

Delivering on the promise of CCUS

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Carbon capture, utilization, and storage (CCUS) will play a crucial role in driving a successful energy transition by enabling decarbonization of industries that are difficult to fully electrify or that rely heavily on hydrocarbon-based feedstocks (e.g., steel, cement, power, etc.).

While CCUS deployments have trailed behind expectations in the past, momentum has picked up in recent years. According to the International Energy Agency (IEA), more than 500 projects are in development globally. In the past two years, developers have announced ambitions to develop as many as ~50 new capture facilities, with a capacity to abate around 125 Mt CO₂ per year by 2030^[1].

With the environment for CCUS becoming more favorable on the heels of legislation like the Inflation Reduction Act (IRA) in the U.S. and the Net-zero Industry Act in Europe, projects in the early stages of development still face headwinds. In this regard, having the right combination of partners, technologies, and incentives is critical to achieving final investment decision (FID).

As these systems tend to be very energy-intensive, equipment selection is critical to maximizing efficiency and reducing total cost of ownership. Outside of the capture technology itself, compressors are among the most important pieces of equipment due to their large contribution to system OPEX.

In this article, we compare various CO₂ compressor technologies and discuss how

early engagement between developers and original equipment manufacturers (OEMs) increases the likelihood of project success.

Factors impacting system design

A number of variables impact the optimal design and equipment configuration of a CCUS system, the most important being the type of capture technology being deployed (i.e., post-combustion, pre-combustion, direct air capture, etc.).

Pre-combustion capture has the benefit of high efficiency, largely due to the high CO₂ concentration in the syngas. However, the overall capital cost of the base gasification process is typically also very high. Equipment selection inevitably comes down to management of the mass from the emitting and capture device. CAPEX can vary substantially on the complexity of the process and the need for specialized equipment, as well as challenges associated with feedstock handling and gas clean-up.

Post-combustion is typically less efficient than pre-combustion capture due to the lower CO₂ concentration in the flue gas, and the large parasitic loads of thermal and electrical duties. However, post-combustion capture technologies are well-established and often more viable for retrofits at brownfield facilities.

Power and compression requirements can vary significantly for post-combustion capture technologies, including membrane, cryogenic, and absorption-based (e.g., amine and hot potassium carbon) systems.

The destination for the CO₂ after it is captured (e.g., transported via pipeline, injected into an aquifer or reservoir, etc.) also has an impact on equipment selection.

Heat requirements are also an important factor in the design. Amine-based capture systems require steam to regenerate the absorbent. If this heat is not available in the form of waste heat from the plant, an external boiler is required. In certain cases, opportunities may exist to reduce duty on the reboiler by recovering waste heat from the CO₂ compressors or other sources, which improves system efficiency.

Expansion turbines can be applied to further increase efficiency if the non-CO₂-rich flue gas stream is compressed and pressurized. This is only the case in cryogenic or hot potassium carbonate capture technologies. In such cases, after the CO₂ is separated, other components in the flue gas are pressurized (as opposed to venting). The pressure energy can then be converted into mechanical energy in an expansion turbine.

Depending on the application, the expansion turbine could potentially be installed on the same shaft used to drive the CO₂ compressor (i.e., dual or hybrid drive). Siemens Energy has several references for hybrid drives in the downstream sector, for example in Purified Terephthalic Acid (PTA) and ammonia plants. It is even possible to install so-called "companders" where the compression and expansion occur simultaneously within the same integrally geared machine to lower turbomachinery CAPEX and reduce space requirements. Also here, Siemens Energy has plenty of references within PTA plants.

Besides pre- and post-combustion, oxyfuel combustion exists as an alternative

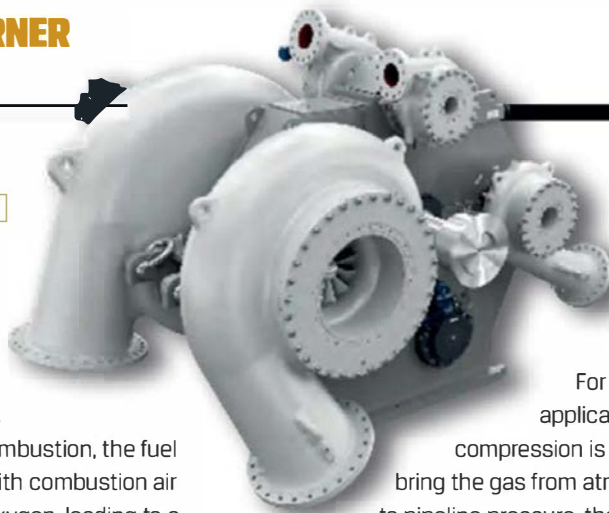


FIGURE 1
Integrally geared compressor.

technology approach for carbon capture.

With oxyfuel combustion, the fuel is not burned with combustion air but with pure oxygen, leading to a high CO₂ concentration in the flue gas. This avoids the requirement for a separation and capture unit downstream. However, oxygen production and costs upstream of the process are important to consider in this scenario.

If a green hydrogen plant is nearby the CO₂ capture application, renewable oxygen produced via electrolysis can be captured and compressed, potentially reducing up-front costs and overall carbon emissions.

Integrally geared compressors

Focusing on CO₂ compression, Siemens Energy has built and executed multiple CO₂ compression units based on integrally geared, single-shaft, and reciprocating compressor technology.

Integrally geared compressors (IGCs), as shown in Figure 1, provide several advantages in CO₂ applications, particularly when it comes to energy efficiency and CAPEX.

IGCs provide the advantage of intercooling after each stage, as each impeller sits within its own volute casing. This has important implications for CCUS applications, as the high molecular weight of CO₂ leads to a comparably high head and pressure rise per stage, which results in a commensurate temperature increase and volume reduction per stage versus lighter gases. Lowering the temperature in between stages via intercooling mitigates this effect, reducing isentropic power requirements.

Additionally, because each stage can be designed individually, the impeller diameter can be reduced to counteract the shrinking flow coefficient due to the decrease in volume flow. The adjustability of the pinion speeds can also counteract the impeller tip speed reduction caused by a reduction in impeller diameter. The end result is higher polytropic stage efficiencies versus

single-shaft compressors and a need for fewer stages.

For a typical CO₂ application where compression is required to bring the gas from atmospheric to pipeline pressure, the number of stages can be reduced by as much as 50%. Another advantage of the individual stage design is that multiple compression jobs can be combined in the same machine. As an example, CO₂ pipeline compression can be combined with mechanical vapor recompression, which is required for some capture processes.

Siemens Energy's IGCs allow for as many as eight stages, with discharge pressures up to 250 bar (Figure 2). Intercooling is possible after every stage. If required, one or more single shaft turbocompressors or reciprocating compressors can be installed downstream of the IGC to achieve discharge pressures of >500 bar. IGCs are suitable with any driver technology, including steam or gas turbines, or electric motors. Another notable advantage IGCs provide is the ability to recover waste heat generated during compression in between stages. The heat can then be reused for the capture process or some district heating, reducing OPEX and carbon footprint of the application.

Siemens Energy has developed a novel IGC system that achieves this by operating the compressor at a slightly higher temperature level. For a typical amine system, 60-80% of the required

steam and heat energy can be met, while only requiring between 1/4 and 1/6 of that heat as additional mechanical power for the compressor at comparable CAPEX and footprint. The resulting Coefficient of Performance (COP) is between 4.0 - 6.0, reducing the specific energy demand per ton of CO₂ captured by up to 1.3 GJ/t.

The company was recently selected to supply two IGC packages for the first large-scale direct air capture (DAC) plant in the world in Texas' Permian Basin. The plant will feature a motor-driven 13,000 hp fully modular wet gas compressor package and a motor-driven 8,500 hp dry gas compressor. The equipment will compress the captured CO₂ for additional processing and pressurize the final product into a pipeline for injection into underground reservoirs. The two compressor packages will enable the plant to capture up to 500,000 metric tons of CO₂ per year when fully operational.

Other technologies

Single-shaft turbocompressors and reciprocating are also suitable for CO₂ applications.

Reciprocating CO₂ compressors are typically used in applications with low flows and very high discharge pressures. Siemens Energy's units, for example, can achieve discharge pressures >850 bar for lubricated service and >100 bar for non-lubricated service. They exhibit turndown capabilities up to 85% (difference between minimum handleable flow and design flow) and can maintain high efficiency over a wide operating range, as pistons can be flexibly turned on and off during operation.

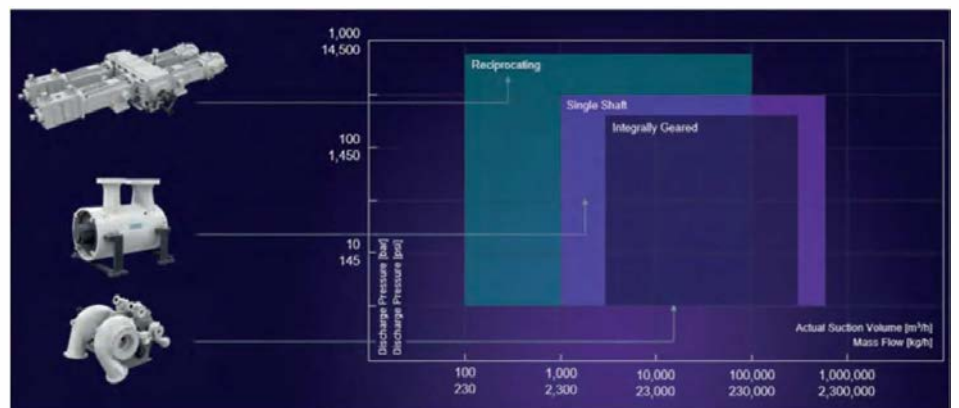


FIGURE 2 Comparison of different compressor technologies for CO₂ service.

Single-shaft turbocompressors offer higher discharge pressures than IGCs (>550 bar) as well, often in a smaller footprint for moderate pressure ratios and high suction pressures. Other advantages include low maintenance and high uptime. All of these characteristics make single-shafts an ideal fit for offshore CO₂ injection into reservoirs.

It is worth noting that once the CO₂ being compressed has reached supercritical pressure (>73 bar), the differences between centrifugal compressors and centrifugal pumps start to obfuscate. Pumps, however, have the capability to process fluids with lower compressibility factors and thus lower temperatures. These temperatures can be achieved through ambient cooling once the CO₂ is at supercritical pressure. This can enable up to 10% power savings for compression from nearly atmospheric to supercritical pressure for pipelines.

Engagement and collaboration

The inherent complexity presented by CCUS

projects (both technically and commercially) necessitates close alignment between the various stakeholders. Developers can benefit by engaging early with process licensors, EPCs, and rotating equipment OEMs to ensure an optimal design.

OEMs can add value by leveraging machine design details which are tightly aligned to process performance. All parties bring unique expertise to the table, and collaboration could lead to cost reductions and debottlenecking. Siemens Energy advocates for a "create-review-confirm" approach, which aims to validate that measures to maximize efficiency at the equipment- and capture system-level translate to efficiency gains at the wider facility level. This helps ensure CO₂ abatement at the lowest cost per ton.

Conclusion: The road ahead

While progress is being made to enhance the viability of CCUS projects globally, more will need to be done to accelerate adoption.

It's estimated that 750mt of annual CCUS capacity will be required by 2030 to reach the IEA's Sustainable Development Scenario (SDS) – a 15-fold increase from where capacity stands today (~50mt).

Furthermore, the IEA estimates that even if global abatement capacity reaches 125 Mt CO₂ per year by 2030, the industry would remain substantially behind the pace needed to reach the Net Zero Emissions by 2050 (NZE) Scenario. Bringing down development costs and expanding the range of viable business cases will require extensive investment and co-creation across the value chain.

In all cases, project stakeholders can benefit by working together from the earliest phases to establish a design that is optimized given plant boundary conditions so that TCO can be reduced to the greatest possible extent.

CT2

REFERENCES: International Energy Agency. Carbon Capture, Utilisation, and Storage. url: <https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage>

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