POINT SOURCE CARBON CAPTURE PROGRAM

NATIONAL ENERGY TECHNOLOGY LABORATORY

OVERVIEW

The National Energy Technology Laboratory's (NETL) Point Source Carbon Capture (PSCC) Program is developing the next generation of advanced carbon dioxide (CO_2) capture concepts to support the United States in achieving ambitious goals for a greenhouse gas (GHG)-neutral economy by 2050, a carbon-pollution-free power sector by 2035, and a 50% reduction from 2005 levels in economy-wide net GHG pollution by 2030. DOE's Office of Fossil Energy and Carbon Management (FECM) employs a comprehensive multi-pronged approach for carbon management that involves the coupling of carbon capture approaches (i.e., point source carbon capture (PSCC) for fossil fuel-based power generation and industrial sources; and carbon dioxide removal [CDR] technologies) with long-duration carbon storage or CO_2 conversion into long-lasting products. The PSCC Program is accelerating commercially deployable solutions that can be applied to a wide spectrum of CO_2 emissions sources with varying CO_2 emission levels, including facilities that produce power, hydrogen, chemicals, cement, or steel.

The PSCC Program is advancing technologies to minimize the environmental impacts of fossil fuel-based power generation and to decarbonize existing infrastructure in the power and industrial sectors. R&D efforts to date have led to reductions in both capital and operating costs through implementation of energy and process efficiencies and development of advanced CO_2 capture media (e.g., solvents, sorbents, and membranes). To achieve deep decarbonization of emissions sources, the program is focused on developing highly efficient, scalable carbon capture technologies with even further cost reductions that are capable of operation under a flexible duty cycle and that can achieve greater than 95% carbon capture.

PROGRESSING R&D SCALE

The progressive 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 at least 95% of 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 (up to 200 tonnes CO_2/day for power generation applications and at least 2.5 tonnes CO_2/day for industrial applications) under actual flue gas conditions for longer durations further progresses advanced point source CO_2 capture 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 facilitate wide-scale deployment of carbon capture systems by providing estimates of the cost for installing commercial-scale, advanced CO_2 capture technologies at new or existing plants. The studies focus on carbon capture systems integrated into specific operating power or industrial plants combined with long duration carbon storage or conversion of the CO_2 into long-lived products. FEED studies incorporate knowledge gained from prior feasibility studies and completed field testing of the specific technologies to complete a detailed design package covering all aspects of the commercial application and capital and operating expenses.

CAPTURE FROM POWER GENERATION SOURCES

Carbon capture for fossil fuel-based power production separates CO_2 emissions from the plant's exhaust gas or syngas stream to prevent its release into the atmosphere. 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 applications such as in natural gas combined cycle (NGCC) power generation.

CARBON CAPTURE TEST CENTERS

NETL utilizes carbon capture test centers to bridge the gap between laboratory research and large-scale demonstrations enabling evaluation of the efficiency, environmental performance, and economic viability of fossil fuel-fired power generation processes with CO_2 capture. Testing is performed on actual fossil-fuel derived flue gas under realistic conditions. The National Carbon Capture Center (NCCC), DOE's primary carbon capture research facility operated and managed by Southern Company in Alabama, provides a platform for testing and evaluating third-party technologies at bench and engineering scale over a range of power generation process conditions. 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 post-combustion 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 post-combustion 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.

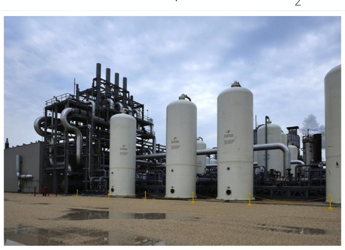
CAPTURE FROM INDUSTRIAL SOURCES

PSCC from industrial sources, such as ethanol plants, mineral production (cement and lime) plants, iron and steel manufacturing plants, and hydrogen production plants is a vital element in reducing overall CO_2 emissions. The PSCC Program conducts R&D to test transformational capture technologies for industrial carbon capture and supports initial engineering design and FEED studies on commercial-scale capture systems that separate at least 95% of the total CO_2 emissions with 95% purity at industrial facilities. The complexity of capturing CO_2 from industrial sources differs across the sector with CO_2 concentrations varying depending on the industry and the specific stream(s) targeted for carbon 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

Steel Plants | 20% CO_2



Hydrogen Plants | 15–45% CO_2

Ethanol Plants | 98–99% CO_2

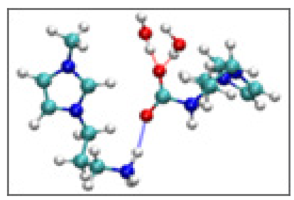
In **cement manufacturing**, CO_2 is primarily released during cement clinker production through the limestone calcination process and the combustion of fuel for process heating. Cement production processes often combine process and combustion CO_2 emissions in a single stack.

In the **iron and steel industry**, primary steel production typically uses iron ore and the process known as blast furnace with basic oxygen furnace (BF-BOF). Capture technologies target CO_2 from the blast furnace gas as it contains the highest CO_2 concentration by volume within the steelmaking process.

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 for steam, requiring CO_2 capture from both streams. 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.

In **ethanol production**, high purity CO_2 is produced as an inherent byproduct of the fermentation process, and CO_2 is also emitted at a relatively low CO_2 concentration as a result of burning fuel for process heating. The high-purity fermentation stream makes ethanol facilities ideal candidates for CCUS. Hybrid capture systems employed at ethanol facilities can capture CO_2 from the bioprocessing stream as well as from the heat production stream to achieve negative emissions.

KEY TECHNOLOGIES



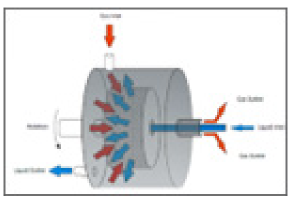
Solvent-based CO_2 capture involves chemical or physical absorption of CO_2 from a gas into a liquid carrier. R&D of advanced solvents (e.g., water-lean solvents, phase-change solvents, high-performance functionalized solvents) aim for low regeneration energy requirements, high CO_2 capacity, and tolerance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

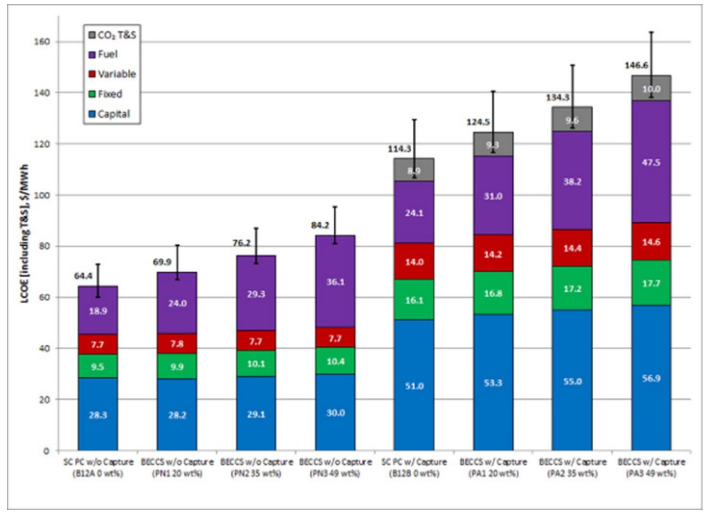
Hybrid systems efficiently combine two key technologies in a single system (e.g., sorbent-membrane system). Hybrid concepts can reduce the overall energy intake of the process by leveraging process synergies, resulting in a more cost-effective system.



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 techno-economic analysis (TEA), life cycle analysis (LCA), systems design, goals and metrics development, and market analyses. These activities provide predictions of the cost and technical viability of carbon capture technologies for both intramural projects at NETL, as well as extramural projects, and provide an unbiased analysis to inform the PSCC Program.



CARBON CAPTURE SIMULATION FOR INDUSTRY IMPACT

CCSI² Carbon Capture Simulation Initiative

The Carbon Capture Simulation for Industry Impact (CCSI²) project operates in conjunction with and in support of the PSCC Program to focus on advancing promising technologies by advancing the multi-scale 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, CCSI²-generated insights accelerate and de-risk 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 timeframes to gather similar quality data, and saving millions of dollars. Data generated in this way more efficiently refines the accuracy of models used in CCSI² frameworks that optimize both design and operation of advanced processes while also helping to ensure robust operation amidst anticipated ranges of uncertainty.

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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