Sargent & Lundy

WHITE PAPER

CO_2 Capture Projects

Best Practices and Insights For Technical Due Diligence in Support of Lenders and Investors

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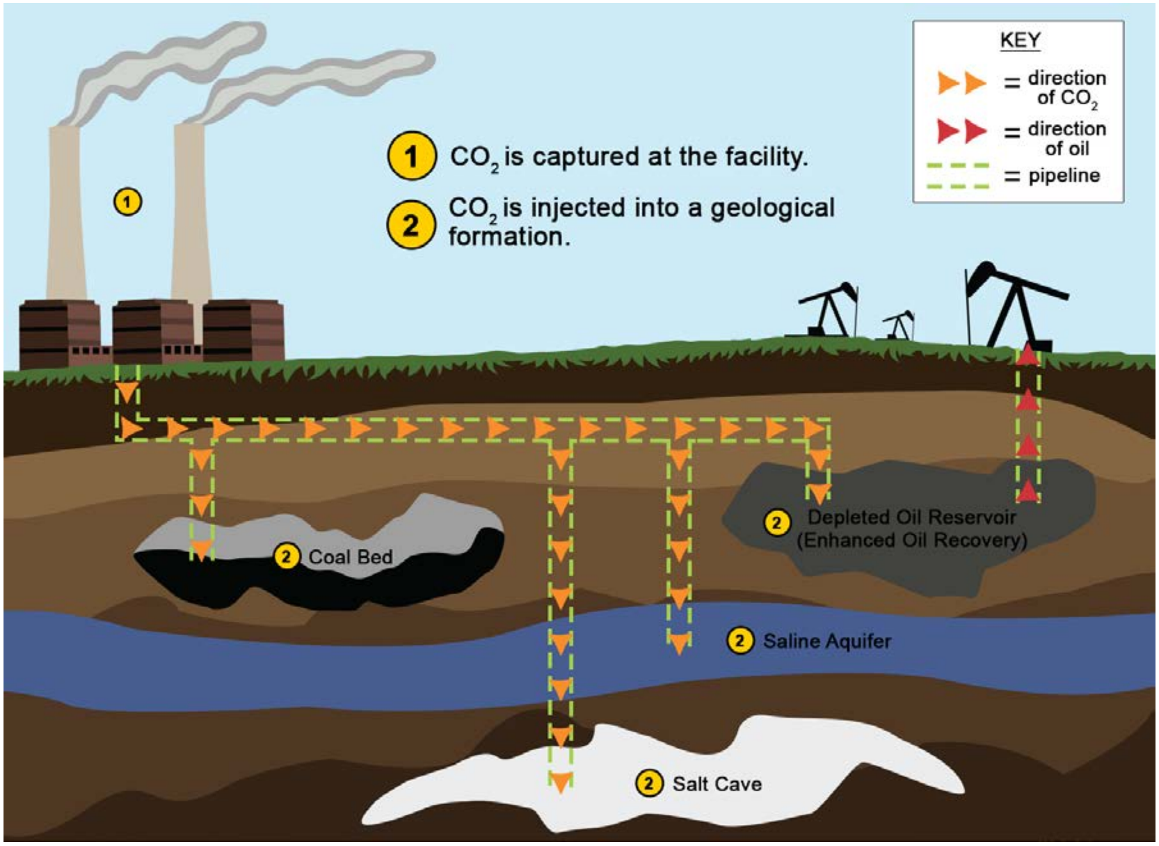


As global emission requirements for carbon dioxide (CO_2) continue to become more stringent, existing and new thermal power projects may look towards CO_2 capture, utilization, and storage to remain viable and emission compliant.

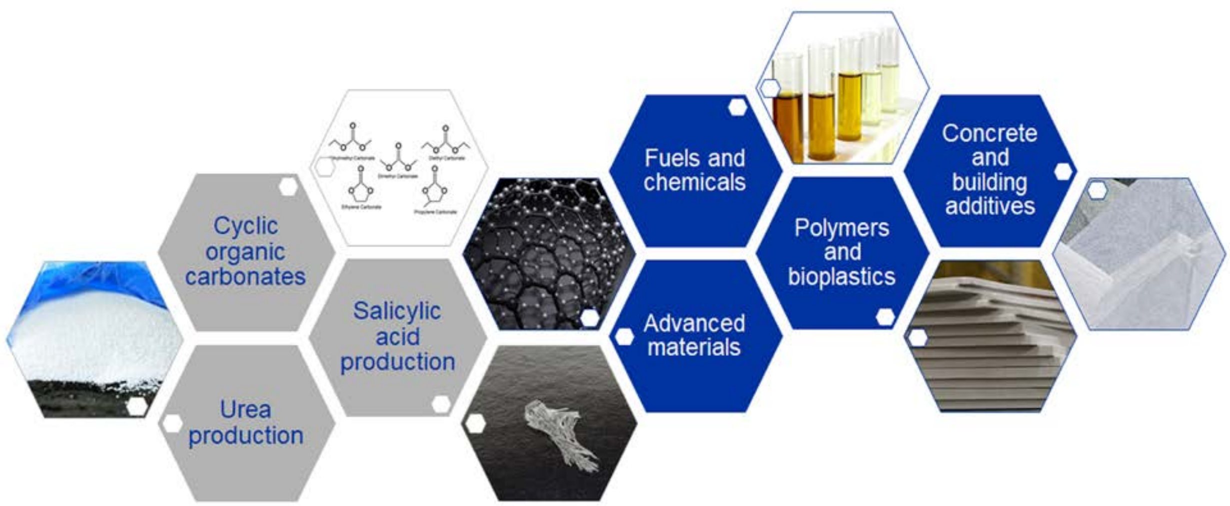
This white paper highlights best practices and insights that Sargent & Lundy has identified during our engineering support of CO_2 capture projects, with a focus on technology viability, plant integration, economics, CO_2 offtake, project development, and permitting. The goal is to assist owners, financiers, and engineers in the due diligence and planning of CO_2 capture projects. Our findings are based on our engineering support of over 40 CO_2 capture projects completed since 2007, including the Petra Nova CO_2 capture project, which is currently the largest CO_2 capture project in the world.

There are many key considerations when performing due diligence of a CO_2 capture project, such as the balance-of-plant capital investment, impact on plant heat rate, proximity to potential CO_2 offtakers, and local permitting restrictions. Sargent & Lundy has addressed these key considerations below through our extensive experience with thermal power plants, air pollution control integration, and previous feasibility, front-end engineering and design (FEED) studies, and owner's engineering support for CO_2 capture systems.

Introduction

Thermal power plants generate exhaust gas with CO_2 through the combustion of fossil fuels. Carbon Capture Utilization and Storage (CCUS) is a process that captures CO_2 emissions from sources like coal fired power plants and either reuses or stores it so that it will not enter the atmosphere. CO_2 storage can occur in geologic formations including oil and gas reservoirs, non-mineable coal seams, and deep saline reservoirs. Alternatively, revenue can be generated through the sale of compressed CO_2 for enhanced oil recovery or as a feedstock for fuels and chemicals, advanced materials, bioplastics, and more.

Figure 1 — Alternate Products Made from CO_2



In general, CO_2 capture technologies have been in development, in one form or another, since the early 1990s, supported in large part by the United States Department of Energy. There are various types of technologies that can be used to capture CO_2. These technologies range from solvent-based or alkali scrubbing to solid sorbents and membranes.

Coal-fired power plants emit a more concentrated amount of CO_2 in the exhaust flue gas than natural gas combustion turbines, making them more cost-effective candidates for CO_2 capture than combined-cycle plants. However, CO_2 capture can be applied on a range of applications from direct air capture to new oxy combustion boilers.

The sections below highlight best practices and insights Sargent & Lundy has identified for CO_2 capture projects that will aid owners, financiers, and engineers in the due diligence and planning of CO_2 capture projects. These findings are based on our experience with over 40 CO_2 capture projects completed since 2007, including numerous feasibility studies, front-end engineering and design (FEED) studies, and owner's engineering support.

CO_2 Capture Key Considerations

Technology Viability

Technology Readiness Level (TRL) is a standardized methodology to assess the maturity level of technology. As shown in Figure 2, TRL ranges from 0 to 9 and covers the idea, prototype, validation, and commercialization phases of a technology.

Figure 2 — Technology Readiness Levels

Idea (Levels 0–3)	**Prototype** (Levels 4–5)	**Validation** (Levels 6–7)	**Commercialization** (Levels 8–9)
Research, Modeling, Validation	Lab Testing, Test Facility	Slipstream Testing	First Commercial and Beyond

For power applications, commercially available processes (those having reached a TRL of 7 or greater) are considered as those that have been demonstrated using slipstream tests (small-scale tests in real-world applications) or have been implemented on permanent installations of at least 5 megawatts equivalent (MWe) capacity. For a coal-fired power plant, amine-based solvent technology is the most widely tested and proven CO_2 capture technology. The commercialization of amine-based technology (TRL 8–9) on coal fired power plants is described below.

An amine-based CO_2 capture system is installed on the back-end of a power plant to treat the flue gas before being emitted. This technology is commercially viable and could be applied in a wide range of applications, including coal-fired boilers, natural gas-fired power plants, and oxy-fuel applications

The world's first commercial-scale post-combustion coal-fired CO_2 capture and storage project was built at the SaskPower Boundary Dam facility and began operating in October 2014. The facility is equipped with the Shell Cansolv CO_2 capture technology and is designed for 90% capture. The project was designed to capture approximately 1 million tonnes (metric tons) of CO_2 per year for sale and storage in a nearby storage site.

Petra Nova is the largest commercial-scale post-combustion coal-fired CO_2 capture project. Petra Nova's CO_2 capture system, supplied by Mitsubishi Heavy Industries America, Inc., began commercial operation in January 2017. The 240-MWe CO_2 capture system was added to Unit 8 (654 MW capacity) at the existing W.A. Parish plant. This CO_2 capture system receives a portion of Unit 8's flue gas as a slipstream.

As the testing and implementation of amine-based technologies for CO_2 capture has progressed, so too has the study of CO_2-amine reaction chemistry and amine solvents. Monoethanolamine is considered the standard solvent in the industry for CO_2 capture. As part of the development of these technologies, vendors such as Fluor (Econamine FG Plus™), Mitsubishi Heavy Industries America, Inc. (KM-CR Process® with KS-1™ solvent), Shell (Cansolv), and ION Clean Energy (Advanced Liquid Absorption System) have begun developing and supplying proprietary amine solvent blends for use in large-scale CO_2 capture applications.

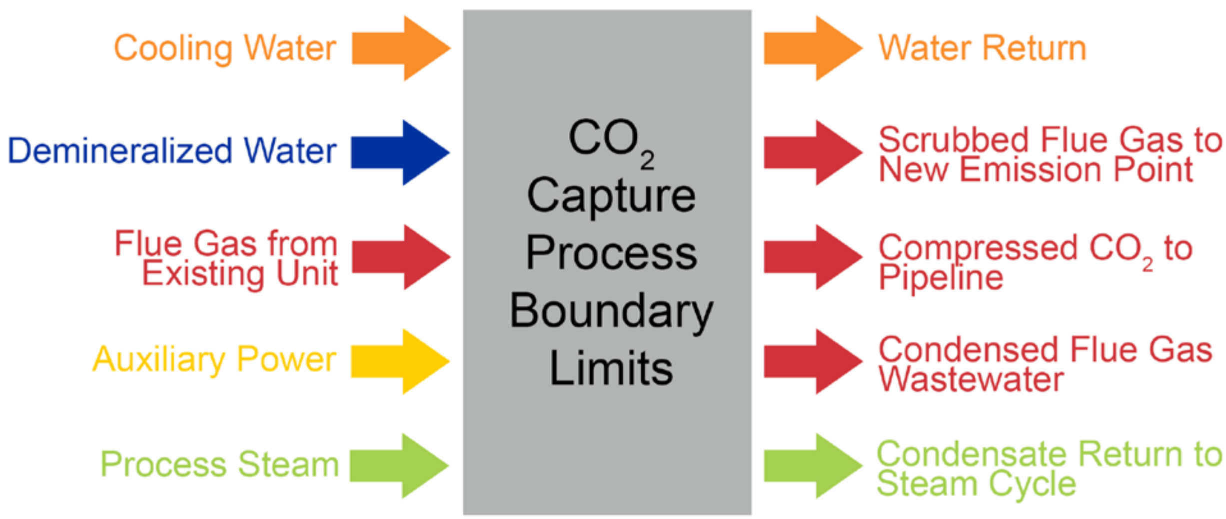
Other commercially available technologies, similar to the amine-based technology, include ammonia-based technologies, which produce an ammonia bi-carbonate byproduct that may be difficult to market in large quantities, and Lurgi's Rectisol technology, which has been installed at the Dakota Gasification Company. Other technologies are in various phases of development and are not yet commercially available. These technologies have not been active in the recent marketplace for CO_2 capture and have not been implemented on traditional coal-fired boilers.

Project participants need to be aware that the selection of technology and the level of development of that technology have a significant impact on project viability. Technologies at a lower TRL may not be suitable for larger projects and are likely not at a place to provide performance guarantees and warranties. There is also an inherent schedule and budget risk associated with technologies that have not been proven at a larger scale. Review of the selected technology and the technology development is a key factor in evaluating an overall project. As discussed in this paper, amine-based technology is a commercial technology that has been demonstrated in two large-scale utility applications.

Plant Integration

Integration of CO_2 capture technology to an existing thermal plant involves installing CO_2 capture equipment in the exhaust gas path upstream of the existing exhaust stack. In addition, amine-based CO_2 capture requires a large amount of process steam, cooling water, demineralized water, and electricity. The source of these utilities must be carefully considered as both have cost impacts to the CO_2 capture project and performance impacts to the existing plant.

Figure 3 — CO_2 Capture Process Boundary Limits



Process steam can be provided by extraction from the existing plant steam process, which results in a significant impact to the net electrical output of the base plant. Auxiliary power can also be sourced from the existing unit, which also results in a reduction in the net electrical output of the plant. A fully integrated system supply steam and electricity from the base unit will impact the overall heat rate of the power plant, and in some ways the power plant will operate similarly to a cogeneration facility. The impact to power plant dispatch and electricity must be carefully evaluated during project development, taking into consideration the base facility corporate structure, local electricity market, and regulators. The impact of the CO_2 capture project to plant performance and dispatch must be thoroughly understood to ensure that the plant remains competitive and continues to dispatch after the addition of the CO_2 capture equipment.

Alternatively, regeneration steam could be provided from a heat recovery steam generator powered by a new combustion turbine that is sized to provide the necessary auxiliary power for the CO_2 capture system. This results in no impact to the existing plants steam turbine operation or net electrical output, but it adds significant capital cost to the CO_2 capture project. This also introduces a new stream of CO_2 emissions.

In most cases, the existing facility's cooling water system will not be able to accommodate the additional cooling loads for the CO_2 capture system; therefore, a new cooling system would be required. The CO_2 capture system also requires a large footprint for the capture, compression, and balance-of-plant equipment. Depending on the level of plant integration, the proximity to the existing unit will need to be considered.

Heat and mass balance calculations can be performed to quantify the impacts of various plant integration configurations. Sargent & Lundy recommends that these calculations be performed for each plant integration configuration considered.

Economics

A key driver for CO_2 capture investment in the United States is the tax credit made available by the Internal Revenue Service (IRS). Section 45Q of IRS regulation identifies business-related credits for carbon oxide sequestration. This section was updated in early 2018 to achieve the following:

- Increase tax credit use cases,
- eliminate the cap on the amount of captured CO_2 eligible for the tax,
- expand the tax credit to include all carbon oxides1, and
- extend the credit availability to all projects that begin construction before January 1, 2024.

The tax credit requires that the captured CO_2 adheres to one of the following for the tax credit eligibility:

1. Captured CO_2 is disposed of in secure geological storage.
2. Captured CO_2 is used for enhanced oil recovery.
3. Captured CO_2 is used for conversion to products or has other beneficial uses.

The value of the tax credit for captured CO_2, which is disposed of in secure geological storage, is valued at $50/tonne; captured CO_2 used for enhanced oil recovery or other beneficial uses is valued at $35/tonne. There are various existing technologies that use CO_2 as feedstock, and many companies have been developing carbon conversions to support the beneficial reuse of captured CO_2. In early 2020, the IRS is expected to provide guidance regarding qualifying for and claiming the CO_2 sequestration credit.

[1] This revision allows industrial facilities, such as steel mills, to participate.

The United States Department of Energy set a benchmark goal for CO_2 capture of $35/tonne for coal-fired applications. As technologies have developed, the cost of CO_2 capture has dramatically reduced, and future large-scale coal-fired facilities are expected to be in the range of $35–$40/tonne, as shown in Figure 4 (developed by the Global CCS Institute and provided in their 2019 Annual CCS Report).

Figure 4 — Levelized Costs – CO_2 Capture, Coal-Fired Power Plants

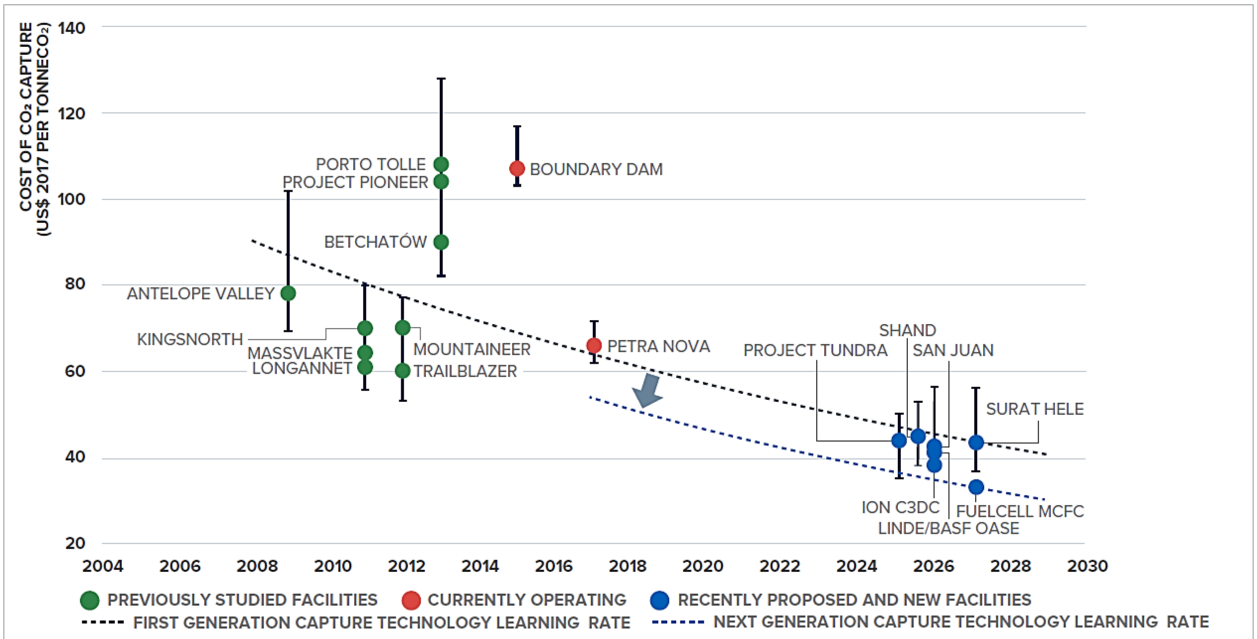
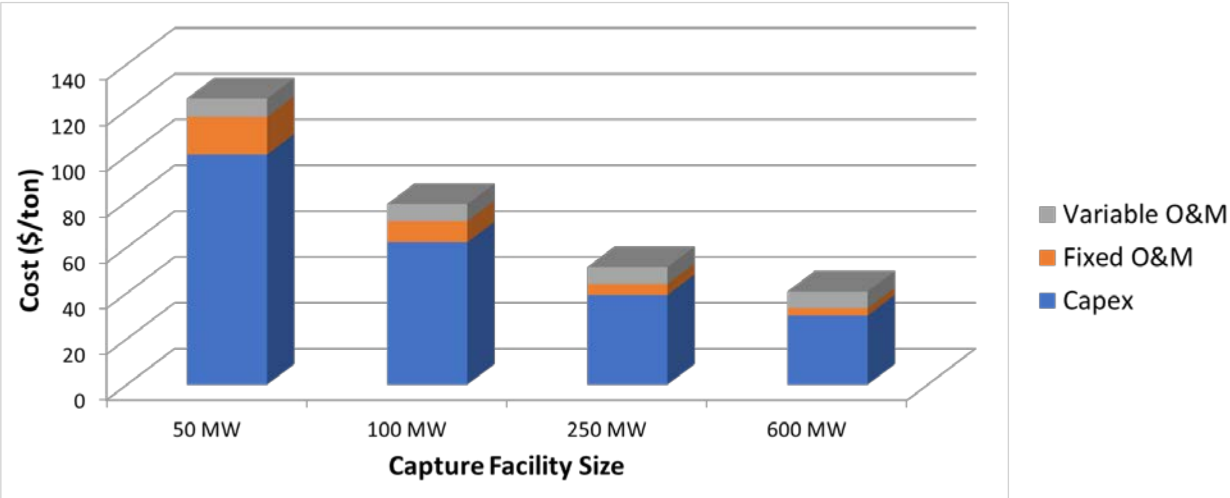


FIGURE 8 LEVELISED COST OF CO_2 CAPTURE FOR LARGE SCALE POST-COMBUSTION FACILITES AT COAL FIRED POWER PLANTS, INCLUDING PREVIOUSLY STUDIED FACILITIES[vii]

Global CCS Institute. "2019 Global Status of CCS." Accessed January 14, 2020.
https://www.globalccsinstitute.com/resources/global-status-report/

It is important to note that the scale of each application impacts the overall cost-effectiveness of the technology. The following graph shows the economy of scale expected for amine-based CO_2 capture applications at coal-fired facilities.

Figure 5 — Amine-Based CO_2 Capture, Coal-Fired Power Plants – Economy of Scale

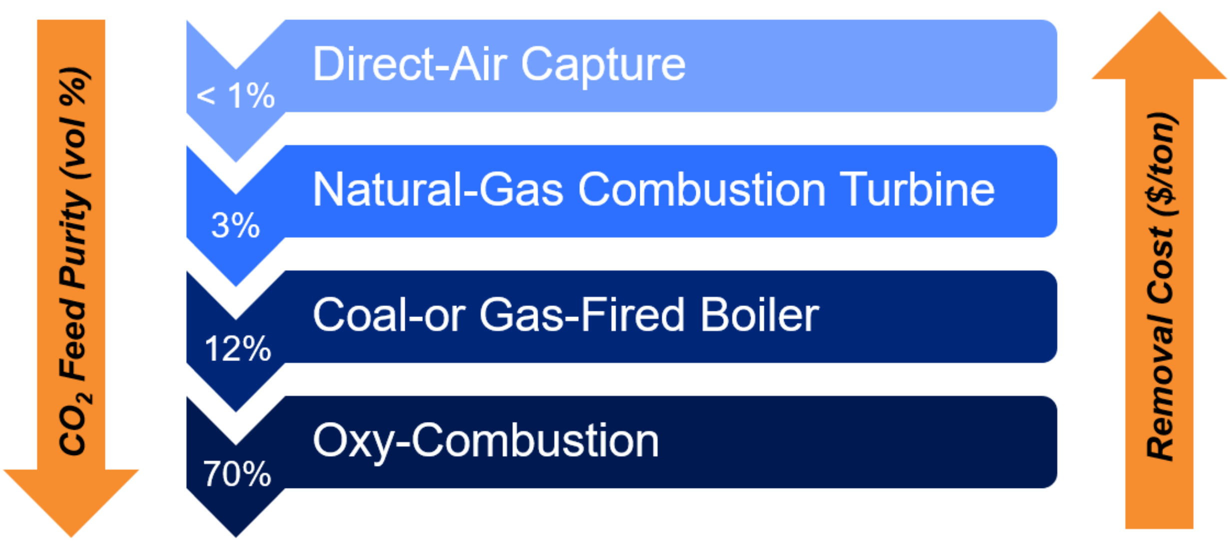


*Costs assume steam and power are supplied by the base unit and do not include costs beyond the fence line.

As the cost of capture decreases for amine-based technology, the cost of installing CO_2 capture at a coal fired facility approaches the value of the tax credit. By selling the compressed CO_2 for enhanced oil recovery or beneficial reuse, an additional revenue may help a project to be financially viable.

The cost of capture ($/tonne) is inversely proportional to the density of CO_2 in the flue gas; the relationship shown is the potential applications of CO_2 capture with their corresponding CO_2 density.

Figure 6 — Cost of Capture Relative to CO_2 Density



For natural gas turbine applications, the cost of CO_2 capture is much higher than coal-fired boilers due primarily to the low CO_2 density in the flue gas (3% versus 12%). Natural gas applications would typically range between $60 and $90 per tonne.

A feasibility study should be conducted as an initial step to understand the plant integration scope and develop an associated order-of-magnitude cost of capture, which can be used to evaluate project viability.

CO_2 Offtake

The economics and financial viability of a project may rely upon the sale of CO_2 to an end user. In a project, it is important to determine the potential offtaker(s) and establish a preliminary arrangement to ensure that there is a market for the product.

Offtake agreements need to consider the proximity of the potential CO_2 capture facility to the offtake and the method of delivery. For example, in many cases the potential point source may need to be connected to an existing oil field by a new pipeline. The responsibility of delivery should be established as part of this agreement.

In addition, the commitment of CO_2 to be made available for sale by the facility and to be purchased by the offtaker should be clearly defined in the agreement. For example, a minimum annual production may be established to ensure the offtaker has enough CO_2 to support their operations. Alternatively, it may also be established that the offtaker commits to taking all the CO_2 generated by the facility, which would ensure the sale of CO_2 beyond any minimum production threshold.

A project feasibility study should be conducted as an initial step to identify the plant integration scope and an associated order-of-magnitude cost of capture which can be used to evaluate the project viability.

Project Development

Developing a CO_2 capture project is a lengthy process that must be accounted for in a project's due diligence and planning. The current IRS 45Q Regulation states that to qualify for the tax credit, projects must begin construction before January 1, 2024.

A preliminary FEED study is currently recommended by all the major amine-based CO_2 capture technology suppliers. FEED studies typically involve a significant amount of engineering, with a duration of 12–18 months. At the conclusion of the FEED study, detailed design and construction can commence, which is expected to take 36–48 months depending on project size and complexity.

Prior to initiating a FEED study, feasibility studies are useful in determining if a facility is a suitable candidate for CO_2 capture by evaluating the recommended level of plant integration, defining the balance-of-plant scope, developing high-level costs of capture, and identifying permitting considerations and potential limitations.

Sargent & Lundy recommends that both a feasibility study and FEED study be performed upfront to ensure the plant integration is fully understood. The project schedule should consider the duration of both the feasibility and FEED study to ensure construction can begin before January 1, 2024.

Permitting

A CO_2 capture project will require environmental permits or approvals for air emissions, water use, wastewater discharges, and/or solid waste management and disposal. Specific limitations and permitting requirements depend upon the type, size, and location of the facility being permitted and the level of plant integration.

Permitting challenges for a CO_2 capture facility include the potential for longer, more complicated Prevention of Significant Deterioration (PSD) permitting, which depends on a variety of factors such as aggregation, project location, and project scope; availability and accessibility of water rights, which will impact the type of cooling system that can be installed; and hazardous waste classifications depending on the type and quantity of solvent related-waste.

In addition, a new pipeline may be required to support the sale or use of the CO_2. Installing a new pipeline can require extensive permitting and right-of-way discussions with land owners and federal agencies, such as the Bureau of Land Management.

Modifying an existing air permit or permitting a new pipeline can be an extensive process, and it could become a limiting factor in the overall project schedule. Therefore, the types of permits, inputs, and permit timelines need to be established at the beginning of a project and integrated into the overall project schedule. Sargent & Lundy recommends developing an Environmental Permit Matrix as an initial step of a FEED study.

Summary

Sargent & Lundy is an industry leader in the integration and development of CO_2 capture projects with over 10 years of experience with various utilities, technology providers, and developers. Sargent & Lundy has been involved in every step of CO_2 capture development, beginning with the United States Department of Energy's pilot projects to the first-of-a-kind commercial projects being built. This experience provides us with the unique expertise necessary to assist in planning, evaluating feasibility, and developing CO_2 capture projects. From this experience, Sargent & Lundy has identified several key considerations for the diligence of a CO_2 capture project, which include technology viability, plant integration, economics, CO_2 offtake, project development, and permitting that are critical for the long-term success of a CO_2 capture project.

For a successful CO_2 capture project, Sargent & Lundy recommends the completion of an upfront feasibility study. Feasibility studies can be completed independently by an experienced owner's engineer and do not necessitate selection of a technology supplier. A feasibility study will evaluate the balance of plant integration scope, develop an overall order-of-magnitude cost of capture, and identify other aspects of a project, such as permitting requirements and potential off-takers, that are used in evaluating the viability of a project. Of critical importance is the impact of the CO_2 capture project integration into the existing thermal power plant. The impact of the CO_2 capture project to plant performance and dispatch must be thoroughly understood to ensure that the plant remains competitive and continues to dispatch after the addition of the CO_2 capture equipment. The ability of the power plant to operate within the local electricity marketplace, and the minimum capacity factor at which the plant will operate impacts the CO_2 quantities available for an offtake agreement.

Sargent & Lundy also recommends development of an environmental permit matrix. The permits identified in the matrix should be tracked in the project schedule to ensure that permits are completed and submitted as soon as the inputs are completed. Modifying an existing air permit or permitting a new pipeline can be very extensive and could become a limiting factor in the overall project schedule. Therefore, the types of permits, inputs, and timelines for each permit need to be established early in a project to be integrated into the overall project schedule.

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About Sargent & Lundy

Sargent & Lundy is one of the oldest and most experienced full-service architect engineering firms in the world. Founded in 1891, the firm is a global leader in power and energy with expertise in grid modernization, renewable energy, energy storage, nuclear power, and fossil fuels. Sargent & Lundy delivers comprehensive project services—from consulting, design, and implementation to construction management, commissioning, and operations/maintenance—with an emphasis on quality and safety. The firm serves public and private sector clients in the power and energy, gas distribution, industrial, and government sectors.

Sargent & Lundy's roles on electric power generation projects include full-design architect-engineer, owner's engineer, lender's independent engineer/technical advisor, and consultant. Our services include specialized technical advisory and consulting services to complete engineering and program management, encompassing procurement, construction management, technology transfer, and assistance with construction. Sargent & Lundy provides professional consulting, engineering, and design services throughout the lifecycle of power generation, transmission, and energy storage projects, from project concept and development, through detailed design and procurement, to construction and operation.

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