POINT SOURCE CARBON CAPTURE PROGRAM

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NATIONAL ENERGY TECHNOLOGY LABORATORY

OVERVIEW

The U.S. Department of Energy/National Energy Technology Laboratory's (DOE/NETL) Point Source Carbon Capture (PSCC) Program is developing the next generation of advanced carbon dioxide (CO_2) capture technologies (e.g., membrane, solvent, sorbent, chemical looping) focusing on reduced cost and improved performance and reliability. DOE's Office of Fossil Energy and Carbon Management (FECM) has adopted a comprehensive, multipronged approach that involves the coupling of CO_2 capture from a point source (fossil fuel-based power generation and industrial sources, e.g. hydrogen, petrochemical, cement production plants) with (1) CO_2 transport via pipeline and injection underground for long-duration storage, (2) conversion into valuable products such as fuels, chemicals and building materials, or (3) use for enhanced hydrocarbon (oil or gas) recovery.

The PSCC Program is investing in innovations to drive down costs and optimize processes to enable widespread use of these technologies to generate CO_2 that can support the expansion of secure domestic energy production. Research and development (R&D) efforts to date have led to significant improvements in cost and performance through implementation of energy and process efficiencies and development of advanced CO_2 capture media (e.g., solvents, sorbents and membranes). The program is focused on developing highly efficient, scalable carbon capture technologies with even greater cost reductions, that are capable of flexible and reliable operation.

PROGRESSING R&D SCALE

The R&D sponsored by the PSCC Program ranges in scale from conceptual engineering and materials design at laboratory and bench scale with testing on simulated and/or actual flue gases (Technology Readiness Level [TRL] 2-5) to engineering-scale testing at host plant sites and front-end engineering and design (FEED) studies (TRL 6-7) to lower both capital and operating costs of point source CO_2 capture.

Laboratory- and bench-scale testing of advanced carbon capture materials and highly efficient components and processes is critical in developing novel carbon capture technologies with potential to economically capture CO_2 from point sources with 95% CO_2 purity. This level of research starts with short duration proof-of-concept and parametric testing using simulated flue gas and may progress to field testing with actual flue gas.

Engineering-scale testing under actual flue gas conditions for longer durations supports the development of advanced PSCC technologies. Engineering-scale testing can be performed at carbon capture test centers or by means of purpose-built pilots installed at existing plants/facilities. Testing under continuous steady-state operation, as well as off-load plant conditions, provides performance data necessary for further process scale-up. Results from field-test campaigns provide critical information for a subsequent FEED evaluation.

FEED studies provide estimates of the capital and operating costs for installing commercial-scale, advanced postcombustion CO_2 capture technologies at new or existing power plants. FEED studies incorporate knowledge gained from feasibility studies and completed field-testing of the specific technologies to define a project scope of work, design basis identifying host site characteristics and permitting requirements, material purchasing and construction schedules, and an engineering design package resulting in preparation of a capital cost estimate including $/tonne net CO_2 captured.

CAPTURE FROM POWER GENERATION SOURCES

Carbon capture for fossil fuel-based power production separates CO_2 from the plant's exhaust gas or syngas stream. The PSCC Program has identified and advanced carbon capture technologies since 2001, with the goal of decreasing the cost and improving the efficiency of carbon capture systems that can be installed on existing or new fossil fuel-fired power plants. The PSCC Program is focused on advancing novel carbon capture materials, equipment, processes, or a combination thereof, for power sector applications.

CARBON CAPTURE TEST CENTERS

The National Carbon Capture Center (NCCC) provides a platform for testing and evaluating third-party technologies at bench and engineering scale. The NCCC infrastructure includes multiple, adaptable test units, offering the flexibility of testing multiple technologies simultaneously under power generation process conditions over a range of scenarios that will enable evaluation of the efficiency, performance and economic viability of fossil fuel-fired power generation processes with CO_2 capture. After 10 years of successful technology development for carbon capture from coal-fired power systems, the NCCC expanded its postcombustion test capabilities to include natural gas-derived flue gas from a natural gas boiler. NETL partners with Technology Centre Mongstad (TCM) in Norway, the world's largest open-access test center for carbon capture technologies, to conduct engineering-scale test campaigns using TCM's postcombustion capture plants, designed to test solvent-based technologies using actual flue gas at the equivalent of approximately 12 MWe, and module testing for emerging (lower TRL) carbon capture technologies. The Wyoming Integrated Test Center (ITC), located at Basin Electric Power Cooperative's Dry Fork Station, is utilized for testing postcombustion carbon capture and utilization technologies. The ITC features five small sites and one large site, utilizing up to 20 MWe equivalent of coal-based flue gas from the power plant.

CAPTURE FROM INDUSTRIAL SOURCES

PSCC from industrial sources (e.g., chemical production [hydrogen, petrochemical], cement production) separates CO_2 from the plant's flue gas or other exhaust streams. The complexity of capturing CO_2 from industrial sources differs across sectors, with CO_2 flue gas concentrations varying depending on the industry and the specific stream targeted for CO_2 capture. Industrial sources that have a highly concentrated stream of CO_2, such as natural gas processing, fertilizer production, hydrogen production and ethanol production, have lower energy requirements for CO_2 separation. For lower-concentration industrial sources, such as iron and steel production, cement manufacturing, and petroleum refining facilities, significant challenges exist in developing carbon capture technologies, including energy requirements, differing gas compositions, varying process temperatures and pressures, and various contaminants.

Point Source Capture for Industrial Sectors

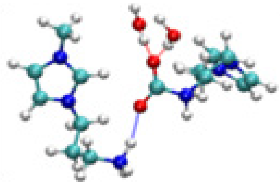
Cement Plants | 15–20% CO_2

Hydrogen Plants | 15–45% CO_2

In **cement manufacturing**, CO_2 is primarily released during cement clinker production through the limestone calcination process and the combustion of fuel for process heating. Cement production processes often combine process and combustion CO_2 in a single stack.

For the **hydrogen production** industry, high-purity hydrogen is produced from natural gas in steam methane reforming (SMR) or autothermal reforming (ATR) plants. In SMR plants, natural gas and steam are reacted to produce synthesis gas (syngas), a mixture of carbon monoxide and hydrogen gas. Hydrogen production emits CO_2 from the process gas and from the combustion of natural gas (flue gas). When producing hydrogen via SMR, there are three separate point sources where CO_2 can be collected or vented from the plant: from the SMR flue gas, from the syngas stream before pressure swing adsorption (PSA), and from the PSA tail gas. In autothermal reforming (ATR) plants, natural gas is partially oxidized with oxygen and steam to produce a hydrogen-rich syngas. The ATR process contains the majority (90%) of the CO_2 in the syngas with the remaining 10% in the flue gas. Economical CO_2 capture is then possible from only the higher concentration syngas stream, avoiding more costly capture from the flue gas.

KEY TECHNOLOGIES



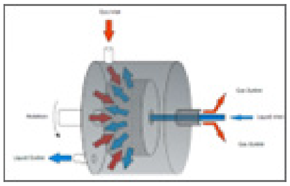
Solvent-based CO_2 capture involves chemical or physical absorption of CO_2 from a gas into a liquid carrier. R&D of advanced solvents (e.g., water-lean solvents, phase-change solvents, high-performance functionalized solvents) aims for low regeneration energy requirements, high CO_2 capacity, and tolerance to impurities.

Sorbent-based CO_2 capture involves the chemical or physical adsorption of CO_2 from a gas using a solid sorbent. R&D objectives include low-cost durable sorbents with high CO_2 selectivity, high CO_2 capacity, resistance to oxidation and minimal attrition. System advancements include sorbent process intensification techniques, novel reactor designs and enhanced process configurations.

Membrane-based CO_2 capture uses permeable or semipermeable materials that allow for the selective transport and separation of CO_2 from a gas. R&D objectives include low-cost, durable membranes (e.g., polymeric membranes, mixed matrix membranes, subambient temperature membranes) with improved permeability and selectivity for CO_2, thermal and physical stability and tolerance to gas contaminants.

Novel concepts include alternative technologies and processes, such as cryogenic separation, electrochemical membranes and additive manufacturing of novel system components and materials. R&D objectives include development of equipment, materials and processes that enable intensified thermodynamic operations, improve process performance and reduce equipment size, lowering capital and operating costs.

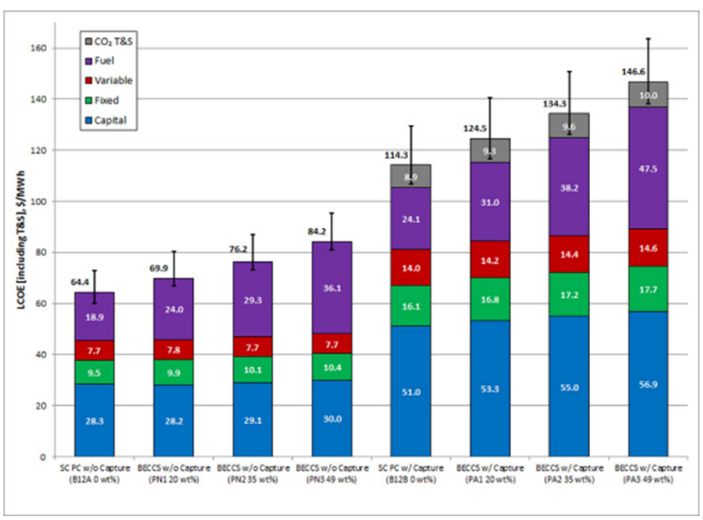
Hybrid systems efficiently combine two key technologies in a single system (e.g., sorbent-membrane system). Hybrid concepts can reduce the process' overall energy intake by leveraging process synergies, resulting in a more cost-effective system.



Enabling technologies are concepts that could improve a whole class of materials, and although the research might be applied to one specific material, it is envisioned that substantial research findings could benefit multiple materials. R&D topics include solvent aerosol emissions mitigation, solvent viscosity reduction, solvent stability improvements, materials compatibility, corrosion resistance improvements and degradation products reduction or separation.

SUPPORTING ANALYSES AND TOOLS

SYSTEMS ANALYSIS — Systems analysis is a major emphasis in the PSCC Program's portfolio. Projects developing advanced carbon capture technologies undergo various screening analyses prior to scale-up efforts to determine whether they can outperform the current state-of-the-art technologies and meet DOE transformational cost targets. Analyses include technoeconomic analysis, life cycle analysis, systems design, goals and metrics development and market analyses. These activities provide cost and technical viability predictions of carbon capture technologies for both intramural projects at NETL, as well as extramural projects, and they provide an unbiased analysis to inform the PSCC Program.



CARBON CAPTURE SIMULATION FOR INDUSTRY IMPACT — The Carbon Capture Simulation for Industry Impact (CCSI[2]) project operates in conjunction with and in support of the PSCC Program to focus on advancing promising technologies by advancing the multiscale understanding required to support the most effective pathways to minimize the cost to capture CO_2. By developing first principles models of carbon capture processes, using uncertainty quantification and rigorous optimization frameworks, CCSI[2]-generated insights accelerate and derisk the scale-up of new and innovative carbon capture technology. These capabilities have been applied to maximize the value of data generated by pilot tests, cutting years off of typical time frames to gather similar quality data and saving millions of dollars. Data generated in this way more efficiently refines the accuracy of models used in CCSI[2] frameworks that optimize both design and operation of advanced processes while also helping to ensure robust operation amidst anticipated ranges of uncertainty.

CCSI[2] Carbon Capture Simulation Initiative

Computational products are consolidated in the CCSI Toolset, which is a comprehensive, integrated suite of validated science-based computational models, the use of which will increase confidence in equipment and process designs. This thereby reduces the risk associated with incorporating multiple innovative technologies into new carbon capture solutions. The scientific underpinnings encoded into the suite of models will also ensure that learning will be maximized through development of successive technology generations.

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