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CCUS
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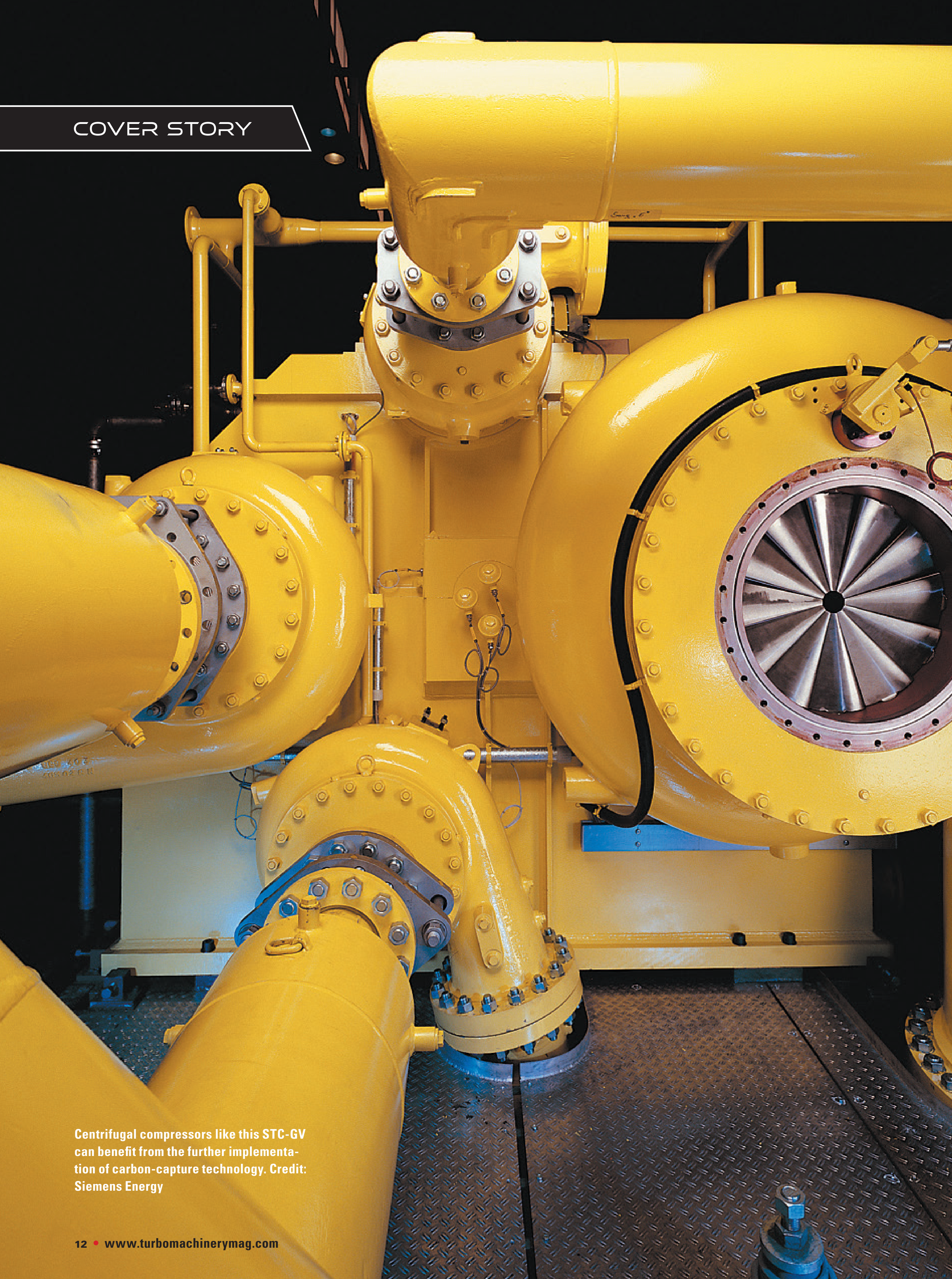

Centrifugal compressors like this STC-GV can benefit from the further implementation of carbon-capture technology. Credit: Siemens Energy

The 'Green New Era' for Turbomachinery?

Carbon capture, utilization, and storage technologies are set to play a diverse role in net-zero emissions goals.

BY TIMOTHY LUKAC

Carbon capture, utilization, and storage (CCUS)—which aims to reduce carbon emissions while simultaneously contributing to the development of a circular carbon economy—is set to play a diverse role in meeting global climate goals. With green initiatives on the rise and regulatory bodies becoming more imposing on emitters, curtailing emissions is now a top concern for carbon-producing entities. To solve this problem, innovative solutions are entering the industry. Fueled by direct support from world leaders and governments, CCUS technologies are one pathway to achieving net-zero emissions. So, what role is the turbomachinery industry playing?

HOW DOES TURBOMACHINERY PLAY A ROLE IN CCUS?

Carbon dioxide (CO_2) compression can be seen as a critical element in carbon-capture storage applications, which makes it an essential building block in the larger picture of global decarbonization.

"Among compression methods, integrally geared centrifugal compressors are a preferred rotating hardware because of the special behavior of CO_2 and the challenging requirements of CO_2 applications," said Ulrich Schmitz, Vice President Marketing at Atlas Copco Gas and Process.

CO_2, like other high mole-weight gases, increases its temperature during compression, making the interstage cooling provided by integrally geared compressors an energy-efficient and cost-effective characteristic, Schmitz explained. Turbomachinery plays an important role in CCUS processes, for example enabling the transportation of the gas by compressing it. Without this essential component, handling CO_2 in the long term would be much more difficult. Compressors also come into play later in the value chain with the creation of aftermarket products. Thus, compressors can be seen as the crux of carbon-capture value generation.

LARGE-SCALE ADOPTION

Large-scale adoption is a challenge in both the United States and Europe. One way to increase adoption is through regulatory avenues. The United States passed the Inflation Reduction Act (IRA), which includes $369 billion in green energy grants and subsidies to accelerate the reduction of carbon. In March, Europe proposed the Net-Zero Industry Act, which aims to establish a framework of measures for strengthening Europe's development of net-zero technologies.

Following the passage of the IRA, Aniruddha Sharma, Chair and CEO of Carbon Clean, a UK-based company focused on carbon capture solutions, said: "Carbon Clean has experienced a 64% leap in inquires, and we expect the United States to become one of our largest markets," Sharma said. "In March, we announced a significant expansion in North America to meet this booming demand. [We opened] a U.S. headquarters in Houston and are currently developing a local supply chain."

Sharma said government support is needed to push CCUS at a significant scale, including policies to economically support these endeavors. This includes setting financial rewards, simplifying the permitting and planning process, ensuring storage sites are developed quickly, and putting a focus on regulation that supports the growth of CO_2 infrastructure and equipment.

The U.S. Department of Energy (DOE), through the National Energy Technology Laboratory (NETL), is working on promoting and developing carbon capture and storage (CCS) technologies. In a recent panel at PowerGen 2023, representatives from the governmental body spoke on the role CCS plays in promoting carbon neutrality.

Jose Figueroa, Carbon Capture Team Supervisor at NETL, informed attendees about the capture technologies his department is helping developing, such as direct air capture. He said that technologies such as CCS and collaboration across different sectors—government, academia, industry, and research organizations—will help support the goal of achieving net zero by 2050 seem more attainable.

STORING CO_2

Currently, geological storage is the most mature technological option for storing CO_2 and offers significant capacity for sequestering CO_2. According to the DOE, CO_2 storage in geologic formations includes oil and gas reservoirs, unmineable coal seams, and deep saline reservoirs.

However, the Clean Air Task Force (CATF) said among the carbon capture, transport, and storage value chain, storage is the key bottleneck impeding the development of carbon capture and storage in Europe. According to the authors of *Europe's Net-Zero Industry Act: What does it mean for carbon capture and storage*, "As CATF determined last year, Europe could face up to a 50% shortfall in storage capacity available to capture projects in 2030." However, the Net-Zero Industry Act is creating better conditions and opportunities for clean-energy technologies in Europe.

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Dr. Marcus Brücher, Senior Vice President of Compression at Siemens Energy, said the company is focusing on storage rather than utilization. "The amount of CO_2 produced from one large power plant is more than the entire beverage industry could consume per year," Dr. Brücher said. "This example furthers the assertion that the viability of such products has yet to find a clear pathway when stress testing a business plan from a financial perspective. Theoretically and scientifically, many products are achievable; storage of CO_2 can provide source points later when economics and financial returns are more favorable for products derived from CO_2."

The "store-for-later" idea runs in tandem with what has been seen in the past with enhanced oil recovery (EOR) production, which, according to an article published in *Reservoir Engineering*, are processes that are "implemented to increase the ability of oil to flow to a well by injecting water, chemicals, or gases [such as CO_2] into the reservoir or by changing the physical properties of the oil."

Daniela Abate, Vice President of CCUS at Baker Hughes, explained that CO_2-EOR has demonstrated its effectiveness, particularly in the United States where it has been adopted in several projects. According to the CCS Institute's Global Status of CCS 2022 report, 11 out of 13 operating CCS projects in the United States are based on EOR.

CARBON CAPTURE

The type of carbon-capture technology employed is what determines the role that turbomachinery plays. "Its role becomes critical for membrane-based, cryogenic, and hot potassium carbonate-based capture technologies, since they are operated with gas streams at medium/high pressures," Abate said.

According to Office of Scientific and Technical Information, membrane-based capture uses semi-permeable membranes to separate CO_2 from a gas stream. Cryogenic capture cools the gas stream to very low temperatures (around -100°C or lower) to distinguish the CO_2 from other gases. Hot potassium capture uses a hot potassium carbonate solution to absorb CO_2 from a gas stream.

Further considerations when determining which turbomachinery to use include "whether it is a retrofit project with limited available space and whether the site already has sufficient energy to run compression or if a new power generation unit will be needed," Abate said.

In these installations, operating profiles are often challenging to manage (largely due to turndown), which can lead to the need for parallel units. However, these obstacles create opportunities, such as developing modular solutions to address plot availability issues and creating more efficient machinery equipped with energy-recovery solutions.

Managing the operating profile is directly tied into the efficiency, reliability, and overall performance of both carbon-capture systems and the associated power generation or industrial process equipment. Here, it's important to compensate for load fluctuations through advanced control strategies or the use of variable speed drives.

Further, beyond turbomachinery considerations, the CO_2 capture method must also be determined. CCUS technologies can remove CO_2 a few ways, including pre-combustion and post-combustion methods.

"Pre-combustion capture has high efficiency, and the increased CO_2 concentration in the syngas significantly enhances absorption efficiency," Dr. Brücher said. "However, the overall capital cost of the base gasification process is high."

He said it comes down to evaluating which technology is fit for a specific application based on the management of the mass from the emitting and capture device. The capital cost can be attributed to the complexity of the process, the need for specialized equipment, the high operating temperatures and pressures found, and the challenges associated with feedstock handling and gas cleanup.

One advantage of post-combustion carbon-capture technology—such as absorption, adsorption, and membranes—is its maturity compared to other carbon-capture alternatives.

"It's viable to retrofit the technology into new and existing plants," Dr. Brücher said.

The downside of post-combustion carbon capture is that it has a low carbon-capture efficiency due to low CO_2 concentration in the flue gas, as well as large parasitic loads of thermal and electrical duties.

However, Abate said that "Once the CO_2-rich flue gas has been compressed and has the CO_2 removed, the CO_2-lean flue gas stream (which typically accounts for more than 80% of the flue gas volume initially compressed) can be expanded to recover energy, which can partially offset the energy required by the CO_2-rich flue gas compression step."

As an example, energy recovery devices, such as turbo-expanders or gas expansion turbines, can convert the pressure energy of the aforementioned gas into useful work, such as electricity generation. This recovered energy can then be used to power the compression process or other parts of the carbon-capture system.

Dr. Brücher concluded: "There is no 'one-size-fits-all' in these technologies. Each has its own strengths and weaknesses that must be considered. Siemens Energy is developing strategies in each technology area to design and provide

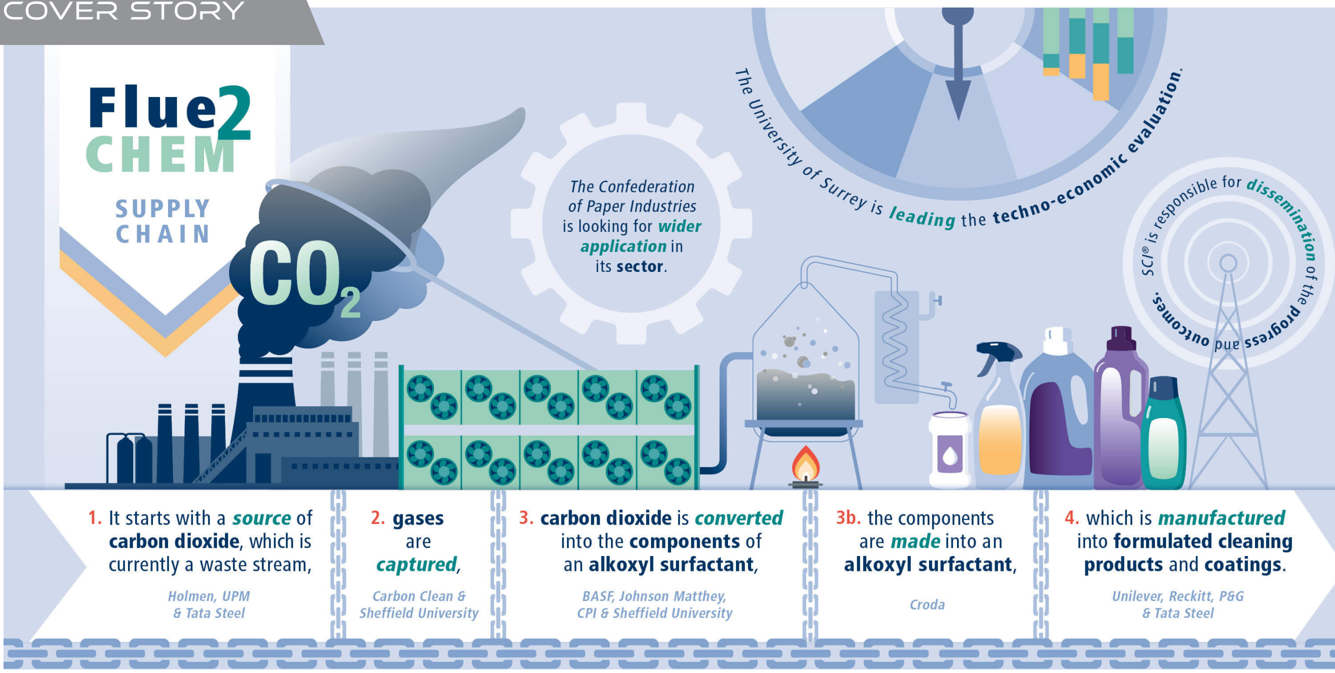

FIGURE 1: Flue2Chem general methodology for converting CO_2 into value-added products. Credit: Society of Chemical Industry

products that contribute efficiency gains to each carbon-capture technology."

OVERCOMING INEFFIENCIES AND INDUSTRY COLLABORATIONS

Implementing carbon-capture tools can impact the overall efficiency of turbomachinery. There's also further value that can be extracted from the process.

"CO_2 capture requires both heat and power, and CO_2 compression requires power which, if supplied directly by the power plant, will reduce its overall efficiency," Sharma said.

Some ways of mitigating this inefficiency include using solvents such as CDRMax, which reduce the amount of heat required for CO_2 capture. "If the captured CO_2 is being used in a downstream process, e.g., methanol or other fuel/chemical products, there are opportunities to integrate with the CO_2 capture plant to meet a large portion of its heat requirement," he said.

Another way the CO_2 can be used in the downstream process is through collaborations such as the Flue2Chem project (**FIGURE 1**). Carbon Clean is collaborating with 14 other organizations, including BASF, Proctor & Gamble, and Unliever, on the Flue2Chem project in the UK: a two-year project that aims to convert industrial waste gases to more sustainable consumer products. The project could result in a saving of 15-20 million tons of CO_2 emissions a year in the UK. As part of the project, Carbon Clean's CycloneCC carbon-capture technology will capture 10 tons per day of CO_2 from three industrial sites.

"Collaboration among OEM; CCS technology provider; engineering, procurement, and construction (EPC); and end users to maximize process efficiency is essential to the success of carbon-capture projects," Dr. Brücher said. "OEMs can provide performance finesse by leveraging machine design details which are then tightly aligned to process performance."

All parties can bring unique expertise and capabilities to the table, and their collaboration could lead to innovations, optimized designs, reduced costs, and more efficient implementation of these technologies.

Efficiency here is created at the machine level, which means reviewing the continuity of that efficiency at the carbon-capture level and then confirming that efficiency at the global facility level.

Dr. Brücher calls it a "create-review-confirm" approach, which can help keep carbon emissions at the lowest GJ/ton possible.

To further emphasize the importance of collaboration, Abate said how partnering with project developers from an OEM perspective, including CO_2 transport infrastructure developers, will help in defining a cost-effective solution. Baker Hughes was recently awarded a contract with Malaysia Marine and Heavy Engineering to supply CO_2 compression equipment to PETRONAS's Kasawari offshore CCS project in Sarawak, Malaysia.

"The project is expected to be [one of] the largest offshore CCS facilities, with a capacity to reduce CO emissions by 3.3 metric tons per annum," she said.

This case shows the benefits of supporting projects in the CCUS space via collaboration. While the industry can reap the rewards associated with regulatory compliance, it also demonstrates its capability of promoting market and technological growth. ■