field-service safety. He named turbine lifting operations as the highest risk area.

"We are finding better ways to lift turbines safely," said Vono.

Hydraulics and pneumatics represent another area of high risk. If the turbine is running and these systems fail, there is a risk for those in the line of fire.

BREAKOUT SESSIONS

A big reason for WTUI's continuing popularity is the level of detail provided on every possible aspect of maintenance for LM2500, LM6000, and LMS100 units. Even the LM5000, which has reached its end-of-life, merits its own discussion forum during the event. After all, there are some of these units still running in the field. Despite the OEM no longer supporting it, the user community meeting provides valuable insight into how to find LM5000 parts and fix problems, and offers advice on workarounds to keep these machines running.

For three days, the event featured breakout tracks for each LM engine. The LM2500 track, for example, was guided by Garry Grimwade, who has operating and maintenance responsibilities for four LM6000s, four GE 10s, and an LM2500-powered combined-cycle unit at Riverside Public Utilities in California. Over the course of the week, he MC'd user discussions and had representatives from GE Vernova brief users on various problems and their recommended fixes. Turbine operators asked questions and heard from their peers about how they solved different challenges.

HRSG MAINTENANCE

Jack Odlum, an engineer at the heat recovery steam generator (HRSG) inspection and repair firm HRST, led a session on the basics of HRSG maintenance. The theme was how to use planning to prevent unnecessary delays during outages. After all, aging HRSGs experience problems such as pitting, creep, and fatigue. He recommended that inspections be done ahead of any major outages and covered the different ways to conduct them. Non-destructive examination (NDE) techniques, he said, include the use of sophisticated camera equipment to detect what the eyes might miss or cannot see. Here is a list of common types of NDE techniques:

- **Ultrasonic thickness (UT)** is used to determine the thickness of a specific component. This is a good way to check for corrosion.
- **Phased array ultrasonic** testing is used to identify any inside diameter cracks or weld voids as well as find other subsurface issues. For external cracking, though, dye penetrant tests and magnetic particle techniques can be employed.
- **Pulsed eddy current (PEC)** determines the relative thickness of ferromagnetic material underneath coverings such as stainless-steel bellows and insulation.
- **Replication** copies the grain structure to identify signs of material creep.
- **Hardness** testing is used to understand material properties.
- **Infrared imaging (FLIR or IR)** reveals the operating temperature on seals, casings, and other surfaces.

Alternatively, borescopes are used to inspect tubes, piping, and other internals inside HRSGs. Drones can also be used to view elevated components.

"Drones are a good way to avoid the need for scaffolding, but they can also spot problems where scaffolding will be required," said Odlum.

The presentation laid out what to look for while inspecting different HRSG components, such as economizers, steam drums, superheaters, and evaporators. Economizers heat water to near saturation before it goes to the evaporator. This increases the amount of steam production. A common issue is flow-accelerated corrosion (FAC). Borescopes and UT are good inspection techniques for FAC. PEC inspection can also be used to inspect what might be happening underneath insulation, such as the presence of drain corrosion.

Odlum provided an example. Operators knew there was an economizer leak but didn't know the precise location. This leak eventually caused a drain failure. When the failed drain was found and replaced, an inspection of the other drains detected extreme corrosion that needed extensive repair. In turn, engineers then checked a sister unit using PEC to see if it suffered from similar corrosion issues. No leaks were found; however, three pipes were identified that needed to be replaced to prevent future leakage issues.

Odlum recommended spot-checking high-risk FAC areas such as tube inlets and headers before or during any outage window. He offered LM turbine users further tips related to the typical kinds of damage that might impact HRSG evaporators and steam drums as well as the best inspection methods and repairs to address them.

DRY LOW EMISSIONS CONTROLS

Next up, Marc Forget of the European Maintenance Support Aero Department at Engie Electrabel, delved into the intricacies of dry low emissions (DLE) controls for GE LM-series machines. He said DLE is all about reaching a compromise between NOx and CO emissions. If you lower the flame temperature, the CO rises, but a higher flame temperature leads to more NOx.

"You have to find the sweet spot within the thermal limits of the unit," said Forget. "The use of a premix system helps to ensure combustion is as complete and as lean as possible."

When a premix combustion system is involved, it causes humming and vibration of the flame. This excites the mechanical components of the engine. Good monitoring and appropriate controls are needed to compensate. Forget stressed the need for accurate temperature controls and the right combustion system design.

He demonstrated his long years of experience and expertise with DLE systems as he explained the dos and don'ts of instrumentation related to DLE systems, such as gas quality and combustion stability measurement tools. There is a lot to know about how to measure different parameters, calculate fuel-flow rates, and maintain DLE combustion systems. He told attendees about various gotchas when removing delicate sensors and instrumentation components, such as Honeywell gas pressure transducers and Woodward fuel metering valves.

"A good wear-mitigation technique is to power down fuel metering valves when the gas turbine has been stopped," said Forget. "Also, you should track valve run hours and protect them against water ingress to avoid problems."

EXCITATION CONTROLS

Another vendor presentation came from Ian Golightly, Senior Controls Engineer at BRUSH (part of Baker Hughes). He discussed the elimination of obsolescence and unscheduled outages by upgrading excitation controls. Older GE aeroderivatives often use analog controls, such as the modular automatic voltage regulator (MAVR), the MicroAVR, and the Prismic A30. These systems sometimes struggle on modern grids where the presence of renewables necessitates fast response and accurate measurement.

"Modern digital AVRs and protection relays can better support and more rapidly synchronize with modern power grids," said Golightly. "Excitation performance on analog controls may not be compliant with the latest NERC regulations."

He explained how to protect relays so they don't trip generators before the AVR limiters operate, as well as the kind of generator protection systems that can adequately prevent damage if turbine operating conditions exceed capability or stability limits.

The 2025 WTUI conference will be held in Long Beach, CA, March 30 – April 2. ■

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CERAWeek 2024 BY S&P:

Houston Energy Conference Draws Thought Leaders on Climate Change

The blockbuster event tackled energy and power markets, supply chains, net zero, and beyond, but the biggest surprise may have been artificial intelligence.

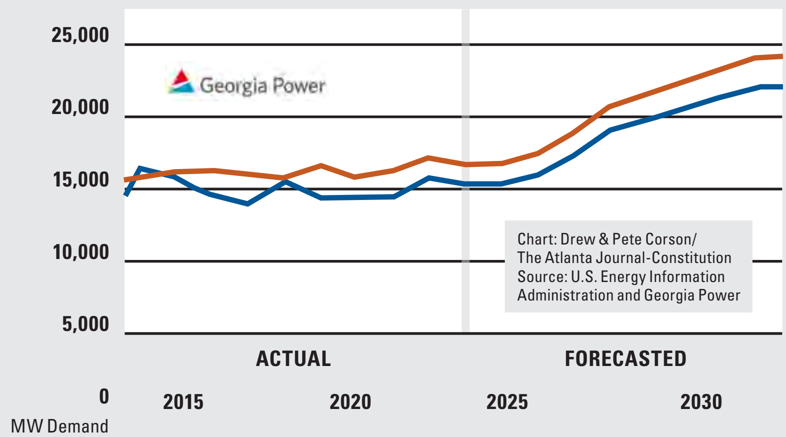
BY MARK AXFORD

Some people call it the Super Bowl of the energy world—this is the 41st year of the famous CERAWeek by S&P Global. Held March 10 – 14 in Houston, this year's theme was multidimensional energy transition: markets, climate, technology, and geopolitics. Maybe too long of a title, but it's hard to be brief about a conference that draws 9,000 attendees and more than 600 speakers from 80+ countries.

Bill Gates talked about a new modular nuclear power technology that is funded and ready for the first installation in Wyoming. Also on stage were the CEOs of ExxonMobil, Chevron, OXY, ConocoPhillips, Hess, TotalEnergies, Saudi Aramco, bp, Petrobras, Siemens Energy, Mitsubishi Power, Baker Hughes, Williams, Cheniere LNG, Bechtel ... and the list goes on.

Each participated in panel discussions and one-on-one interviews with Dr. Daniel

AI Data Centers Boosting Demand



Utilities Scrambling for Generation

Yergin ("Dan"), author and co-founder of CERAWeek.

There were also international government officials, including Danielle Smith, Premier of Alberta, Canada, and the ministers of energy from Kuwait, Brazil, Abu Dhabi, and beyond. The discussions ranged from oil and gas markets, renewable energy, climate change, battery storage, and electric cars.

But there was an elephant in the room that kept popping up in every discussion: artificial intelligence (AI)—the effect of AI on all aspects of the energy business. Numerous U.S.-based utilities got a surprise in 2023: Their forecasts for future electricity demand required large revisions due to the explosive growth of AI data centers.

Data centers have been around since the late 90s as passive warehouses to store customer data for banks, Amazon, and the like. However, there is a new breed of data centers for AI applications. The AI data center is more than a warehouse; it utilizes data as input to *manufacture* an intellectual product. The sophisticated chips made by NVIDIA run faster and hotter and consume five times more electricity, much of it for cooling, as a legacy data warehouse. These AI data centers run 24 x 365 baseload and demand high levels of reliability. They tend to be located near metropolitan areas that have strong fiber optic infrastructure.

Loudon County, Virginia has the largest AI data center concentration in the world. It is served by Dominion Energy, which is racing to get additional gas turbine generators installed. Dallas and Atlanta also have attracted large numbers of AI data centers. Georgia Power, the utility that serves metro Atlanta, recently stunned regulators when it disclosed a huge correction to its load forecast, pointing to AI data centers as the main culprit.

Many big cities are now pulling back the economic incentives previously offered to attract data centers. Soaring power consumption is also delaying coal plant closures in Kansas, Nebraska, Wisconsin, and South Carolina.

You might say there was a second elephant in the room: the recent "pause" to the permitting of new LNG export facilities by the U.S. Department of Energy (DOE). With the United States now being the largest producer of LNG, all the major players were in the auditorium listening to U.S. Secretary of Energy Janet Granholm explain that the Biden Administration's pause should be "well in the rearview mirror" by early 2025. She said the pause was called for "in order for our DOE labs to conduct a data-based assessment of what further expansions of U.S. exports mean for our climate, for global energy, for national and global security, our allies and for domestic prices."

The audience was not impressed, especially Senators Joe Marchin and Dan Sullivan. "The pause ought to be paused immediately." A pause cannot be called temporary if it has no end date—that's a freeze.

Interesting to note that on March 22, the last day of the conference, 16 U.S. states filed suit against the U.S. government stating: "The LNG export ban is not justified by any statutory authority and thus is beyond the President's powers," and stated that the ban is "arbitrary and capricious" and "unconstitutional."

Among the 16 governors signing the lawsuit was Alaskan Governor Mike Dunleavy.

Dunleavy was concerned that without an immediate reversal of the pause, buyers of U.S. LNG would worry that purchases might be affected by future presidential edicts. Indeed, within days after the pause was issued on Jan. 26, the country of Qatar announced funding for a major expansion of its LNG export complex. Also, Russia announced to Europe the availability of additional LNG supply.

Dunleavy noted that Alaska is developing a US$43 billion LNG export terminal near Anchorage and while it is not directly affected by the pause, the quest for private financing will be damaged. Dunleavy has also been frustrated by questionable restrictions placed on drilling and exploration for minerals on federal land in Alaska. He summed it up by saying, "This won't be cleared up for Alaska unless Donald Trump is re-elected."

No surprise that many aspects of energy policy in the United States and other countries are often at the top of the political agenda. ■

Mark Axford is the founder of Axford Turbine Consultants and is a contributing editor for Turbomachinery International.

MYTH: Nothing Lasts Forever, Not Even Coatings

Turbomachinery coatings are designed to be an added layer of protection for base materials, but even coatings wear down.

BY KLAUS BRUN & RAINER KURZ

I recently accompanied my wife to a nail salon and watched in utter fascination the level of care and sophistication with which the young manicurists treated and painted my wife's nails. There were several cleaning steps, surface pre-treatment, and, as far as I can remember, at least three layers of different coatings and goofily colored nail paints. The process obviously has to be repeated every couple of weeks, at a substantial cost. This, I felt, was a little exaggerated, but I was smart enough not to voice my opinion to my wife.

On the other hand, I often see the internals of the compressors, steam turbines, or gas turbines where the blade coatings are in deplorable conditions, with large areas worn away and, in some cases, completely flaked off. So, why can't we put the same love and care into the coating of a blade that my wife puts into painting her nails? A multi-million-dollar turbomachine certainly deserves to be treated with a lot of care, albeit maybe not as much as my wife requires. The answer is another cliché: Nothing is perfect (except maybe my wife).

The most basic function of a coating is to protect the blade's base material. But that is not the entire story. Specifically, it is often difficult to find a suitable material that meets all the critical operational requirements for a specific turbomachinery internal flow path application. In these cases, a coating can sometimes be utilized that exploits the physical or chemical advantages of two or more materials. Coatings can be designed to address multiple problems simultaneously, such as wear, erosion, corrosion, and fouling. Similarly, coatings are also often used to reduce blade or casing construction costs by protecting the surface of a less-expensive base metal.

WHAT IS A COATING?

A coating is one layer of one substance over another. This creates a composite system that enhances the properties beyond those of each constituent alone, i.e., the whole is greater than the sum of the two parts. In modern turbomachines, coatings are vital to overcoming many technological limitations. For example, in gas turbines, thermal barrier coatings in combination with cooling are used to allow hot sections of the turbine to heat well above the temperature of what the base metal would be able to handle. Similarly, in compressors and steam turbines, anti-erosion coatings are often used to drastically extend the life of the blades in very harsh operating environments.

There are many types of coatings used in turbomachines. Their selection and application come down to form, fit, and function—what is the machine supposed to do, and what does the design need to protect or enhance?

The most common coatings in turbomachines are used for:

- wear protection
- shielding
- anti-fouling
- erosion protection
- corrosion protection/anti-pitting
- drag reduction
- oleophobic and hydrophobic surface protection
- thermal barrier and heat transfer protection/insulation
- sliding wear
- electrochemical attack
- cosmetic enhancement

Coatings can be made from different materials such as simple metals (e.g., titanium, nickel, and chrome), organics (e.g., Teflon and polymers), high strength/hardness alloys, and various types of ceramics. They can be applied using cold and hot sprays, weld overlays (cladding), dipping, chemical reactions, baking, and chemical/physical vapor depositions.

UNFORTUNATELY, NO COATING LASTS FOREVER

The same forces that a coating was designed to protect against will eventually cause all coatings to fail. The most common coating-failure mechanisms are liquid or solid erosion, mechanical surface wear, corrosion and pitting, flaking due to lack of adhesion, thermal and chemical blistering and cracking, and spallation due to mechanical or chemical incompatibility of the coating layers or base material. Thus, from a turbomachinery-design perspective, a machine cannot be designed to solely rely on the coating to avoid any type of catastrophic failure or performance deterioration. Instead, all coatings are intended to extend the design life and performance of the machine.

However, the base material design must allow the machine to be functional for some time even when the coating has failed. Thus, coatings are an enhancement and not a stand-alone protection. If an internal turbomachine coating wears away, the machine cannot just fall apart because it relies on the coating to properly function. This is reflected in standard machine design standards such as NACE MR0103/ISO 17945, which state that a coating can be used but the base material itself must be NACE-compliant without the coating. Coatings solely serve as an added layer of protection to something that, in its base function, must be adequate by itself.

Finally, when designing a turbomachine's internal surface and appropriate coatings, one also needs to consider the coating's mechanical interaction with the base material. Coatings are physically connected to the base material and therefore can have an impact on the mechanical and dynamic properties of the base material. For example, a coating can affect the stiffness and damping of a blade, which can change its natural frequencies, mode shapes, and overall dynamic behavior.

When developing a new coating for a turbomachine or applying an existing coating to a new turbomachinery part, the coating's function, life, durability, adhesion, wear resistance, and mechanical/chemical properties must be carefully considered. Coatings can significantly enhance a turbomachine's performance and life but remember that no coating will last forever. ■

(Derrick Bauer of Ebara-Elliott contributed to this article.)

Klaus Brun is the Director of R&D at Elliott Group. He is also the past Chair of the Board of Directors of the ASME International Gas Turbine Institute and the IGTI Oil & Gas applications committee.

Rainer Kurz is a recent retiree from Manager of Gas Compressor Engineering at Solar Turbines Inc. in San Diego, CA. He is an ASME Fellow and has published over 200 articles and papers in the turbomachinery field.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