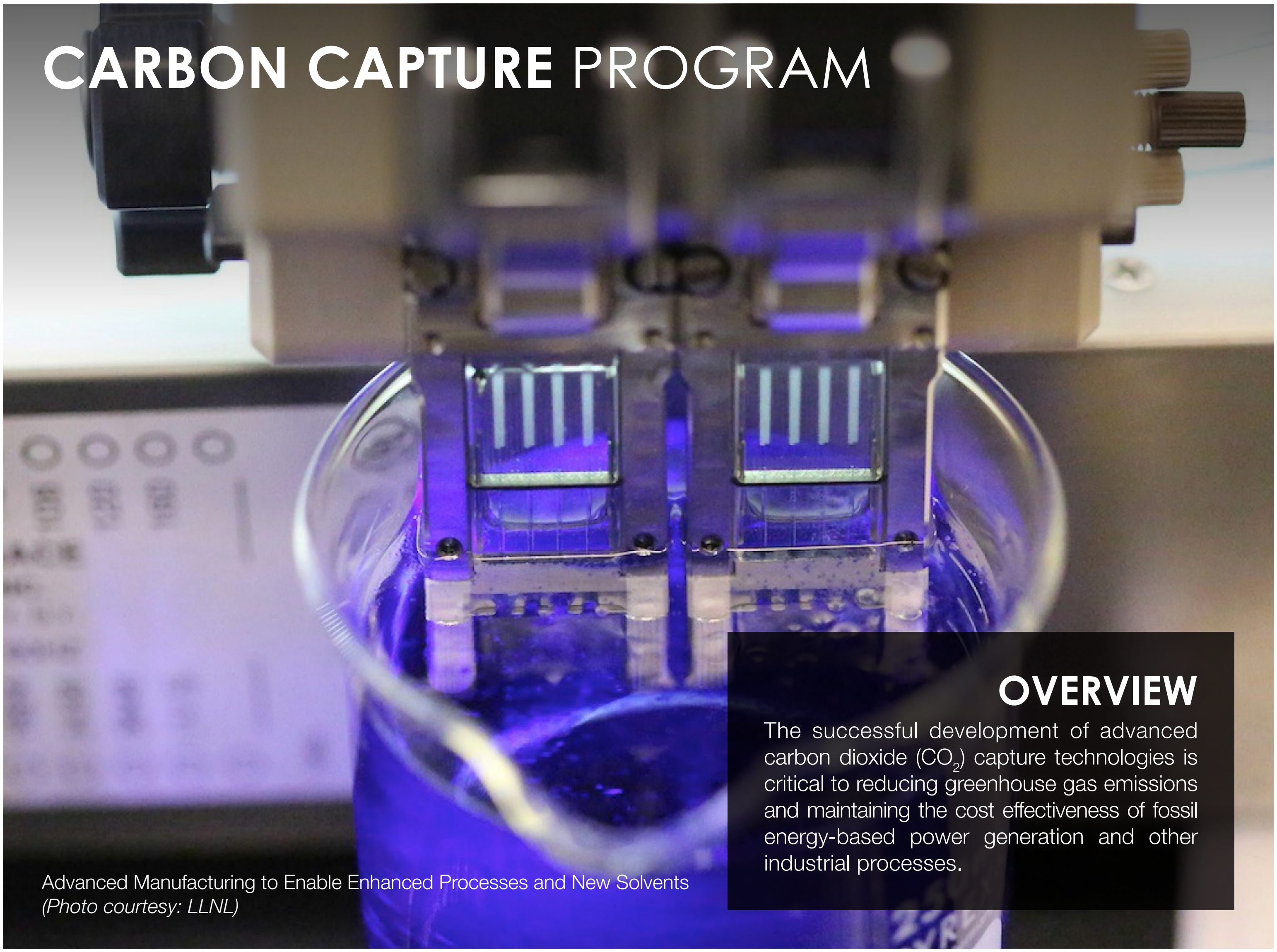
CARBON CAPTURE PROGRAM



Advanced Manufacturing to Enable Enhanced Processes and New Solvents
(Photo courtesy: LLNL)

OVERVIEW

The successful development of advanced carbon dioxide (CO_2) capture technologies is critical to reducing greenhouse gas emissions and maintaining the cost effectiveness of fossil energy-based power generation and other industrial processes.

NETL
NATIONAL ENERGY TECHNOLOGY LABORATORY

DOE's Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL) estimates that the deployment of one current first-generation CO_2 capture technology—chemical absorption with an aqueous monoethanolamine solution—used to remove 90 percent of the emissions from a new pulverized coal (PC) power plant would increase the cost of electricity (COE) by approximately 80 percent and derate the plant's net generating capacity by as much as 20 percent. This energy penalty occurs due to the diversion of some of the energy produced by the plant (in the form of both steam and electricity) to operate the CO_2 capture process.

Commercially available CO_2 capture technologies are currently used in various small-scale industrial applications. However, these first-generation technologies are not ready for widespread deployment on fossil energy-based power systems. The U.S. Department of Energy's (DOE) Carbon Capture R&D Program is focused on supporting research and development (R&D) of innovative technology solutions that address the three major issues with existing commercial CO_2 capture technology:

- Reducing the negative impact on power-generating capacity
- Scaling up innovative technologies to the size necessary for full-scale deployment at fossil energy power systems
- Improving the cost-effectiveness of innovative technologies for CO_2 capture so that fossil-based systems with carbon capture are cost-competitive

RESEARCH PATHWAYS

To ready CO_2 capture technologies for widespread deployment, the DOE FE/NETL **Carbon Capture** Program is developing technologies that have the potential to provide step-change reductions in both cost and energy penalties. The program's research is focused on enabling cost-effective implementation of carbon capture technologies throughout the power- generation sector. NETL research addresses both new and existing power plants. Current research and development (R&D) is investigating solvent, sorbent, membrane and novel concept technologies.

Developing a successful CO_2 capture technology requires putting together multiple pieces of a puzzle. Laboratory-scale testing of process chemistry and physics and the evaluation of associated operating parameters alone are insufficient.

Research efforts must also involve the development of new chemical production methods, novel process equipment designs, new equipment manufacturing methods, and optimization of process integration with other power-plant systems. NETL research encompasses a wide-scale effort, integrating the advances and lessons learned from computational simulation, fundamental research, technology development, large-scale testing, and demonstration.

RESEARCH GOALS

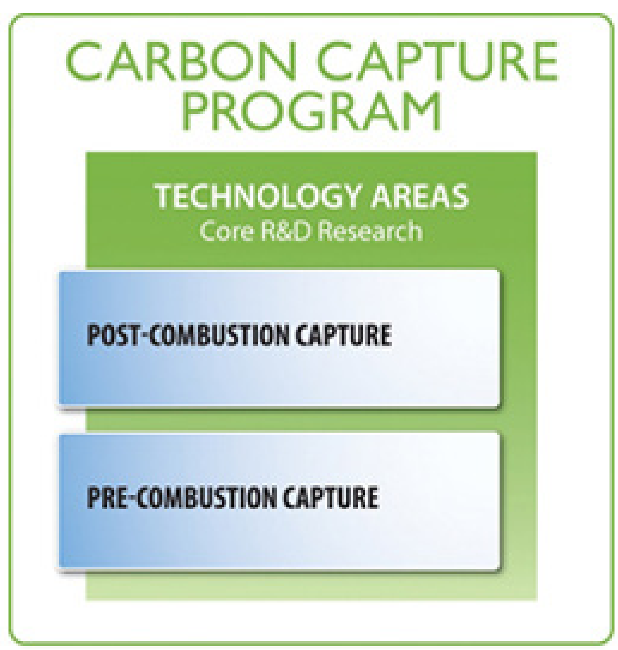
The core RD&D projects being pursued by the program leverage public and private partnerships to support the goal of broad, cost-effective carbon capture deployment. DOE FE/NETL is targeting demonstration of **Second Generation** technologies that result in a captured cost of CO_2 of $40/tonne in the 2020–2025 timeframe. DOE FE/NETL is also committed to extending R&D support to even more advanced **Transformational** carbon capture technologies that will further increase competitiveness of fossil-based energy systems beyond 2025.

CORE TECHNOLOGY AREAS

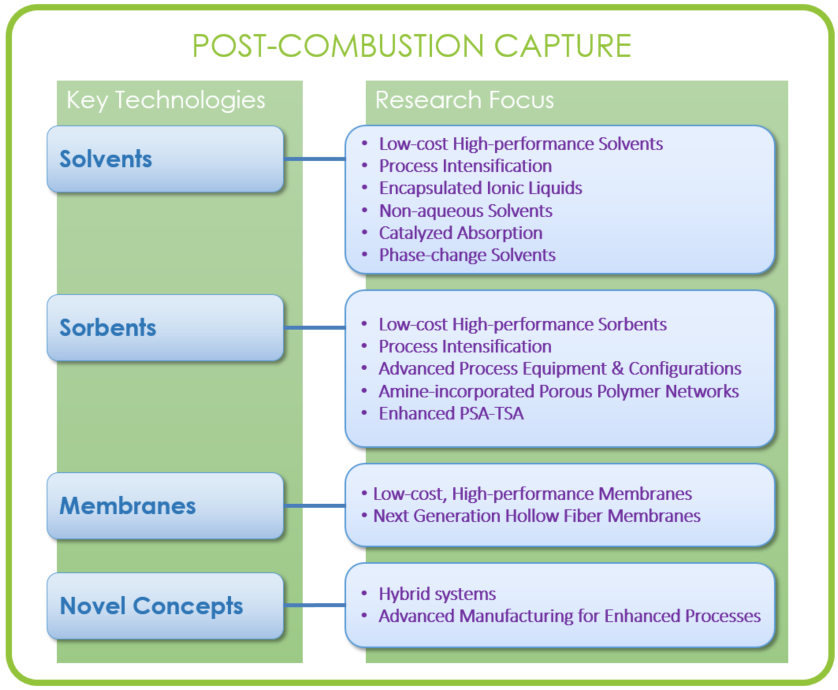
The program consists of two core research technology areas, **Post-combustion Capture** and **Pre-combustion Capture.**

Within these two areas, DOE FE/NETL pursues a comprehensive approach with multiple pathways that includes a broad portfolio of technologies to increase probability of success and mitigate the risks inherent to new technology research efforts. The **Carbon Capture** Program continues to benefit from large-scale demonstrations of first-generation technologies conducted as part of the Clean Coal Power Initiative, as well as R&D collaborations on advances in core technologies with the National Carbon Capture Center and the Advanced Research Projects Agency-Energy.

DOE's Carbon Capture Program aims for the development of second generation CO_2 capture technologies that will be ready for demonstration-scale testing around 2020. Development and scale-up of new technologies in the energy sector historically takes up to 15 years to move from the laboratory to pre-deployment and another 20 to 30 years for widespread industrial scale deployment.



The Carbon Capture Simulation Initiative (CCSI) toolset is a fully integrated software suite developed specifically for improving the speed and accuracy of developing and scaling technologies. The CCSI Toolset delivers industry researchers and engineers a key capability needed to develop technology to achieve targets for low-carbon energy. The CCSI Toolset is a comprehensive integrated suite of validated multi-scale computational models and tools that provides new capabilities critical during technology development and scale up.



Post-combustion Capture is primarily applicable to conventional PC-fired power plants, where the fuel is burned with air in a boiler to produce steam that drives a turbine-generator designed to generate electricity. The carbon is captured from the flue gas after complete fuel combustion. The principal challenge in post-combustion capture is separating the CO_2 generated during combustion from the large amounts of nitrogen (from air) found in the flue gas. In this area, the R&D effort is focused on advanced solvents, solid sorbents, membrane-based systems, and novel concepts that include hybrid technologies.

Solvent-based CO_2 capture involves chemical or physical absorption of CO_2 from flue gas into a liquid carrier. The absorption liquid is regenerated by increasing its temperature or reducing its pressure. Research projects in this key technology focus on the development of low-cost, non-corrosive solvents that have a high CO_2 loading capacity; improved reaction kinetics; low regeneration energy; and resistance to degradation. In addition, considerable effort is being applied to development of process design and integration that leads to decreased capital and operating costs and enhanced performance of these systems. Transformational technologies that may be pursued include encapsulated ionic liquids, non-aqueous sorbents, catalyzed absorption that accelerates CO_2 uptake in solvents with lower regeneration energies, and solvents that change phase in the presence of CO_2.

Solid sorbents—including sodium and potassium oxides, zeolites, carbonates, amine-enriched sorbents, and metal organic frameworks—are being explored for post-combustion CO_2 capture. A temperature or pressure swing facilitates sorbent regeneration following chemical and/or physical adsorption. A key attribute of sorbents (compared with most modern solvent-based systems) is that CO_2 separation does not occur in an aqueous solution, which reduces sensible heating and stripping energy requirements. Research projects in this key technology focus on developing sorbents with the following characteristics: low-cost raw materials, low attrition rates, low heat capacity, high CO_2 adsorption capacity, and high CO_2 selectivity. Another important focus of this research is to develop cost-effective process equipment designs that are tailored to the sorbent characteristics. Transformational concepts being considered include structured solid adsorbents (e.g., metal organic frameworks), enhanced pressure-swing-adsorption (PSA) and temperature-swing-adsorption (TSA) processes, and amine-incorporated porous polymer networks.

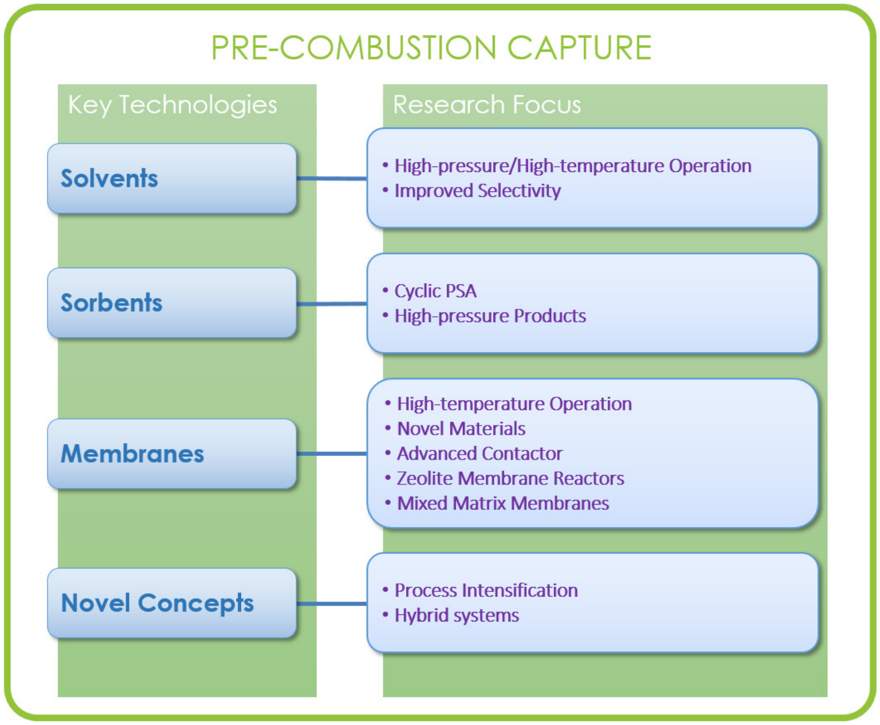
Pilot-scale Pre-combustion Membrane and Post-combustion Solvent Testing

Membrane-based CO_2 capture uses permeable or semi-permeable materials that allow for the selective transport and separation of CO_2 from flue gas. Generally, gas separation is accomplished by some physical or chemical interaction between the membrane and the gas being separated, causing one component in the gas to permeate through the membrane faster than another. Selectivity for CO_2 in today's membranes is usually insufficient to achieve the desired purities and recoveries.

Therefore multiple stages and recycle streams may be required in an actual operation, leading to increased complexity, additional energy consumption, and higher capital costs. Research projects in this key technology address technical challenges for the use of membrane-based systems, such as large flue gas volume, relatively low CO_2 concentration, low flue gas pressure, flue gas contaminants, and the need for high membrane surface area. The research focus for post-combustion membranes includes development of low-cost, durable membranes that have improved permeability and selectivity, thermal and physical stability, and tolerance to contaminants in combustion flue gas. Also under development are gas absorption membrane technologies where the separation is caused by the presence of an absorption liquid on one side of the membrane that selectively removes CO_2 from a gas stream on the other side of the membrane. Transformational membrane technologies under investigation include next generation hollow fiber membranes.

Novel concepts for CO_2 capture include hybrid systems that combine attributes from multiple technologies, electrochemical membranes, and advanced manufacturing to enable enhanced processes.

Pre-combustion Capture is applicable to IGCC power plants, where solid fuel is converted into gaseous fuel (hydrogen and carbon monoxide, or "syngas") by applying heat under pressure in the presence of steam and oxygen. In order to facilitate carbon capture and increase the hydrogen production, the syngas is then shifted in what is referred to as a water-gas-shift (WGS) reaction to produce additional hydrogen and convert the carbon monoxide into CO_2. In this case, the carbon is captured from the shifted syngas, and afterward, the remaining hydrogen is combusted in a gas turbine that generates power. In this area, R&D efforts are focused on advanced solvent, solid sorbent, and membrane-based systems for the separation of H_2 and CO_2, and novel concepts with specific emphasis on high-temperature/novel materials, process intensification, and nanomaterials. Just as in post-combustion efforts, novel concepts including hybrid technologies that combine attributes from multiple technologies (e.g., CO_2 separation and WGS) are being investigated.



Research and development efforts associated with solvent-based pre-combustion capture include modifying regeneration conditions to recover the CO_2 at a higher pressure, improving selectivity to reduce H_2 losses, developing a solvent that has a high CO_2 loading at a higher temperature to improve IGCC efficiency, and combining temperature-swing and pressure-swing regeneration to lower cost and energy penalties.

The materials, regeneration characteristics, and process configurations for pre-combustion sorbents are similar to those described for post-combustion sorbents but applied to the unique high-temperature/high-pressure conditions of IGCC systems (to avoid the need for syngas cooling). Technologies include integrating capture directly with the WGS reaction to help drive equilibrium toward CO_2 and H_2 production while eliminating the need for syngas cooling and development of hybrid systems.

As with sorbents, the general characteristics of pre-combustion membranes are similar to those for post-combustion. Membrane designs include metallic, polymeric, or ceramic materials operating at elevated temperatures, with a variety of chemical and/or physical mechanisms that provide separation. Technologies include integration of a membrane-based system with WGS, high-density and -pressure nanoscale membranes, high-temperature/high-pressure seals, process intensification.

Novel Concepts under investigation include hybrid systems that combine attributes from multiple technologies, process intensification and integrating capture directly with the water-gas shift reaction to help drive equilibrium toward CO_2 and H_2 production while eliminating the need for syngas cooling.

Contacts

Lynn Brickett
Technology Manager
Carbon Capture
412.386.6574
lynn.brickett@netl.doe.gov

John Litynski
HQ Program Manager
Carbon Capture
202.586.8087
john.litynski@hq.doe.gov

Customer Service
1.800.553.7681