Pilot Test of Novel Electrochemical Membrane System for Carbon Dioxide Capture and Power Generation (DE-FE0026580)

Presented to:

2018 NETL CO_2 Capture Technology Project Review Meeting

Pittsburgh, PA

August 13-16, 2018

Electrochemical Membrane (ECM) Carbon Capture Pilot Pant Project

- Design an ECM-based carbon capture pilot plant (60 T/D) prototypical of a commercial unit
- Fabricate and install the pilot-scale plant at a coal facility
- Conduct pilot plant tests, demonstrating >90% capture (>95% CO_2 purity)
- Complete Techno-Economic Analysis (TEA) of ECM carbon capture applied to a 550 MW baseline supercritical PC plant, achieving 30% less COE compared to amine scrubbers
- Determine Environmental, Health and Safety (EH&S) requirements of ECM Carbon Capture plants

Project Team Structure

fuelcellenergy

AECOM

- TEA Support (review ECM system design, equipment and plant costing)
- Pilot system key equipment specification and selection
- Flue gas clean-up system design
- Interconnection system design

Southern Company

- Demonstration site host
- Construction management
- Permitting support
- Pilot plant installation and test support

McAbee Construction

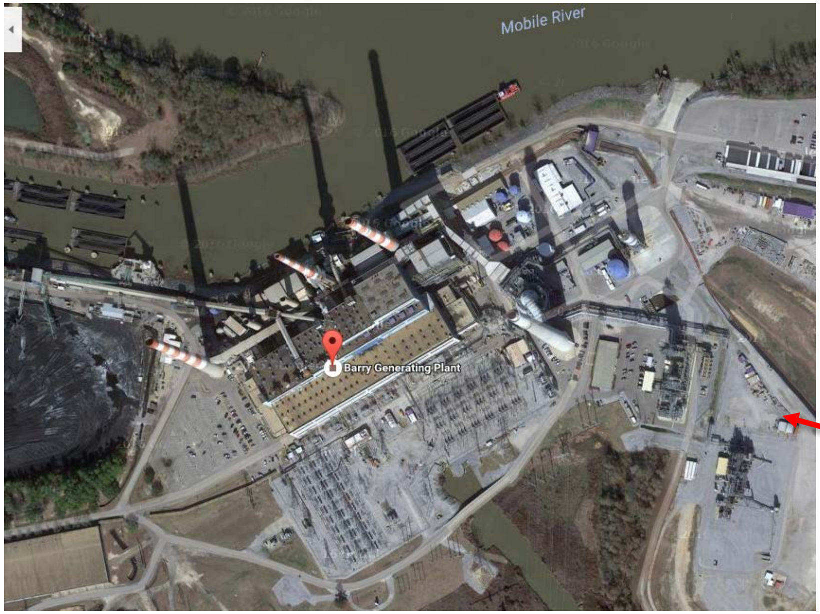
- Site construction
- Plant installation
- Maintenance support

Innovative Design Eng Associates

IDEA

- Engineering Support
  - Instrumentation
  - Electrical

Pilot Demonstration Site



- James M. Barry Electric Generating Station, Alabama Power/Southern Co.
- Location: Bucks, Al
- Nameplate Capacity: 2,370 MWe, Mix of Coal and Natural gas

Southern Company

Work Breakdown Structure

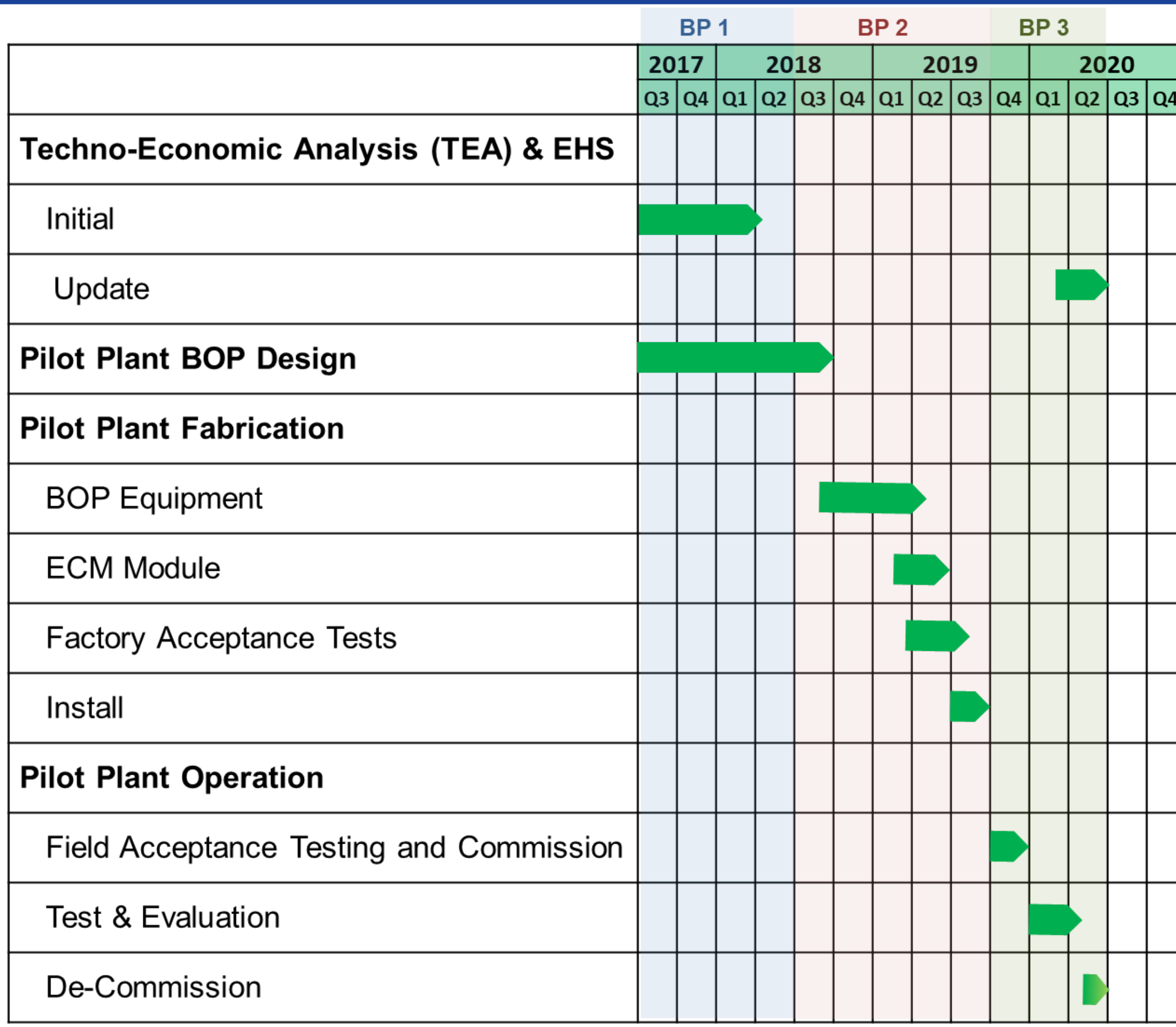
Pilot-Scale ECM System Testing
Project Work Breakdown Structure

- **Task 1** Project Management and Planning
  - **Task 1.1** Project Management and Planning
  - **Task 1.2** Briefings and Reports
- **Task 2** Preliminary Techno-Economic Analysis & EH&S Assessment
  - **Task 2.1** Systems Analysis
  - **Task 2.2** Economic Analysis
  - **Task 2.3** Prelim. EH&S Assessment
- **Task 3** Pilot-Scale ECM System Design
  - **Task 3.1** Detailed Process Design
  - **Task 3.2** Equipment Specifications and Selection
  - **Task 3.3** Detailed Mechanical Design
  - **Task 3.4** Detailed Electrical Design
  - **Task 3.5** Tie-In Engineering
- **Task 4** ECM System Fabrication & Installation
  - **Task 4.1** Final Design & Documentation
  - **Task 4.2** ECM Module Fabrication
  - **Task 4.3** BOP Equipment Fabrication
  - **Task 4.4** BoP Skid Fabrication
  - **Task 4.5** Factory Acceptance Testing
  - **Task 4.6** System Installation
- **Task 5** ECM System Commissioning, and Testing
  - **Task 5.1** System Commissioning
  - **Task 5.2** System Testing
- **Task 6** Decommissioning
- **Task 7** Final Techno-Economic Analysis & EH&S Assessment
  - **Task 7.1** Systems Analysis Update
  - **Task 7.2** Economic Analysis Update
  - **Task 7.3** Final EH&S Assessment

All Budget Periods	Budget Period 1	Budget Period 2	Budget Period 3

Project Schedule Overview

Completed BP1 tasks and submitted continuation application to initiate BP2

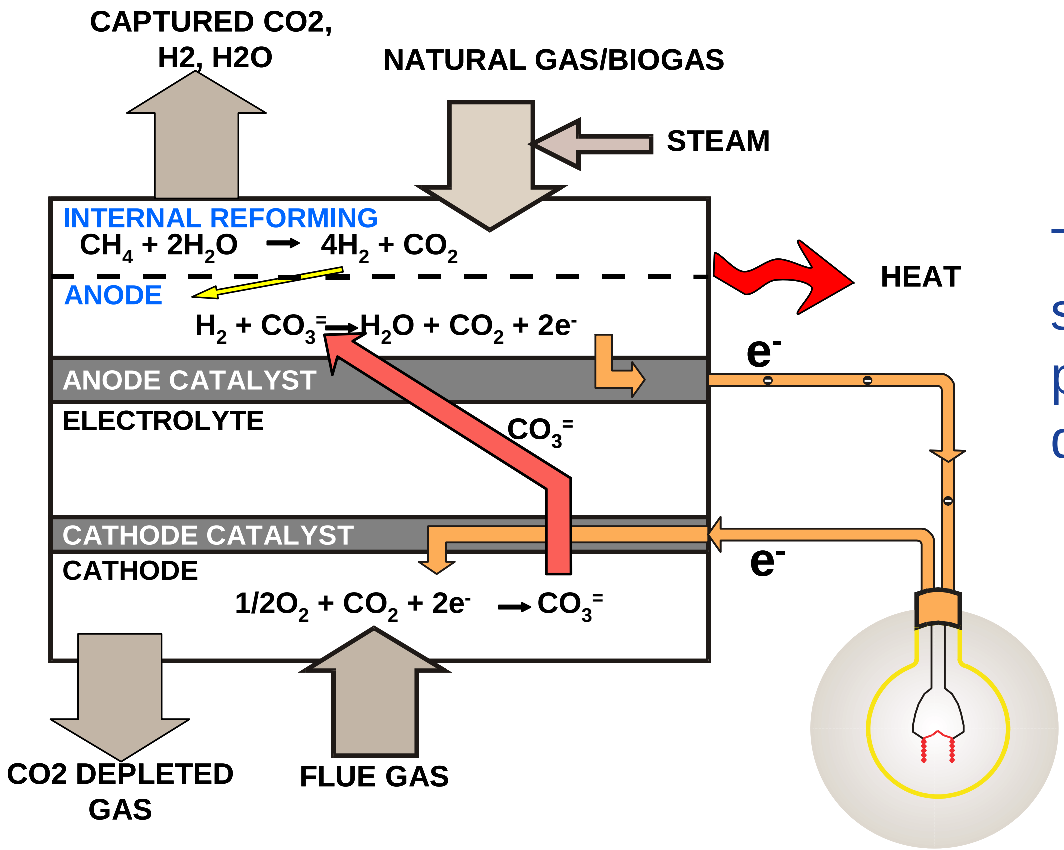


Project Budget: $34.12 MM

DOE Share: $15MM, Cost Share: $19.12 MM

Electrochemical Membrane (ECM) Technology Overview

ECM Operating Principle

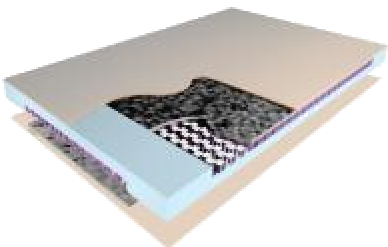


The driving force for CO_2 separation is electrochemical potential, not pressure differential across the membrane

Net Results

- Simultaneous Power Production and CO_2 Separation from Flue Gas of an Existing Facility
- Excess Process Water Byproduct
- Complete Selectivity towards CO_2 as Compared to N_2

Modular Technology



ECM Assembly
Using Planar Cells (~9000 cm^2)

ECM Stack
(Using ~400 ECM Assemblies)

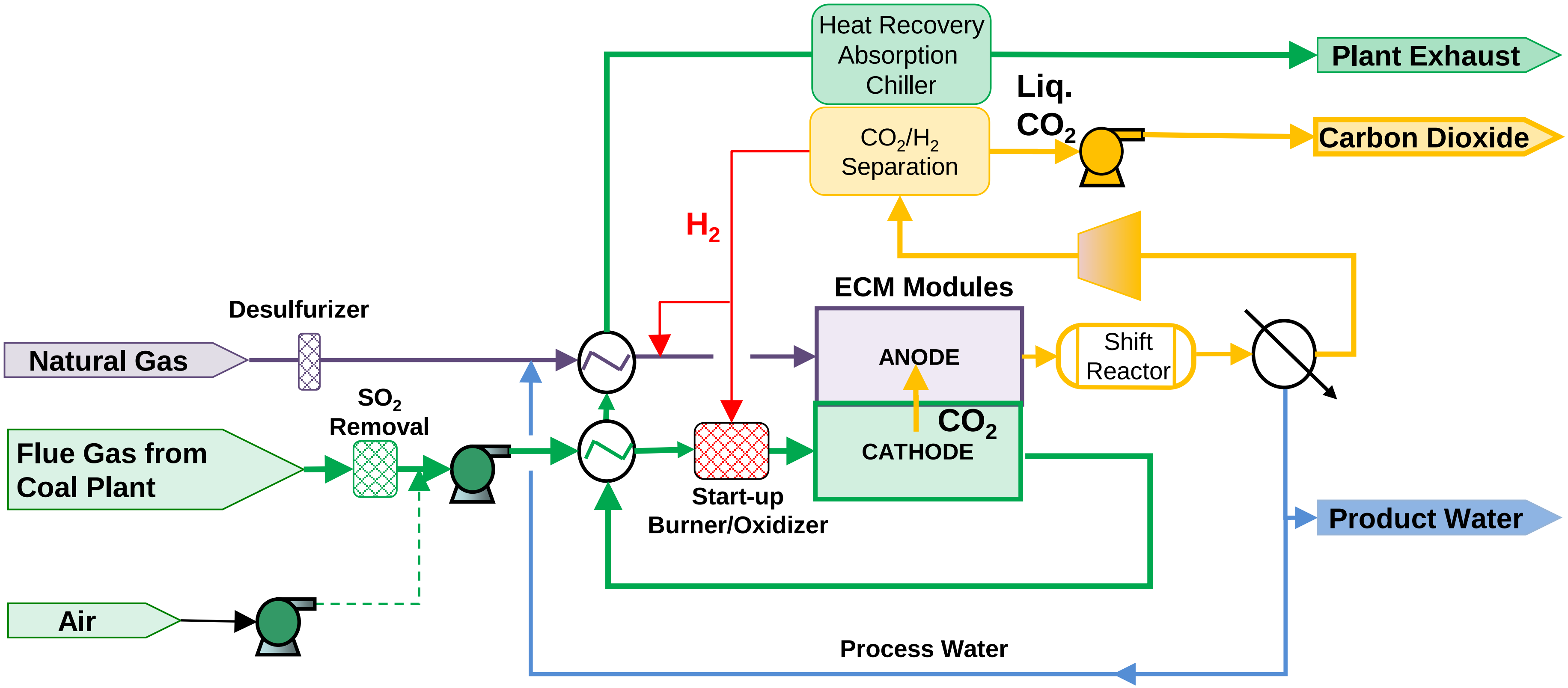
ECM Module
(4 Stacks)

Enclosed Module

Modules Utilized in Large-Scale Applications

ECM Pilot Plant Development

Simplified Process Flow Diagram



- Re-application of commercially-proven fuel cell technology for CO_2 Capture
- Opportunity for Co-Production of Syngas or H_2

Design Basis Summary

Modes of Operation

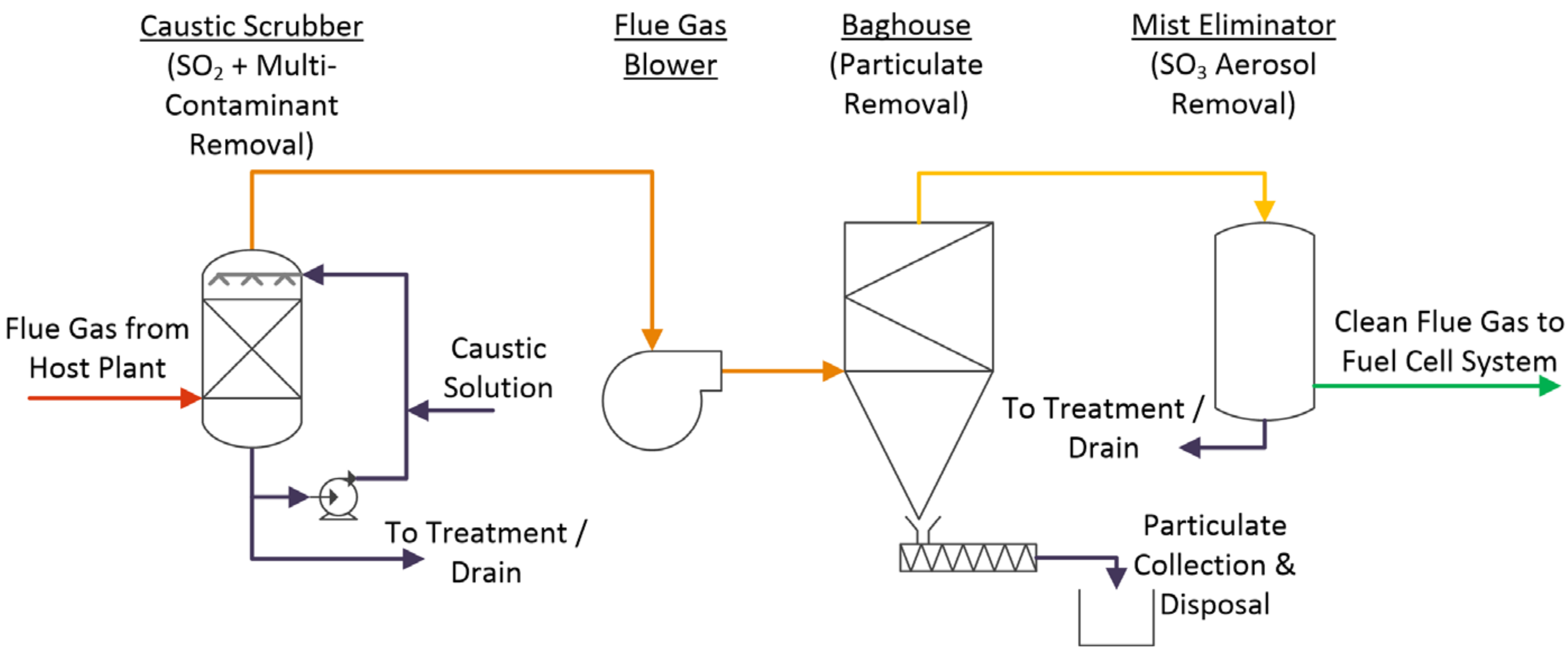
1. 90% Carbon Capture from Coal-fired Boiler (CFB) Flue Gas (FG)
2. Stand-alone: Power generation only, no flue gas processed
3. transient/parametric evaluation:
   - 70% Carbon Capture from CFB FG
   - Dynamic response to reduced FG availability (i.e. turn down)
   - Ability to accommodate variable FG carbon loading (e.g. lower CO_2 conc.)
   - Emergency trip/shutdown

Pilot Plant Performance

Operating Mode	90% Capture Coal-Derived FG		70% Capture Coal-Derived FG		Stand-Alone (No FG Available)	
MCFC Gross Power, DC	**1863.4**	**kW**	**2542.9**	**kW**	**3112.3**	**kW**
Energy & Water Input						
Natural Gas Fuel Flow	169.4	scfm	243.2	scfm	329.9	scfm
Fuel Energy (LHV)	2877.8	kW	4087.0	kW	5723.1	kW
Water Consumed/(Produced)	(1.8)	gpm	(2.4)	gpm	(0.3)	gpm
Consumed Power						
AC Power Consumption	(611.0)	kW	(911.6)	kW	(206.0)	kW
Inverter Loss	(74.5)	kW	(101.7)	kW	(124.5)	kW
Total Parasitic Power Consumption	**(685.6)**	**kW**	**(1013.3)**	**kW**	**(330.5)**	**kW**
Net Generation & Efficiency						
CEPACS Plant Net AC Output	**1177.8**	**kW**	**1529.6**	**kW**	**2781.8**	**kW**
Electrical Efficiency (LHV)	**40.9**	**%**	**37.4**	**%**	**48.6**	**%**
Carbon Capture						
Total Carbon Capture, %	**92**	**%**	**75**	**%**	**N/A**	
Carbon Capture from FG, %	**90**	**%**	**70**	**%**	**N/A**	
Total CO_2 Captured, Tons per Day	**67**	**T/D**	**93**	**T/D**	**0**	**T/D**
CO_2 Purity	**99.6**	**%**	**99.6**	**%**	**N/A**	

- Pilot Plant is designed to capture up to 90 tons per day of CO_2
- The system is net water producer during the above modes of operation

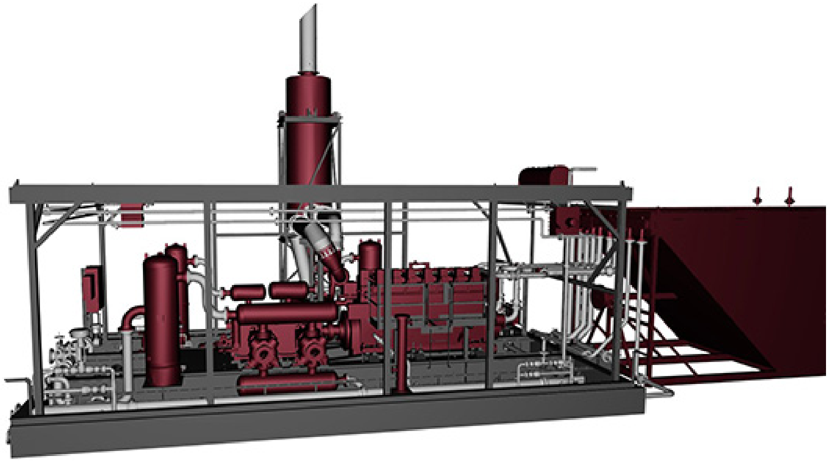
Flue Gas Polishing System



- Cleanup equipment train design, specifications, and RFQ process completed in partnership with AECOM
- Vendor bids selected for each piece of equipment, ready for purchasing

Anode Gas Compressor

- Key Design Features:
  - Fuel cell anode exhaust contains the “captured” CO_2 from the flue gas.
  - Carbon capture process requires anode exhaust gas be compressed from ~18 psia to 265 psia.
  - Includes inter-stage cooling and water knockout.
- Engineering specification created to obtain bids from five (5) vendors:
- Evaluated bids for Reciprocating (3) and Screw Type (2) compressors.
- Selected compressor based on lower power consumption and lower price than comparable units.



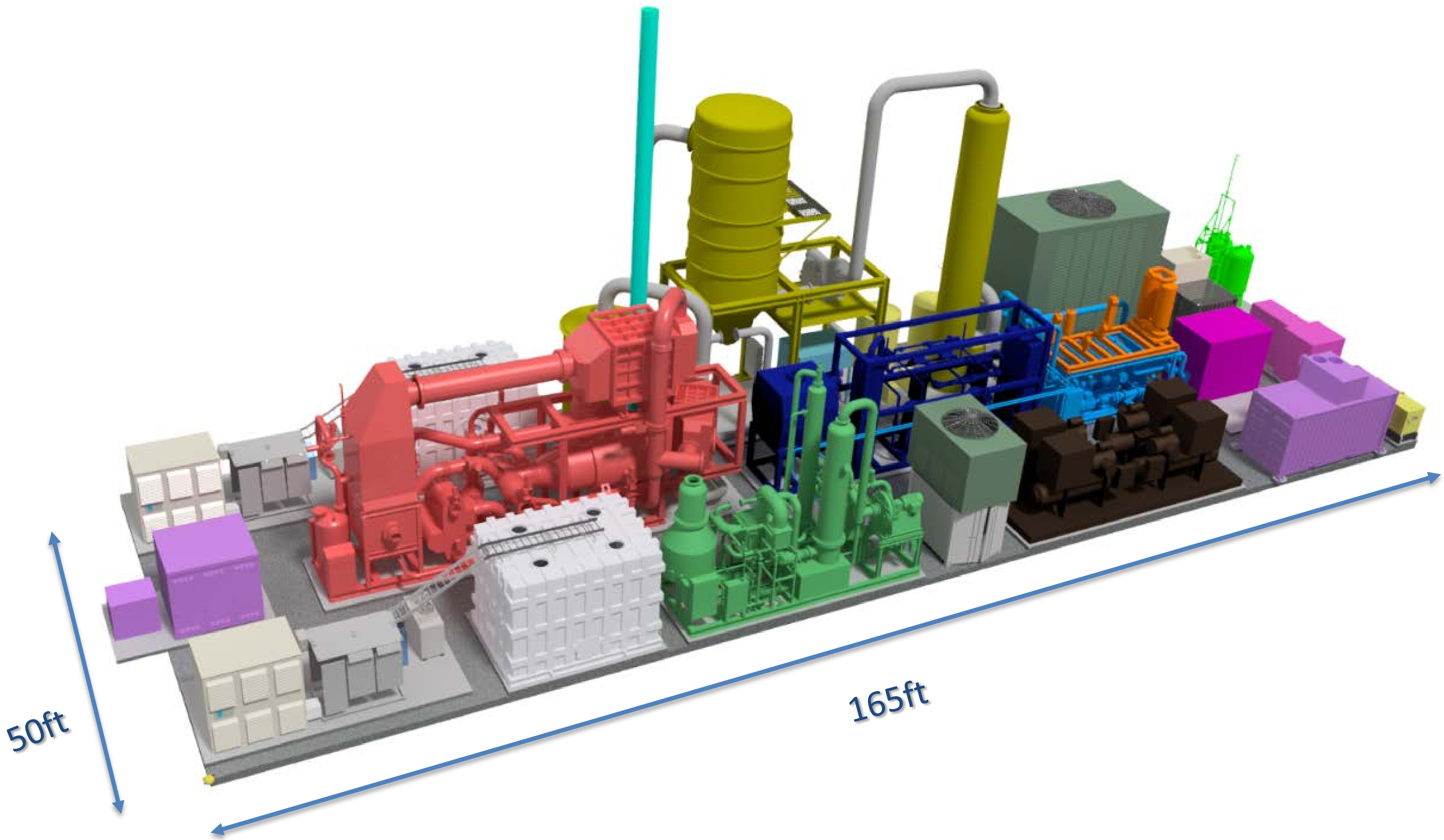
Compressor Skid Design

Reciprocating Compressor

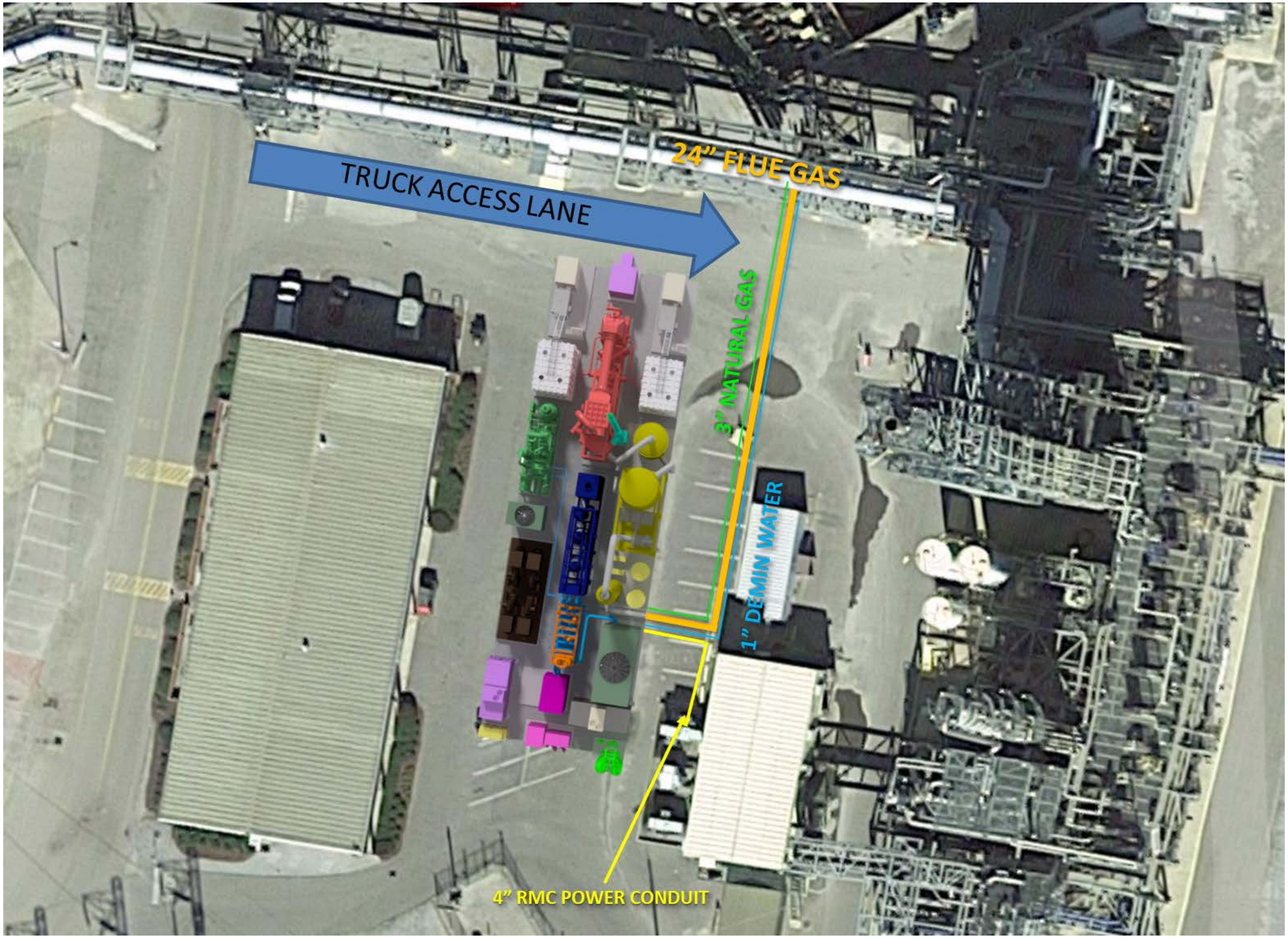
Ammonia Absorption Chiller

- Key Design Features:
  - Absorption technology selected to utilize thermal energy of process, raising system efficiency by avoiding parasitic power penalty of mechanical chiller
  - Chiller performance specified to be ~ 100 Tons

General Arrangement



Site Plan Overview

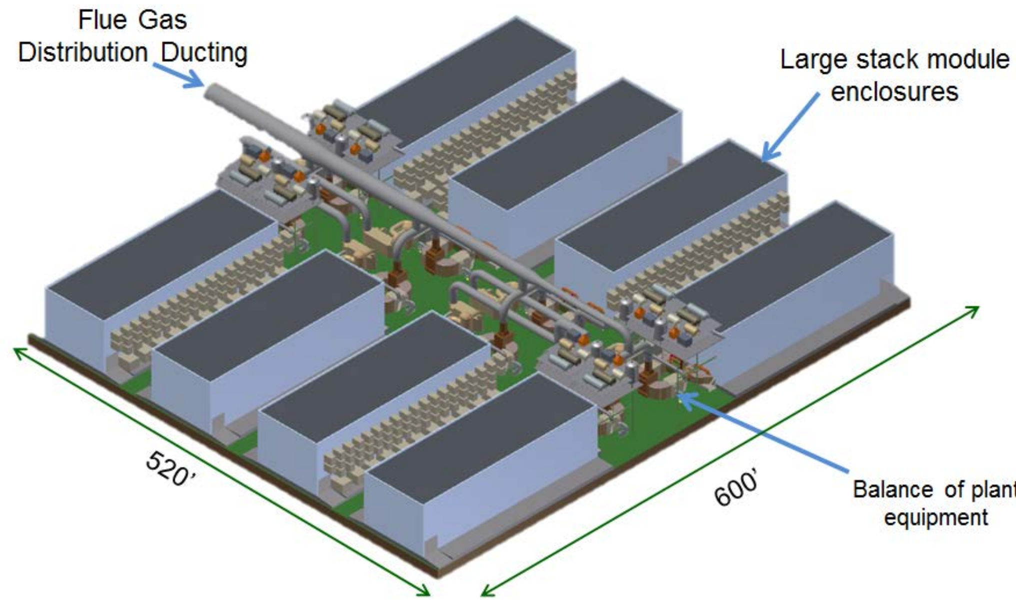


Techno-Economic Analysis

Large Scale Coal Capture System

Combined Electric Power and Carbon-dioxide Separation (CEPACS) System Concept Implementation for 550 MW Reference Supercritical PC Plant*

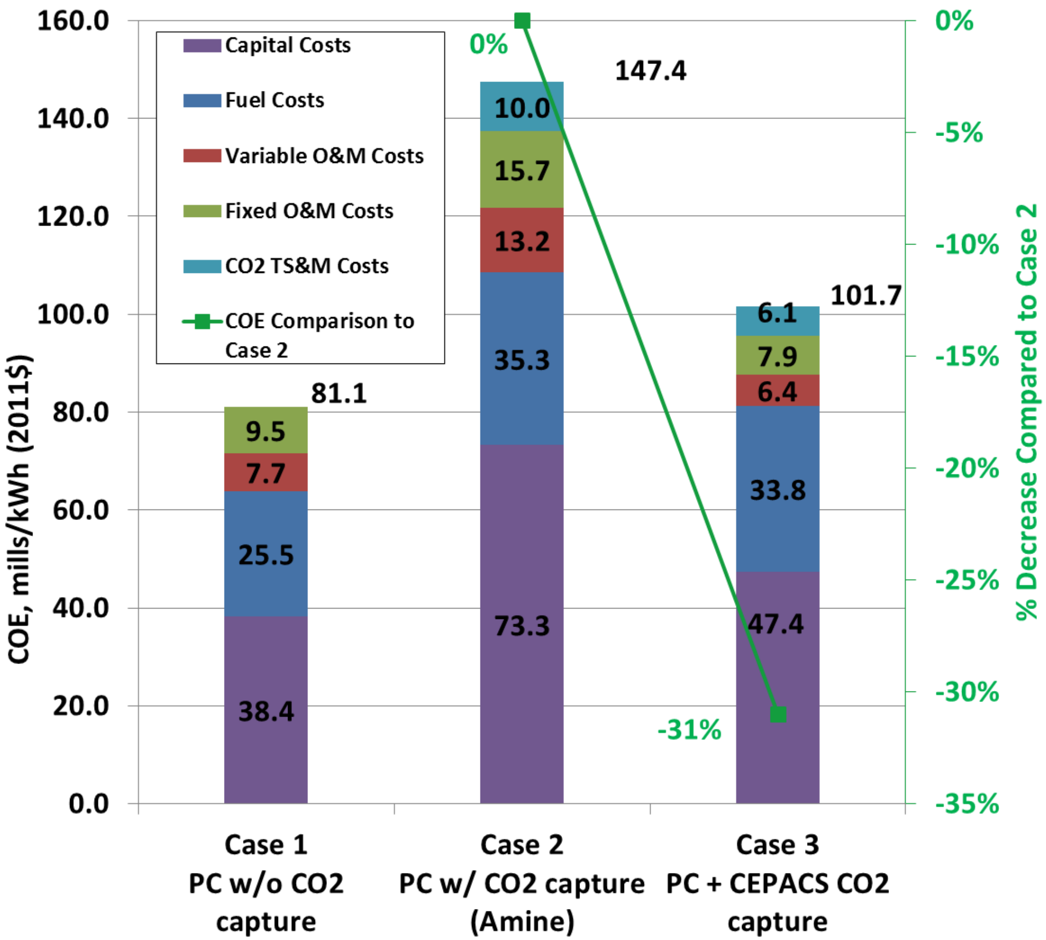
- 4.3 Million tons of CO_2 capture per year
- 319 MW ECM-based system would capture 90% of CO_2 from 550-MW plant
- 2.5 GWh power generated per year @ 40.7% Efficiency (based on HHV NG)
- Large-scale field-erected stack enclosures can be operated independently, allowing for high plant availability
- Incremental process innovations have reduced ECM stack count from 1792 to 1664 (vs. previous TEA in prior project)
- Packaging improvements have been implemented to incorporate CO_2 purification BoP equipment within ~7 acre footprint

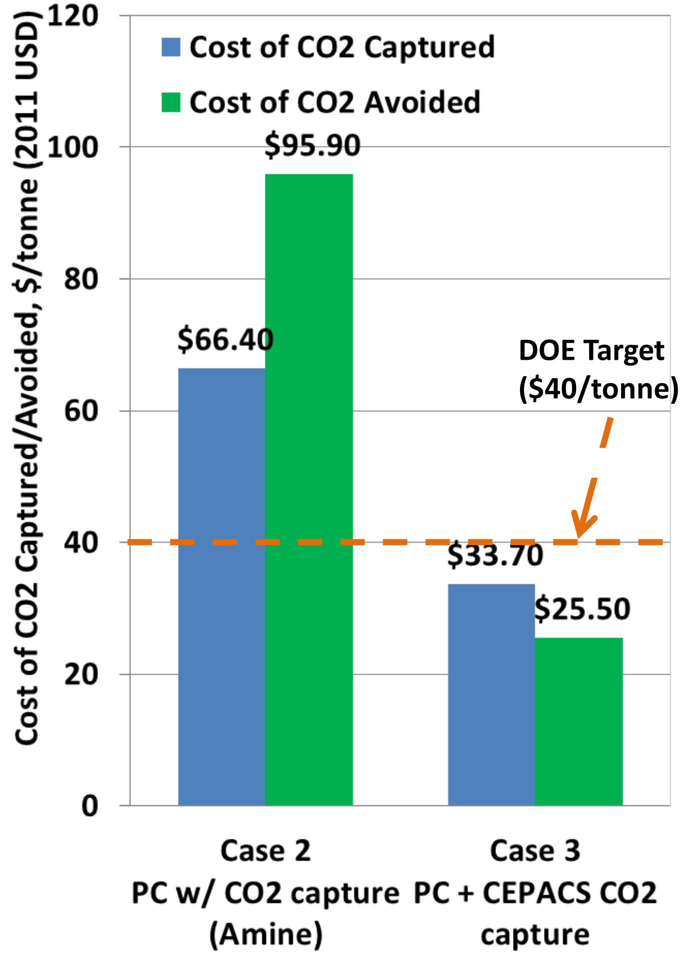


319 MW ECM Plant for capture from coal systems

* Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 2a, DOE/NETL-2010/1397, September 2013.

fuelcellenergy AECOM CEPACS System Economics

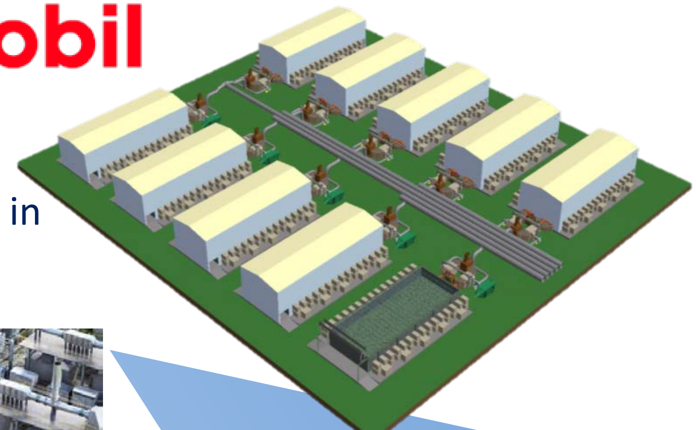




- PC plant retrofitted with CEPACS system has 31% lower COE than the plant with amine scrubbing for CO_2 Capture
- ECM-Based CEPACS System can meet DOE Target of <$40/tonne CO_2 captured (2011 USD)

Carbon Capture Deployment

Large Scale Future Systems
- 320-MW plant for capture from 550-MW coal system, developed in DOE program: 18,000 tons/day CO_2 capture
- 160-MW plants for capture from 500-MW NGCC developed in ExxonMobil program: >5,000 tons/day CO_2 capture

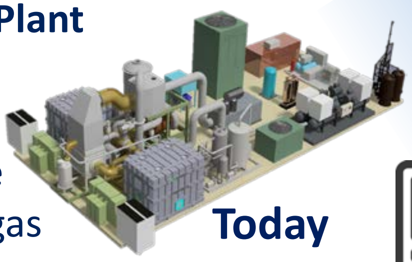


ECM-based projects
- Single or multiple-unit system
- Coal and natural gas power plants
- Industrial thermal systems
- Commercial CO2 offtake or sequestration
- 1 to 50-MW fuel cell power
- Up to 3000 tons/day CO2 capture

Future

Near Term

ECM-Based Pilot project at Plant Barry, AL
- On line in 2019
- 90% capture from coal flue
- Demonstration of natural gas capture under ExxonMobil program
- 60 tons/day CO_2 capture



Today

Project Size

Time

Project Accomplishments and Status

- Techno-Economic Analysis and Environmental Health and Safety analysis completed for ECM technology applied to a reference supercritical PC plant
  - Estimated COE is 31% less than baseline approaches (amines), with cost of CO_2 captured estimated at $34/tonne (2011 USD)
- BP1 engineering design of pilot system complete
- Tie-in engineering effort (AECOM-led) complete
- Continuation application to proceed to BP2 of the project was submitted to DOE
- Ready to initiate BP2 tasks for plant construction

Acknowledgements

Support from DOE/NETL (Co-operative Agreement DE-FE0026580) and guidance from: José Figueroa, Lynn Brickett, John Litynski, Angelos Kokkinos, and others at NETL