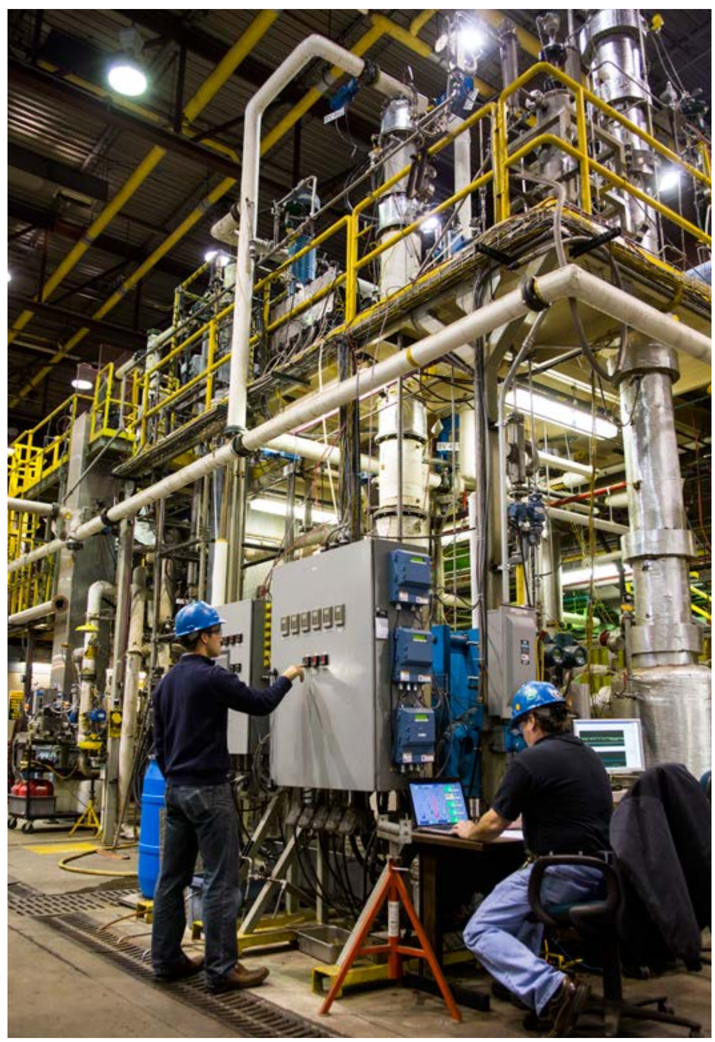
# ADVANCING $CO_2$ CAPTURE TECHNOLOGY

The Energy & Environmental Research Center (EERC) continues working with the U.S. Department of Energy (DOE), the North Dakota Industrial Commission Lignite Research Council, and a growing list of private sector partners to develop, evaluate, and reduce the energy requirements and associated costs of promising carbon capture technologies. The goal is to advance technologies along the development pathway in preparation for scale-up and deployment. The EERC has designed and fabricated world-class systems to test postcombustion and precombustion capture technologies on its existing solid fuel combustion and gasification test facilities.

Many test campaigns have been conducted on precombustion and postcombustion capture technologies, and since 2008, the EERC has worked with DOE and 30 private sector partners under the EERC's Partnership for $CO_2$ Capture ($PCO_2C$) Program, which has completed three phases. The program has provided participating partners with key technical information on carbon capture technologies, matching respective interests in technologies, plant configurations, and fuel types. Flue gas pretreatment, postcombustion capture solvents, and oxycombustion and precombustion technologies have all been tested. Aspen and Aspen Process Economic Analyzer engineering and costing models were developed to understand the technical factors affecting system performance and cost as technologies are commercialized.

*Precombustion capture project technology providers and sponsors.*

*$PCO_2C$ sponsors and technology providers.* 9/16



## EERC TRACK RECORD

- Over 3000 combined hours of precombustion testing of membranes and other technologies.
- Over 3600 combined hours of postcombustion and oxycombustion $CO_2$ capture.
- Mitigated risk on several technologies, including Shell–Cansolv, Hitachi, and ION Engineering.

## COMBUSTION

| Combustor Name | Type | Scale | Feed Rate, lb/hr | Flue Gas Production, scfm | System Pressure, psi | Nominal Furnace Exit Temperature, °F | Gas Cleanup Devices |
|---|---|---|---|---|---|---|---|
| CTF[1] | Single-burner furnace | Pilot | 50–100 | 60–130 | Balanced draft | 2500 | SCR,[2] ESP,[3] WFGD,[4] FF,[5] DSI,[6] CC,[7] |
| PTC[8] | Single-burner furnace | Pilot | 50–100 | 60–130 | Balanced draft | 2500 | SCR, ESP, WFGD, DSI, CC |
| CFBC[9] | Circulating fluidized bed | Pilot | 300 | 525 | Atmospheric | 1450–1650 | FF, in-bed sulfur capture |

## GASIFICATION

| Gasifier Name | Type | Scale | Feed Rate, lb/hr | Syngas Production, scfm | System Pressure, psi | Gasifier Nominal Temperature, °F | Warm-Gas Capability |
|---|---|---|---|---|---|---|---|
| CFBR[10] | Fluidized bed | Bench | 4 | 8 on air 1.5–2 on $O_2$ | 150 | 1525 | Full stream |
| TRDU[11] | Transport reactor | Pilot | 200–500 | 400 on air 250 on $O_2$ | 120 | 2000 | Slipstream, 5% |
| EFG[12] | Entrained flow | Bench | 4–16 | 16–20 | 300 | 2730 | Full stream |
| HPFBG[13] | Fluidized bed | Bench | 4–20 | 30–40 | 600–1000 | 1600–1800 | Full stream |
| Carbonizer | Fluidized bed | Pilot | 100–150 | 150 on air | 150 | 1200–1800 | Slipstream |
| AFBG[14] | Fixed bed | Pilot | 33–70 | 35–75 on air | Ambient | 1300–1550 | Cold-gas cleanup |

*[1]Combustion test facility; [2]Selective catalytic reduction; [3]Electrostatic precipitator; [4]Wet-flue gas desulfurization; [5]Fabric filter; [6]Dry sorbent injection; [7]Carbon capture; [8]Particulate test combustor; [9]Circulating fluidized-bed combustor; [10]Continuous fluid-bed reactor; [11]Transport reactor development unit; [12]Entrained-flow gasifier; [13]High-pressure fixed-bed gasifier; [14]Advanced fluid-bed gasifier.*

## CAPTURE TESTING PLATFORMS

Through previous EERC programs, world-class facilities have been established on-site and include postcombustion technology systems, oxy-fired combustion capabilities, and precombustion systems listed above. The specific systems are described briefly as follows.

### POSTCOMBUSTION

The EERC has designed and built an industrial-scale postcombustion capture system available for testing. The system includes a solvent absorber and stripper system that is used to capture the $CO_2$ from the flue gas generated by a multifuel combustion system. This capture system was designed to be flexible, allowing for the evaluation of multiple solvent types.

The solvent-based capture system consists of three main columns (two absorption columns and one desorption column), each constructed from 10-in.-inside-diameter stainless steel column sections of varying lengths bolted together to achieve a desired total height. The absorption columns are fitted with structured packing, provided by Sulzer Ltd., and the desorption column utilizes Koch-Glitsch IMTP® 25 316L stainless steel random packing.

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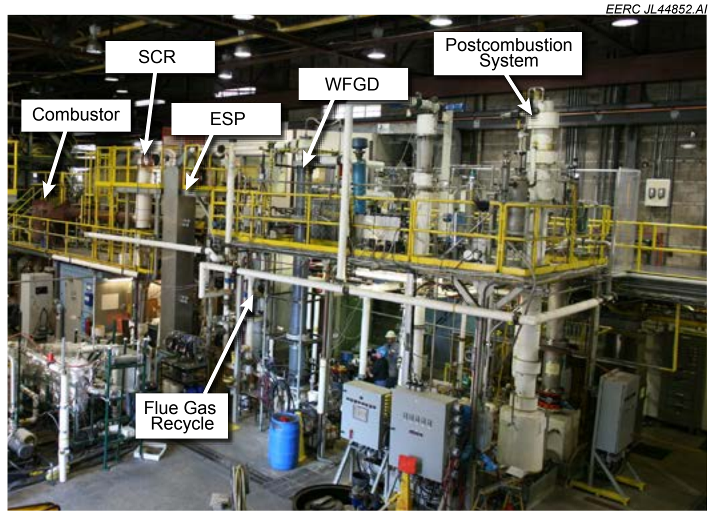



*CTF and capture equipment.*

Packing height, size, and type can easily be modified to accommodate different solvents and test conditions. The columns are designed to handle up to 130 scfm of flue gas generated by the CTF above. A second combustion system of equal size to the CTF, the PTC, is also located to the side of the CTF and can provide flue gas to the capture system.

## IMPORTANCE OF TESTING AT EERC PILOT SCALE

- Build confidence:
  - Successful EERC pilot-scale demonstration gives investors confidence in technology applicability at full scale.
- Mitigate risk:
  - Pilot demonstrations reduce risk by screening above bench scale but in a cost-effective, meaningful manner.
- Expand reach:
  - Highly variable system that can perform on multiple fuels and equipment configurations, making results attractive to a wide range of end users.

A demister is installed near the top of the absorber column to prevent solvent entrainment through the flue gas exit. The system is also equipped with a water wash column to minimize solvent emissions. Additionally, the EERC has integrated and tested various pretreatment and $CO_2$ capture technology systems supplied by technology developers.

### OXY-FIRED COMBUSTION

The oxy-fired combustion system is retrofitted to the CTF, the same system that can provide flue gas to the solvent and solid sorbent capture equipment. The combustor is uniquely equipped to develop an understanding of heat-transfer issues along with fouling and slagging problems that may arise because of the $CO_2$-rich atmosphere in the furnace and convective pass. In addition, the CTF has the ability to operate with various types of burners and a suite of gas cleanup systems that include an ESP, fabric filtration, SCR, spray dryer absorber (dry scrubber), and wet scrubber. Flue gas concentrations of $O_2$, $CO_2$, and $SO_2$ are obtained simultaneously at the furnace exit and stack. The oxyfuel system has the capability to produce 140 scfm of flue gas, with $CO_2$ concentrations as high as 90%. This system includes a range of options for recycling various amounts of flue gases containing a range of oxygen levels for enriched combustion testing.

**"A TECHNOLOGY MUST BE PILOTED AT A LEVEL THAT ALLOWS FOR MEANINGFUL ENGINEERING SCALE-UP TO COMMERCIAL SIZE."**

*International Energy Agency Greenhouse Gas R&D Programme. Integrated Carbon Capture and Storage Project at SaskPower's Boundary Dam Power Station; 2015/06, August 2015.*

### PRECOMBUSTION

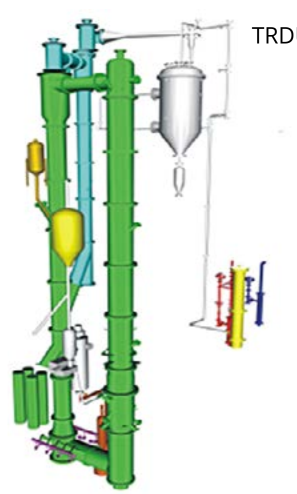
The EERC has multiple gasification systems capable of gasifying coal, biomass, and other solid or liquid feedstocks, as shown in the examples below.

The systems each have warm-gas cleanup capabilities. The EERC has a bench-scale warm-gas cleanup train that is portable and can be placed at the back end of each gasifier. The train is capable of reducing sulfur levels to as low as 0.010 ppm and particulate to less than 0.1 ppm with ceramic/metal candle filters and has fixed-bed reactors for reducing mercury or other contaminants. Water–gas shift reactors, including sour, high-temperature, and low-temperature shift, can be inserted at any location in the cleanup train.

Gas separations using hydrogen/$CO_2$ separation membranes can be performed at elevated temperatures without the need to quench the syngas. A hydrogen membrane can be inserted at any point in the cleanup train to simulate the desired operating conditions, but it would normally be installed after the sulfur removal and shift reactors, depending on the sensitivity of the membrane to sulfur. If needed, a small slipstream of the syngas from any gasifier can be pulled for hydrogen separation testing.

Pilot-scale tests have been performed to compare the capabilities of physical solvents, solid sorbents, and a novel method using thermal-swing adsorption/desorption on activated carbon. Tests were also performed on several metallic (e.g., palladium/copper or palladium/gold) gas separation membranes to determine throughput (flux) in relation to pressure and degradation as a result of impurities in coal-derived syngas, including sulfur, chlorine, and tar.

$H_2$ Separation Membrane



TRDU

EFG

*Examples of the EERC's gasification capabilities.*

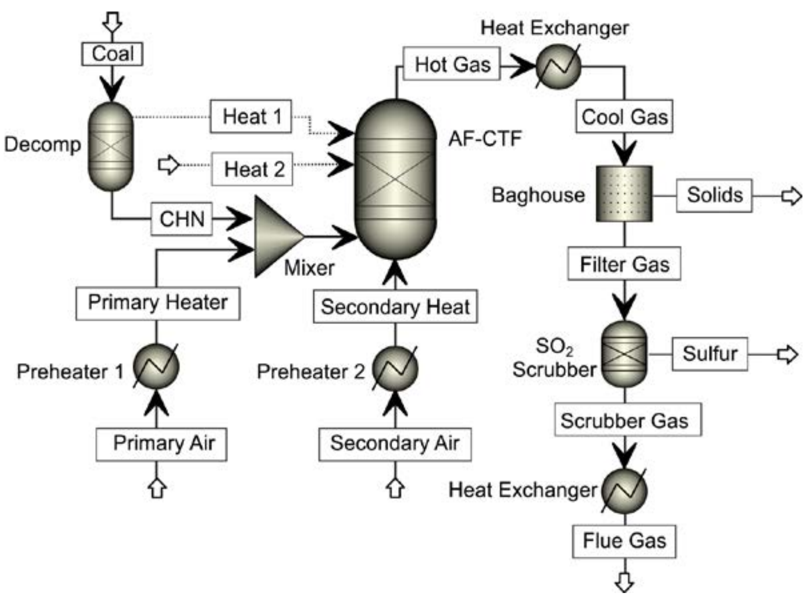
## LOOKING TO THE FUTURE

The EERC aims to continue the improvement of $CO_2$ capture technology by working with clients on demonstrating and improving cutting-edge technologies, moving forward new ways of reducing parasitic load requirements, investigating supercritical $CO_2$ cycles which use $CO_2$ as the working fluid, and testing novel liquid–gas contactors for postcombustion capture.

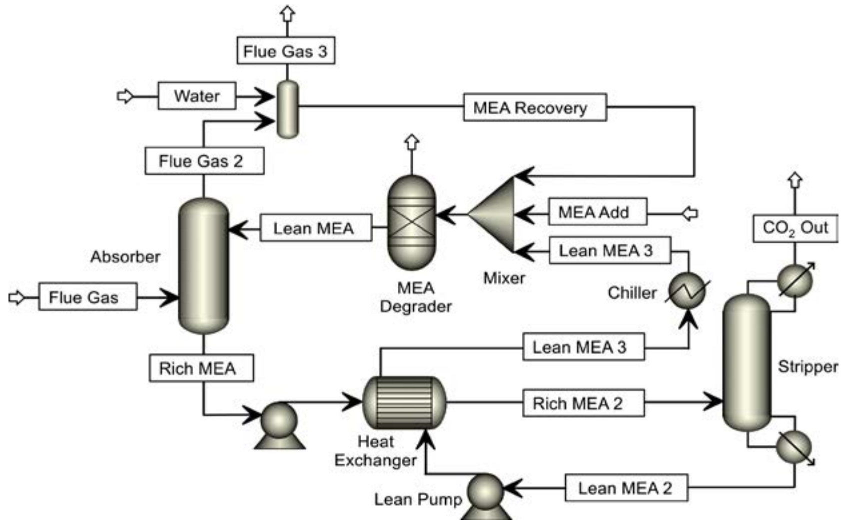
## MODELING CAPABILITIES

Extensive modeling capabilities have been developed at the EERC utilizing the Aspen Plus® modeling software. With this software, carbon capture process flow models, including detailed mass and energy balances, can be created around the entire power generation system. Modeling of the EERC pilot systems has been conducted and validated with operational data that allows investigations of technology scale-up and projected performance.

Plant configurations with various $CO_2$ capture technologies can also be investigated through the use of the Integrated Environmental Control Model (IECM) developed at Carnegie Mellon University. Through these two model platforms, pilot-scale information can be utilized to evaluate the integration of $CO_2$ capture technologies and develop options for plant operation challenges.




*An Aspen Plus model of a combustion system with flue gas cleaning.*




*An Aspen Plus process model for a $CO_2$ capture system.*

Aspen Plus model data can be used with the Aspen Process Economic Analyzer to determine the capital and operating costs of a process integrated with a coal combustion power plant. The capital and operating costs can be combined with technology performance to develop economic assessments at virtually any scale.

The EERC is a member of the International Test Center Network which facilitates knowledge transfer from carbon capture test facilities from around the world.

The EERC is also a member of the Industrial and Academic Stakeholders Board for the Carbon Capture Simulation for Industry Impact (CCSI$^2$) Program. The program is a partnership among national laboratories, industry, and academic institutions to apply cutting-edge computational modeling and simulation tools to accelerate the commercialization of carbon capture technologies.

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