WHITE PAPER

Carbon Capture System Design for Natural Gas Power Generation

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While select coal power generation units have begun the process of adopting carbon capture, utilization and storage (CCUS) technologies, new regulations like the New Source Performance Standards (NSPS) could drive the adoption of CCUS in a much broader set of applications — including natural gas turbines for baseload power generation.

As new regulations increasingly push fossil-fueled power plants to explore emissions reduction technologies, natural gas turbine operators will face this engineering challenge with relatively limited experience planning and executing CCUS projects. It is critical to understand and anticipate common nuances as early as possible in the design process to develop cost-effective solutions. While the examples below focus on natural gas power combustion turbines, many of the underlying lessons are applicable to a range of CCUS applications.

The State of Carbon Capture Technology

CCUS includes a variety of technological approaches for removing and storing or reusing carbon. Among the more prevalent:

- **Membrane-based CCS,** which uses selective membranes to remove carbon dioxide, can employ a pre-concentration cycle to achieve CO_2 removal rates targeting 60%-80% without a need for chemical usage or steam. However, today's membrane-based systems are typically not suited to handling the large, continuous volumes of gas, low CO_2 concentration levels, and stringent emissions regulations proposed in baseload power generation.
- **Cryogenic systems** cool flue gas to approximately -120 degrees Fahrenheit or lower, allowing CO_2 to be separated from light gases as a solid and subsequently sublimated for transport. In addition to CO_2, this process removes other pollutants such as nitrous oxides (NOx), sulfur oxides (SOx), heavy metals and particulates. While cryogenic approaches show promise in applications with high CO_2 concentration levels, concerns such as high upfront capital costs, a lack of proven commercial applications and potential scalability for high gas volumes may limit this technology's relevance for prototypical power generation applications.

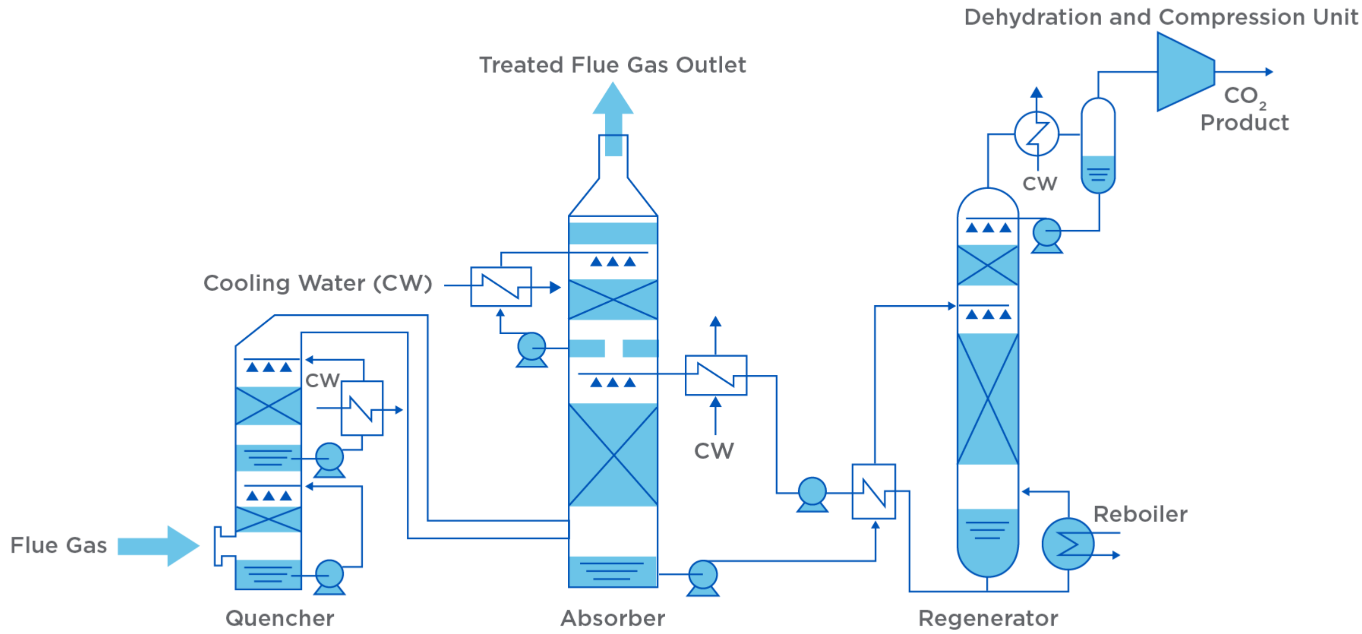

Figure 1: Prototypical amine CCUS arrangement.

- **Advanced amine technology** is the primary approach deployed in power generation applications (see Figure 1). Targeting a CO_2 removal rate of 90% or more, amine is employed as a solvent to absorb carbon from a cross flow of quenched flue gas. Chilled ammonia may be an alternative to amines, potentially reducing energy consumption but requiring additional cooling infrastructure.

- For all of these technologies, captured CO_2-rich gas may be subsequently utilized in industrial applications — such as chemical production or enhanced oil recovery (EOR) — or stored in geologic formations. Other CCUS technologies not covered here include sorbent, enzymes, oxy-combustion and calcium looping.

Growing Legislative and Regulatory Support for CCUS

- Recent legislation, including the Infrastructure Investment and Jobs Act (IIJA) of 2021 and the Inflation Reduction Act (IRA) of 2022, has jump-started investment in carbon capture systems, increasing 45Q tax credits for carbon sequestration while extending the deadline for eligible construction to begin by 2033. Power generation facilities will need to capture at least 18,750 metric tons (MT) of CO_2 annually to be eligible for the 45Q tax credit of $85/MT CO_2.

- The 2024 New Source Performance Standards (NSPS), issued by the U.S. Environmental Protection Agency under the Clean Air Act, imposed stricter emissions limits for projects with construction or reconstruction after May 23, 2023 (see Figure 2). While these standards are technology-agnostic, emissions limits of 100-150 lbs. CO_2/MMBtu effectively imply a need for CCUS technology to achieve compliance in baseload generation applications.

As organizations in the power generation industry and beyond adapt to the new incentives and requirements, they will face challenges related to original equipment manufacturer (OEM) availability, scale-up of the supply chain for CCUS processes, and cost estimation uncertainty for these largely novel projects. The key lessons outlined below provide a practical foundation for anticipating a number of CCUS planning complexities.

LOW LOAD	20% capacity or less	120-160 lbs. CO_2/MMBtu
INTERMEDIATE	Between 20% and 40% capacity	1,170-1,560 lbs. CO_2/MMBtu
BASELOAD	Greater than 40% capacity	100-150 lbs. CO_2/MMBtu

Figure 2: NSPS requirements for power generation.

Key Lessons for Planning CCUS Projects

Every CCUS technology provider will have its own nuanced system design requirements. A proactive planning process is the right way to avoid underestimating seemingly simple design aspects that could end up driving higher longer-term costs and greater engineering complexity.

Understanding the unique aspects and requirements of each OEM is important for identifying those smaller-scale aspects that could lead to unforecasted capital expenditures and a surprising amount of complexity or engineering effort being required during front-end engineering and design (FEED).

Determining the Appropriate Basis for Codes and Industry Standards

CCUS technologies are most comparable to technologies commonly implemented in the process industry, such as amine gas treating, so technology providers may be accustomed to process industry codes and standards (such as ASME B31.3 and API standards). For projects being developed at power plants, the end user is likely accustomed to typical power industry codes and standards (such as ASME B31.1 and ANSI standards).

Rather than adopt a blanket approach, it is advisable to exercise case-by-case engineering judgment in blending practices and codes from the power and process industries. This decision can have a substantial impact on costs due to divergent equipment specifications in each industry. Reaching alignment between all parties on the project basis for codes and industry standards early in project development can minimize rework and inefficiencies during FEED execution.

Planning for Chemical Supply, Storage and Safety Needs

CCUS technologies rely on solvents and chemical consumables such as amine or glycol. Planning for the supply, transportation and storage of these chemicals includes:

- Accurately assessing supply chain constraints and operating costs.
- Specifying an adequate volume of on-site chemical/gas storage in addition to integrating truck delivery with the plot plan near this storage (including truck access routes and spill containment zones and storage).
- Anticipating how chemical usage might create additional needs for fire safety detection or prevention systems and/or trigger more rigorous requirements from the authority having jurisdiction (AHJ).
- Maintaining a sufficient and reliable supply of critical gases such as nitrogen can prove challenging. On-site production might be necessary, thereby increasing costs, expanding the physical footprint and driving a higher auxiliary load. While some solutions only require bottle racks for purging and shutdowns, others might require a continuous feed, requiring equipment such as an on-site pressure swing adsorption (PSA) system to maintain a consistent, cost-effective gas supply.

Anticipating Visible Emissions Plumes

Water-saturated flue gas could create a visible plume from a power generation stack that previously generated no visible emissions. While this may be attributed only to additional moisture in the flue gas and may not be an environmental concern, this change could lead to additional public relations discussions.

Cooling System Design

The cooling systems required by CCUS technologies command a substantial physical footprint and are key drivers of project costs and design challenges. Limited space can pigeonhole a project with a certain design, as footprint restrictions limit alternatives based on available vendor sizing.

Water usage considerations also might prove decisive for cooling system design. Dry cooling technologies reduce water consumption and wastewater generation, making them attractive to end users with water restrictions or to those who are operating without a permitted wastewater discharge. However, dry cooling technologies come with a larger footprint, higher capital costs and reduced energy efficiency. Additionally, some process streams might require temperatures that can only be achieved by wet cooling technologies during hotter ambient conditions. In this case, water-conscious end users could opt for a hybrid cooling approach.

Material Selection and Pipeline Coordination in Natural Gas Applications

While not unique to natural gas combustion applications, pipeline coordination issues are representative of the broader system design issues that may arise from CCUS implementation in a variety of different contexts. As an example, a design needs to account for how the pipeline will depressurize downstream of the CCUS tie-in. In some applications, a connection back to the CCUS vent system will be needed to handle depressurization requirements. Understanding these coordination nuances early in project development can help avoid surprises and redesign during later stages of FEED execution.

Temperature threshold is another crucial design basis consideration for CO_2 pipelines, including selection of materials of construction. If a pipeline contractor provides a temperature limit, designers should investigate the basis of this limit and potential options that could allow for a higher pipeline design temperature. Increased temperature limits for the pipeline could allow for reducing capital and operations and maintenance (O&M) costs associated with additional cooling demands for the CCUS plant.

Wastewater Design Considerations

Regardless of the technology used to capture CO_2, contaminants may end up in the wastewater and trigger treatment requirements from relevant regulatory bodies. Segregating streams based on treatment needs can be an effective option for limiting operating costs in many projects.

Most coal plants employ flue gas desulfurization (FGD) upstream of CCUS systems, capturing ammonia along with sulfur compounds, chlorides and other metals. While flue gas from natural gas combustion will have fewer contaminants, without this upstream FGD, all flue gas contaminants may be absorbed by water circulating in the direct contact cooler (DCC). The main contaminants of concern are ammonia from upstream selective catalytic reduction (SCR) systems, as well as low concentrations of SOx.

Flue gas from coal-fired plants also has a higher dew point compared to flue gas from natural gas combustion. This means that in coal-fired applications, the DCC will always be condensing excess moisture from the flue gas. By contrast, flue gas from natural gas applications has a lower dew point, so the amount of condensate produced will depend upon ambient conditions and the absorber inlet temperature set point. CCUS systems for natural gas turbines might even become water-negative in certain operating ambient conditions, requiring freshwater makeup (treated to reverse osmosis permeate or demineralized quality standards). In most cases, substantial blowdown water management, and possibly treatment, will be required.

Many CCUS technology providers have difficulty accurately predicting blowdown water quality. In this context, pilot data on water quality can prove immensely valuable for engineering and design. As a worst-case scenario, it can be assumed that all constituents in the flue gas remain water soluble and end up in the discharge; however, this can lead to overly conservative design of wastewater treatment systems.

CCUS systems also may require expansion of demineralized water production to support operation. Investigating and scrutinizing water quality requirements for specific systems may help control costs if demineralization is not required.

Redundancy, Maintenance and Other Considerations

Large equipment like compressors typically demand substantial space, particularly if redundancy criteria require multiple units. Reviewing the applicability and/or waive-ability of redundancy requirements — and whether this constitutes an acceptable risk profile — may have a substantial impact on the capital costs of the project. A thorough cost-benefit analysis early on is recommended, as the project will become harder to modify deeper into the FEED or engineering design phases.

Other common design considerations include:

- In addition to the engineer-procure-construct (EPC) contractor and carbon capture technology provider, other suppliers may need to expend cash during the FEED process.
- CO_2 compressor installation in a dedicated building versus simple noise enclosures.
- O&M costs associated with off-site management of contaminated waste streams.
- Ongoing material replacement, such as activated carbon.

Conclusion: Navigating the CCUS Challenge for Long-Term Success

The evolving landscape of carbon capture technology presents both challenges and opportunities for the power generation sector. The complexities associated with designing and deploying CCUS systems require a collaborative approach, blending deep understanding of process, power and regulatory complexities. Taking the time to understand the complex interplay of emissions, energy efficiency and supply chain considerations is fundamental to refining an optimal design capable of economically meeting regulatory requirements and securing carbon sequestration credits.

By proactively planning for the outlined complexities, organizations can better position themselves to navigate the uncertainties inherent in today's CCUS projects. A focus on early-stage planning is the smart way to execute CCUS projects that not only comply with current standards but are well-positioned for long-term economic viability and scalability.

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