the ENERGY lab

PROJECT FACTS

Carbon Capture

# Bench-Scale Development and Testing of Rapid PSA for $CO_2$ Capture

## Background

The mission of the U.S. Department of Energy/National Energy Technology Laboratory (DOE/NETL) Carbon Capture Research & Development (R&D) Program is to develop innovative environmental control technologies to enable full use of the nation's vast coal reserves, while at the same time allowing the current fleet of coal-fired power plants to comply with existing and emerging environmental regulations. The Carbon Capture R&D Program portfolio of carbon dioxide ($CO_2$) emissions control technologies and $CO_2$ compression is focused on advancing technological options for new and existing coal-fired power plants in the event of carbon constraints.

Pulverized coal (PC) plants burn coal in air to produce steam and comprise 99 percent of all coal-fired power plants in the United States. Carbon dioxide is exhausted in the flue gas at atmospheric pressure and a concentration of 10–15 percent by volume. Post-combustion separation and capture of $CO_2$ is a challenging application due to the low pressure and dilute concentration of $CO_2$ in the waste stream, trace impurities in the flue gas that affect removal processes, and the parasitic energy cost associated with the capture and compression of $CO_2$. Solid sorbent-based technologies have the potential to effectively reduce the energy penalties and costs associated with post-combustion $CO_2$ capture for both new and existing PC-fired power plants. Pressure swing adsorption (PSA) technology is commonly used for gas separation and has the potential to remove $CO_2$ from flue gas by adsorbing the $CO_2$ at high pressure and then desorbing it at a low pressure.

## Project Description

W.R. Grace & Company (Grace) has teamed with the University of South Carolina (USC), Battelle Memorial Institute, and Catacel Corporation to develop a unique rapid PSA process for cost-effective post-combustion $CO_2$ capture from coal-fired power plants. The rapid PSA process could enable $CO_2$ capture from a 550 megawatt (MW) power station with no more than a 35 percent increase in the cost of electricity (COE). PSA is a favorable process for $CO_2$ capture as adsorption and desorption are achieved with electrical energy rather than with the extraction of steam from the power plant's steam cycle, which is important for retrofitting into existing plants.

This project will build on promising results from a previously developed proprietary PSA cycle configuration for $CO_2$ capture from a coal-fired power plant that demonstrated a total separation energy of 25 kilojoules per mole (kJ/mol) compared to 39 kJ/mol for a monoethanolamine system. The new PSA cycle is capable of achieving over 90 percent $CO_2$ recovery and over 95 percent $CO_2$ purity using commercial 13X zeolite pellets. Although this $CO_2$ capture technology could be retrofitted to a coal-fired power plant,

## CONTACTS


**Shailesh Vora**
Carbon Capture Technology Manager
National Energy Technology Laboratory
626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-7515
shailesh.vora@netl.doe.gov

**Barbara Carney**
Project Manager
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4671
barbara.carney@netl.doe.gov

**James A. Ritter**
Principal Investigator
University of South Carolina
301 Main Street
Columbia, SC 29208
803-777-3590
ritter@cec.sc.edu


## PARTNERS

University of South Carolina
Battelle Memorial Institute
Catacel Corporation

## PERFORMANCE PERIOD

| Start Date | End Date |
|---|---|
| 10/01/2011 | 09/30/2014 |

## COST

**Total Project Value**
$3,748,626

**DOE/Non-DOE Share**
$2,998,705 / $749,921

## AWARD NUMBER

DE-FE0007639

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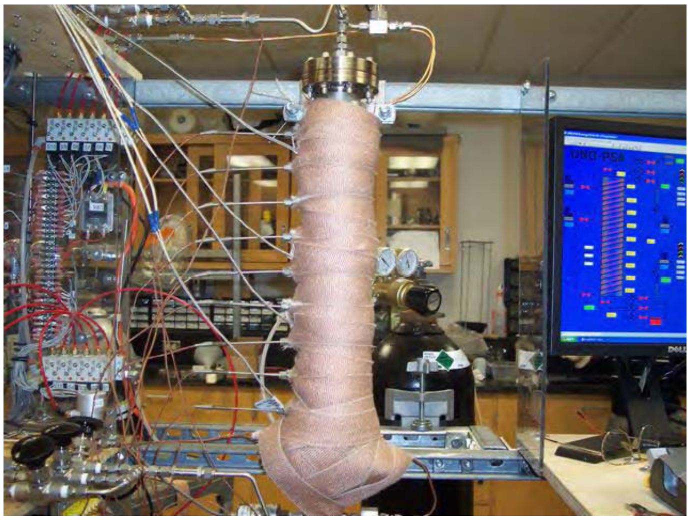
the adsorption columns would be exceedingly large and thus capital intensive. The project team will develop a rapid version of the proprietary PSA process, taking advantage of a much shorter cycle time—30 seconds compared to 300 seconds for a conventional PSA cycle. This would increase the feed throughput, a measure of the size of the adsorption columns, by a factor of 10 or more, concomitantly decreasing the column size by an order of magnitude or more. The new process could significantly reduce both the capital costs and plant footprint, while also reducing the operating costs.



*The unique 1-bed PSA apparatus designed to mimic various PSA cycle configurations.*

The rapid PSA concept is conceptually simple but difficult to implement. The key to the success of this project is finding a suitable match between the adsorbent and the PSA cycle configuration for a full-scale rapid PSA process. A select team of experts has been assembled to demonstrate the feasibility of the rapid PSA concept for $CO_2$ capture at the bench scale, and their research will focus on the materials, structure, and PSA cycle.

## Primary Project Goal

The project goal is to develop and test a bench-scale, cost-effective, rapid PSA process for post-combustion $CO_2$ capture from coal-fired power plants such that, when scaled to a 550 MW coal-fired power plant, it could achieve the DOE goal of less than 35 percent increase in the cost of electricity.

## Objectives

The specific project objectives are the development of (1) an attrition resistant and low pressure drop structured adsorbent based on commercial 13X zeolite that is compatible with the high velocities associated with rapid PSA operation, and (2) a rapid PSA cycle configuration in concert with the structured adsorbent so that the resulting rapid PSA process delivers exceptional performance at reduced capital and operating costs.

## Planned Activities

- Design and construct a single-column rapid PSA test bed with standard commercial zeolitic adsorbents.
- Perform baseline testing and compare test results to conventional pelletized adsorbent material.
- Develop and optimize a simulation model to improve the adsorbent 3-D structure based upon the baseline study results.
- Explore alternative operational strategies using process modeling and data to further optimize the rapid PSA process.
- Incrementally improve the zeolite adsorbent materials to mitigate any weaknesses identified in baseline testing.
- Investigate possible optimizations of the adsorbent, structure materials, and manufacturing process to reduce size and cost of the optimized structure.
- Based on optimized adsorbent, bed structure, and PSA process, develop and test a multi-column rapid PSA test bed on simulated coal-fired flue gas.
- Validate scale-up economics for the adsorbent structure production processes and prepare a final techno-economic feasibility study for a 550 MW coal-fired power plant.
- Complete an environmental, health, and safety assessment of the rapid PSA technology.

## Accomplishments

- Six candidate adsorbent materials were identified for testing with thermogravimetric cycling analysis to determine performance characteristics.
- Various experimental apparatus were designed, built, and operated. The adsorbent materials were tested and the material identified as “zeolite 13X-small” demonstrated the largest $CO_2$ adsorption capacity of the materials screened.
- Metal substrates were coated with a slurry prepared using zeolite 13X-small. The coated metal foil sample passed the adhesion test and was further tested for characterization and working capacity.

- Construction and testing of the Dynamic Volumetric Frequency Response (DVFR) apparatus was completed and shake-down runs were conducted. A suite of mathematical models was also developed to discern the dominant mass transfer mechanism of adsorbate-adsorbent pairs by determining which model or combinations thereof best fit the data from the DVFR apparatus.

- Construction and testing of the single-column rapid PSA system was completed.

- A preliminary design of the pressure drop test bed apparatus was completed.

- A computational fluid dynamics (CFD) model was developed for several geometries characteristic of typical structured sorbent materials. The predicted pressure drop for the unit cell models was evaluated and the results were verified against analytical expressions where possible. The agreement attained between CFD and the analytical results provide confidence in the CFD modeling process moving forward as geometries become more complex.

## Benefits

Bench-scale development of the unique rapid PSA technology—based on a successful, previously developed PSA cycle—will confirm the capability of this technology to cost-effectively capture $CO_2$ from coal-fired flue gas. This technology holds promise to achieve the DOE goals of capturing at least 90 percent of the $CO_2$ with less than a 35 percent increase in the COE when scaled to a 550 MW coal-fired power plant.