Getting Started with Carbon Capture and Storage (CCS)

Technical and Economic Considerations for Gas- and Coal-Fired Power Plants

Carbon Capture and Storage (CCS) has emerged as a promising carbon reduction strategy for gas- and coal-fired power plants. Understanding how it works and the decisions that must be made at each stage of the process can help power plant managers make informed decisions.

Power plants utilizing fossil fuels such as coal and natural gas are under tremendous pressure to reduce carbon emissions. CCS provides a pathway for gas- and coal-fired power plants to meet proposed new emission reduction requirements from the Environmental Protection Agency (EPA) in the near term while still retaining the value of existing assets.

To maximize the potential benefits of CCS, power plants need a solution customized to their operations and context. Each stage of the process (capture, transport and storage) includes many technical and economic considerations that must be evaluated to develop a solution tailored for a specific plant. Working with a qualified partner who can oversee the entire project, from design to operations to long-term monitoring, will help power plants make effective decisions and ensure safety, compliance and smooth operations.

Stages of CCS: Capture, Transport, and Storage

Carbon Capture and Storage (CCS) is a technology used to reduce carbon dioxide (CO_2) emissions from industrial processes and fossil fuel power generation. It involves three main steps:

- Capturing CO_2 produced by power plants or industrial activities
- Transporting this captured CO_2 to a storage site
- Securely storing it underground in geological formations

CAPTURE

Gaseous CO_2 produced by gasification or combustion of fossil fuels is captured at the plant (pre- or post-combustion).

TRANSPORT

Gaseous CO_2 is treated and compressed into a liquid or liquid-like (supercritical) state for transport to the storage location via pipeline, truck or rail.

STORAGE

CO_2 is injected into a safe storage location, usually an underground geologic formation such as a deep saline aquifer.

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Considerations in Designing a CCS Solution

Each stage of the CCS process has its own challenges, tradeoffs and constraints. In designing a CCS solution, many factors will come into play, including the plant's size, location (and access to suitable geologic storage), fuel type and plant processes, financial resources and regulatory requirements.

Policy, economic and market forces must be considered at every stage when developing an overall CCS strategy. These include:

- **Tax credit** eligibility (45Q and other Federal, state and local sources).
- **Funding** availability (government subsidies, internal capital investment, tax equity investment, electricity ratepayer structure).
- **Monetization** opportunities (carbon markets, tax credit monetization).
- **Business and operational** considerations (power dispatch impact, operational disruption).
- **Regulatory** requirements (EPA mandates, other).

Capture

The first step in CCS is capturing carbon at the power plant. There are three main processes that exist in the industry today: pre-combustion or gasification, post-combustion, and oxy-combustion. The most promising method is post-combustion because it is relatively easy to retrofit to existing plants and is the most mature technology. However, both pre-combustion and oxy-combustion have experienced significant technological advancement thanks to DOE-funded studies. Each process, in combination with fuel type (natural gas, coal, biomass or fuel oil), has different challenges. There are several considerations in designing a capture method.

- **Fuel Type/Combustion Method:** Different capture methods are appropriate for different types of power plants. For existing plants, it is important to choose a capture method that works with the fuel and electricity generation process used and can be retrofitted into existing operations.
- **CO_2 Concentration:** The higher the CO_2 concentration, the easier (and less expensive) it is to capture and purify. For post-combustion capture, the CO_2 levels in flue gas will impact solvent choice, equipment size, and energy use for capture. CO_2 concentrations are higher for PC and IGCC plants than for NGCC plants. Reducing impurities in the gas stream and improving the solvent can slow down the degradation of the capture agents, which can lead to lower operational costs and less frequent solvent replacement.
- **Energy Penalty:** All CCS methods consume energy, which reduces the energy available to produce electricity—a problem known as parasitic load. Capture processes such as solvent regeneration and water treatment require a significant amount of energy, which can result in an energy penalty ranging from 10% for Integrated Gasification Combined Cycle (IGCC) to 20% for coal-based oxy-combustion. The energy penalty is dependent on the separation technique and the plant processes. Process optimization techniques (e.g., waste heat recovery/steam extraction to generate heat for solvent regeneration) can improve the efficiency of the capture process and reduce the energy penalty.
- **Scale and Economics:** Economies of scale play a significant role in CO_2 capture systems. Larger installations can spread the high fixed costs of equipment and construction over more units of captured CO_2, reducing the cost per unit. Plant modularization, where the capture system is built in modules that can be easily replicated, may reduce capital expenditures (CapEx) because it can lead to economies of scale in manufacturing and potentially simplify construction.

The following table provides a high-level overview of some of the main differences.

Pathway	Pre-Combustion Capture (Gasification)	Post-Combustion Capture	Oxy-Combustion Capture
How It Works	• A carbon-based feedstock (e.g., coal, biomass) is transformed into a gas (syngas) by reacting it with oxygen and steam at high temperatures • Syngas is cooled and cleaned of impurities and then burned to produce electricity • CO_2-H2 separation is typically by physical solvent in an Acid Gas Removal (AGR) unit. Membrane is an option.	• CO_2 is captured from exhaust gases after combustion • CO_2-N2 separation is typically by chemical solvents (e.g., amines, aqueous ammonia); physical solvents, chemical or physical sorbents, or membrane technologies may be feasible • The solvent is heated or processed to separate pure CO_2 from other components in flue gas	• Fuel is burned in pure oxygen instead of air; the resulting flue gas is mainly water vapor and CO_2 • Water vapor is condensed out, leaving mostly CO_2 • Needs supply of high-purity oxygen
What It's Used For	• Integrated Gasification Combined Cycle (IGCC)	• Pulverized Coal (PC) • Natural Gas Combined Cycle (NGCC)	• All combustion processes
Advantages	• Produces higher concentration of CO_2 than post-combustion for efficient capture • Reduces sulfur dioxide and nitrogen oxide emissions	• Easiest to retrofit • Suitable for various types of fossil fuel plants • Most mature CO_2 capture technology	• Produces higher concentration of CO_2 than post-combustion for efficient capture • Low levels of pollutants
Drawbacks	• Not cost-effective to retrofit • Requires more complex technologies and equipment including air separation unit • Higher capital costs	• Energy-intensive/high parasitic load • Higher levels of pollutants in coal plants	• Not cost-effective to retrofit • Requires additional equipment to supply oxygen, raising costs • Energy-intensive/high parasitic load

Transport

The next stage of CCS is transporting the captured CO_2 to the storage site. Captured CO_2 is first compressed to either a liquid or supercritical state, depending on the transport method. The safest and most common method for transporting CO_2 is via pipeline. However, in areas where pipeline infrastructure is not available or is impractical, CO_2 can be transported in liquid form in high-pressure vessels by truck or rail. Considerations in choosing a transport method include the following.

- **Distance Between CO_2 Source and Sink:** Pipelines have a clear cost benefit for longer distances, but capital and operating expenses may not be justified for short routes that are easily covered by truck or rail.
- **Volume of CO_2:** Pipelines are most cost-effective for large volumes of CO_2; the more CO_2 you are transporting, the lower the per-ton cost will be. If the volume of CO_2 from a single plant is not high enough to justify the capital expense of a pipeline, it may be possible to aggregate CO_2 from multiple point sources.
- **Availability of Existing Infrastructure:** It is sometimes possible to take advantage of local infrastructure, such as existing railways, to reduce capital expenditures for transport. In some cases, there may be an obsolete natural gas pipeline that could be converted for CO_2 transport.
- **Right-of-Way and Permitting:** State and local permitting for new pipelines has been increasingly contentious, with eminent domain rights under challenge in multiple states. The recent cancellation/delay of two major pipeline projects in the Midwest was a setback for the industry. Consideration must be given to community impact, environmental concerns, and the legal and regulatory environment. Engaging with stakeholders early and ensuring transparent communication can help in navigating these complex issues.

	Pipeline	Truck/Rail
Process	• CO_2 flows through a pipeline	• CO_2 is transported in high-pressure vessels by truck and/or rail
CO_2 State	• Supercritical (cools to liquid state during transport)	• Liquid
Advantages	• Continuous flow/high efficiency • Lower operating costs for high volumes and distances • Reduced handling and storage requirements • Safety	• Highly flexible • Can be scaled up or down based on demand • Can access areas without pipeline infrastructure • No large CapEx investment • Faster to deploy than greenfield pipeline
Disadvantages	• High upfront CapEx investment • Requires fixed infrastructure, limiting flexibility • Permitting/right-of-way challenges	• Higher costs for long distances and high volumes • Requires more handling and storage • Environmental impact of vehicle emissions
Best For	• High volumes/long distances	• Low volumes/short distances

Injection and Storage

The final step in CCS is the injection of the CO_2 into a geologic formation for long-term storage. Site selection and characterization are extremely important for the overall success of the project. CO_2 is usually stored in deep saline formations located several thousand feet below the Earth's surface. The formations typically consist of porous rock (such as limestone or sandstone) saturated with salty water (brine). CO_2 is injected deep into the formation, displacing some of the brine. In some cases, it may be possible to use a depleted oil & gas reservoir for CO_2 storage or to use captured CO_2 for Enhanced Oil Recovery (EOR). These options, where available, may reduce upfront costs or even enable some cost recovery by selling CO_2 for EOR; however, it is important to weigh the potential advantages, costs and risks of these strategies holistically.

There are several considerations in selecting an injection site.

Geology & Reservoir Characteristics	Legal, Regulatory and Permitting	Economics
• Rock type, porosity and permeability • Formation depth • Temperature • Salinity (≥10,000 ppmt tds) • Total storage capacity • Presence of cap rock to prevent vertical migration • Containment integrity/leak potential • Injectivity considerations • Subsurface flow • Plume migration potential	• Local regulatory and permitting environment • Approval timelines • Pore space rights acquisition (based on plume extent) • Compliance with long-term monitoring, reporting and verification (MRV) requirements	• CapEx (upfront costs associated with the injection and storage infrastructure) • Ongoing costs for operations, compliance and long-term monitoring • Availability of existing wells or EOR opportunities

Risk Management for CCS

Risk management is an essential part of CCS planning—including not only physical and safety risks but also environmental, regulatory, legal, economic and business risks. A proactive approach to CCS risk management can help power companies mitigate these risks and ensure a smooth, safe and successful project. An effective risk management strategy is holistic, integrated and proactive. That includes:

- Assessing risk across the CCS value chain (capture, transport and storage) and developing holistic risk management strategies across all phases of the project.
- Developing project plans and goals based on realistic project timelines and budgets.
- Incorporating good system design practices to ensure flexibility, resiliency, reliability and compliance across the lifetime of the project.

Cross-Chain Risk Management

- Assess and understand the interdependencies within the CCS value chain components
- Identify and analyze technical tradeoffs to mitigate risks across the chain
- Develop strategies to manage risks associated with the integration of capture, transport, and storage phases

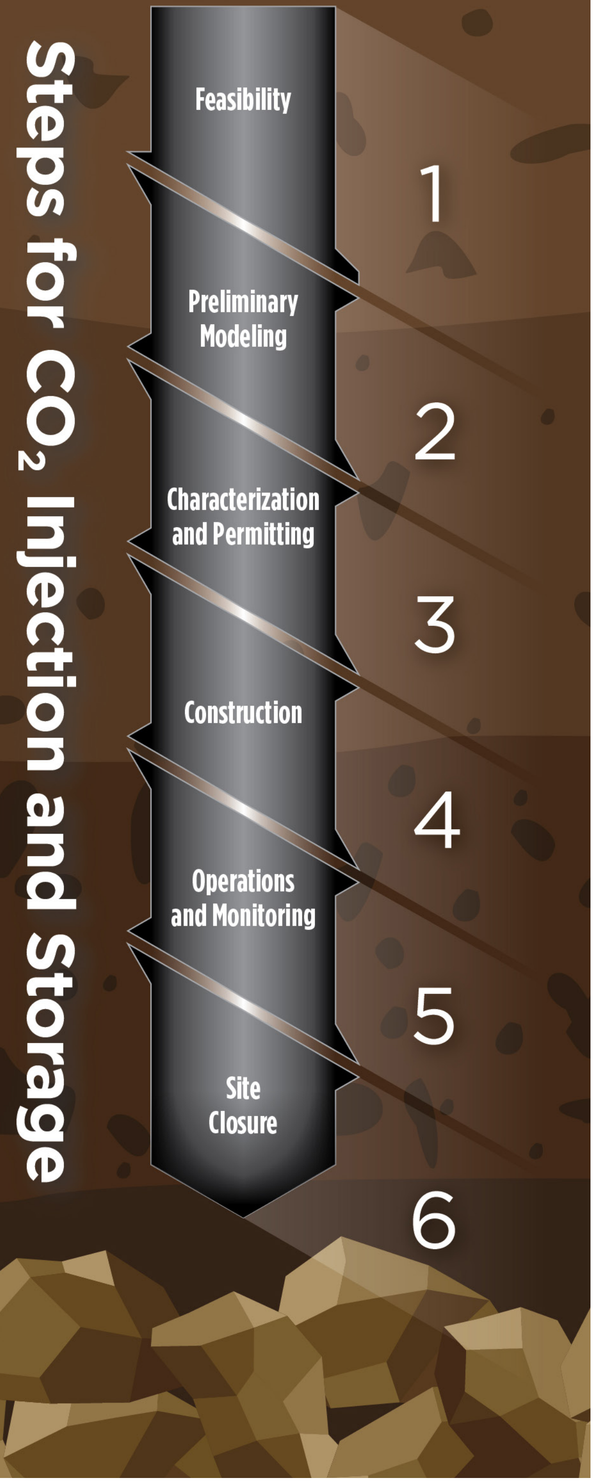
Project Schedule and Budget Integration

- Construct a comprehensive project timeline that aligns with budget constraints
- Optimize capital expenditure through strategic planning and phasing of project elements
- Sequence critical data acquisition and design milestones to streamline project development
- Prioritize permitting activities to ensure project progression without delays

System Design Integration

- Design the CCS system with flexibility to handle operational variances and unexpected events
- Incorporate redundancy to reduce the risk of system failures and downtime
- Maintain consistency across the system to ensure smooth operations
- Implement measures to ensure tax credit eligibility, minimize downtime and recapture risk

Carbon storage is a multi-stage process that begins with project feasibility and ends with operations and monitoring until a site is closed. CCS requires a long-term commitment to ensure that the CO_2 plume is safely contained and not migrating out of the storage formation.



Battelle: Your Partner for Carbon Capture and Storage

The Battelle Carbon Storage Services team works with power companies across all stages of CCS, including initial planning and strategy, design and implementation, site operations and monitoring, reporting and verification. We can help you develop a CCS strategy to meet your carbon reduction goals while **controlling risks**, **maximizing tax incentive potential**, and **ensuring smooth operations**.

25+
years of CO_2 storage experience

75+
CCS projects completed worldwide

100+
subsurface and geotechnical experts

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