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Pilot Test of Novel Electrochemical Membrane System for Carbon Dioxide Capture and Power Generation

Hossein Ghezel-Ayagh

2016 NETL CO2 Capture Technology Meeting

August 8-12, 2016

Pittsburgh, PA

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Electrochemical Membrane (ECM) Technology Development Path

DE-FE0007634
Electrochemical Membrane for Carbon Dioxide Capture and Power Generation

- Preliminary Technical and Economic Feasibility Study (PT&EFS)
- Technology Gap Identification including Effects of Trace Contaminants
- Environmental, Health & Safety (EH&S) Review
- Bench-Scale Testing of 0.2 T/D ECM (>90% Carbon Capture)

Electrochemical Membrane (ECM) Technology Development Path

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

- Techno-Economic Analysis (TEA) Updates Achieving 30% less COE of Baseline Supercritical PC Plant with Amin Carbon Capture
- EH&S Updates
- Design a Small Pilot Scale Plant (>40 T/D) Prototypical of a Commercial Unit
- Fabricate and Install the Pilot Scale Plant
- Conduct >2 months Tests at a Coal Plant Facility Demonstrating >90% Capture (>95% CO2 Purity)

DE-FE0007634
Electrochemical Membrane for Carbon Dioxide Capture and Power Generation

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ECM Project Team Structure

The FCE team is comprised of diverse organizations with expertise in key functional areas:

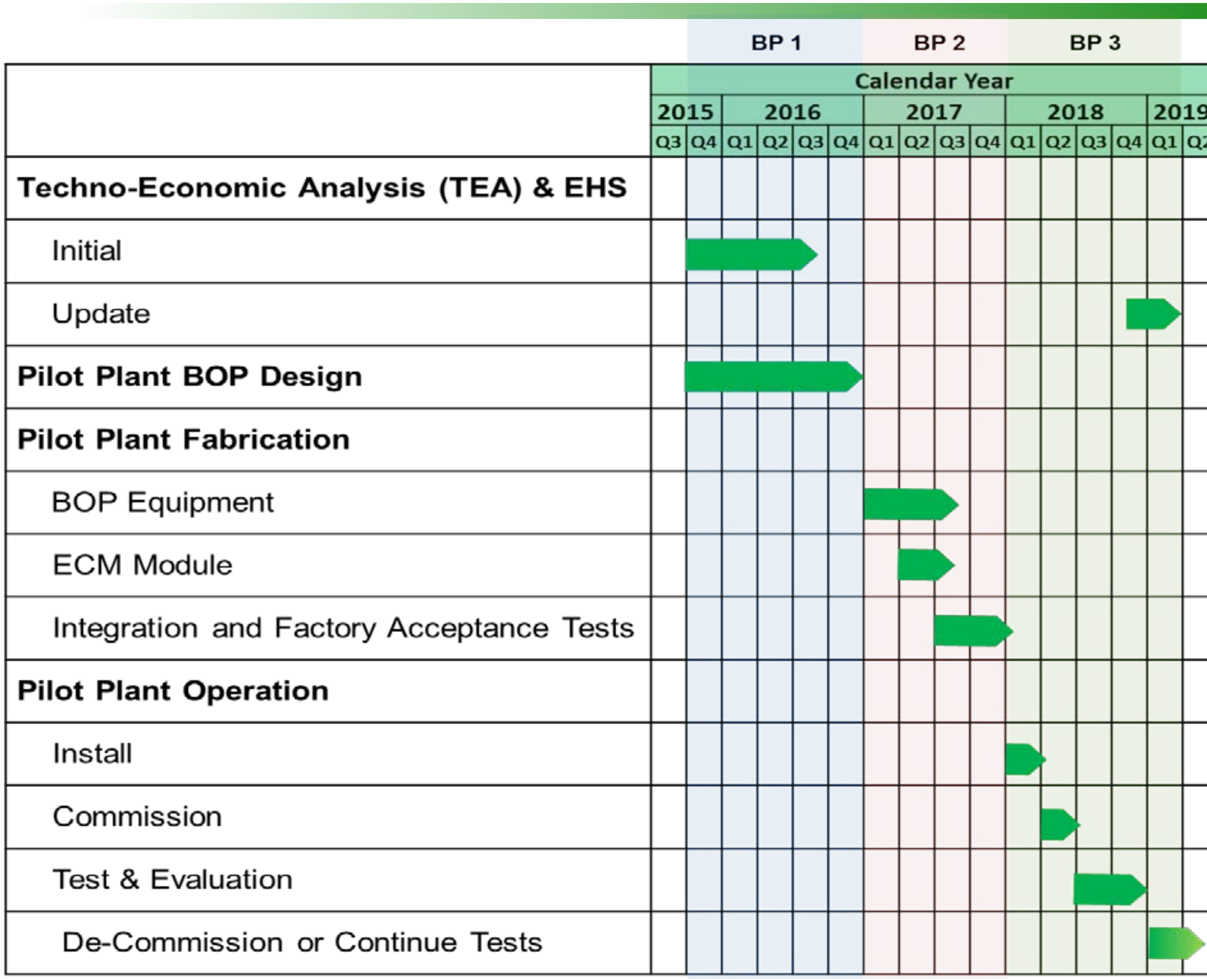
FuelCell Energy Inc. (FCE), Danbury, CT

- **Key experience:** Manufacturing and commercialization of fuel cell power plant systems in sizes ranging from 300kW to Multi-MW**.**
- **Project Role:** Prime Contractor

AECOM, Austin, TX
Process Technologies Organization

- **Key Experience:** Global leader in providing engineering, construction and technical services including pollution control systems
- **Project Role:** Support TEA (review ECM system design, equipment and plant costing), pilot system key equipment specification and selection, flue gas clean-up system design

Project Schedule and Budget



	Budget Period 1 (10/1/2015 - 12/31/2016)		Budget Period 2 (1/1/2017 - 12/31/2017)		Budget Period 3 (1/1/2018 - 3/31/2019)		Total Project (10/1/2015-3/31/2019)	
	Government Share	Cost Share	Government Share	Cost Share	Government Share	Cost Share	Government Share	Cost Share
Total	$ 4,033,959	$1,008,490	$ 7,765,275	$5,466,983	$ 3,200,766	$2,253,433	$ 15,000,000	$8,728,906
Cost Share	80.00%	20.00%	58.68%	41.32%	58.68%	41.32%	63.21%	36.79%

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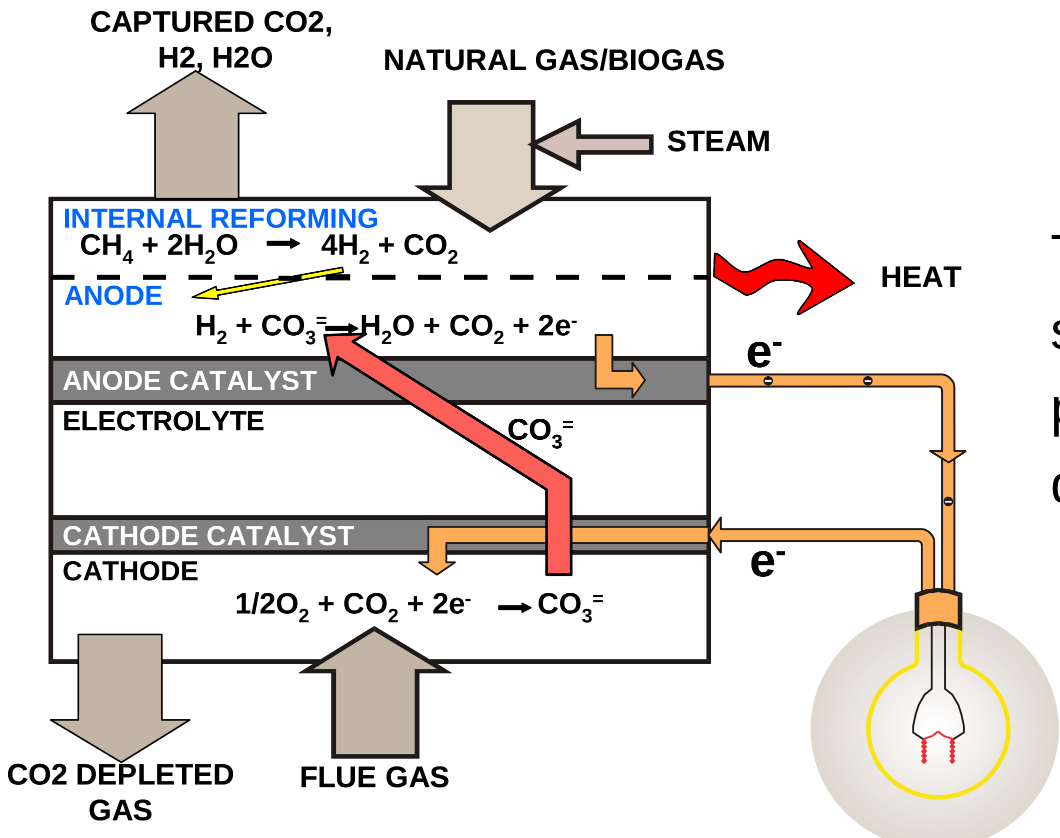
Electrochemical Membrane (ECM) Technology Overview

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

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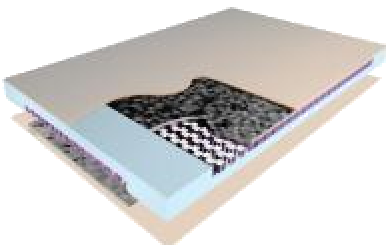
Modular Technology




ECM Assembly

ECM Stack
(Using 400 ECM Assemblies)

ECM Module
(4 Stacks)

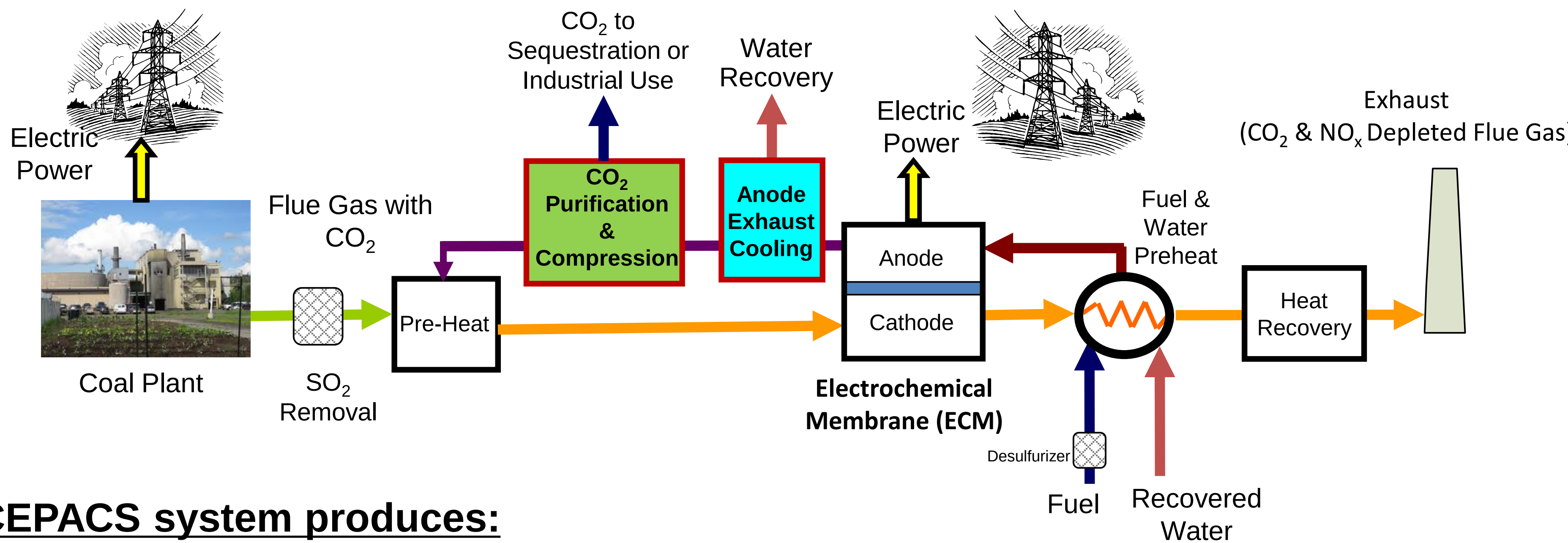
Enclosed Module

Modules Utilized in Large-Scale Applications

Techno-Economic Analysis

Application of ECM for CO_2 Capture from a 550MW PC Plant

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

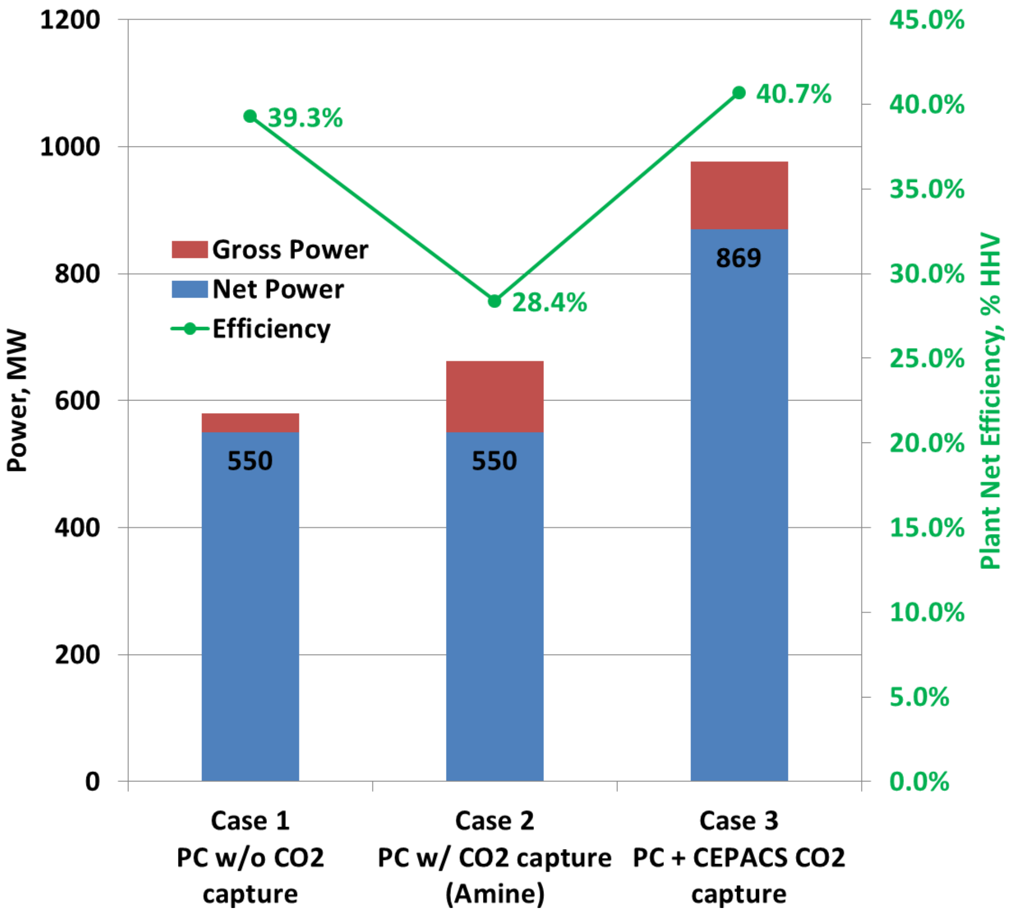


CEPACS system produces:

- Supercritical CO_2 (90% CO_2 capture from PC Plant)
- Excess Process Water
- Additional 319 MW of clean AC power @ 40.7% Efficiency (based on HHV NG)

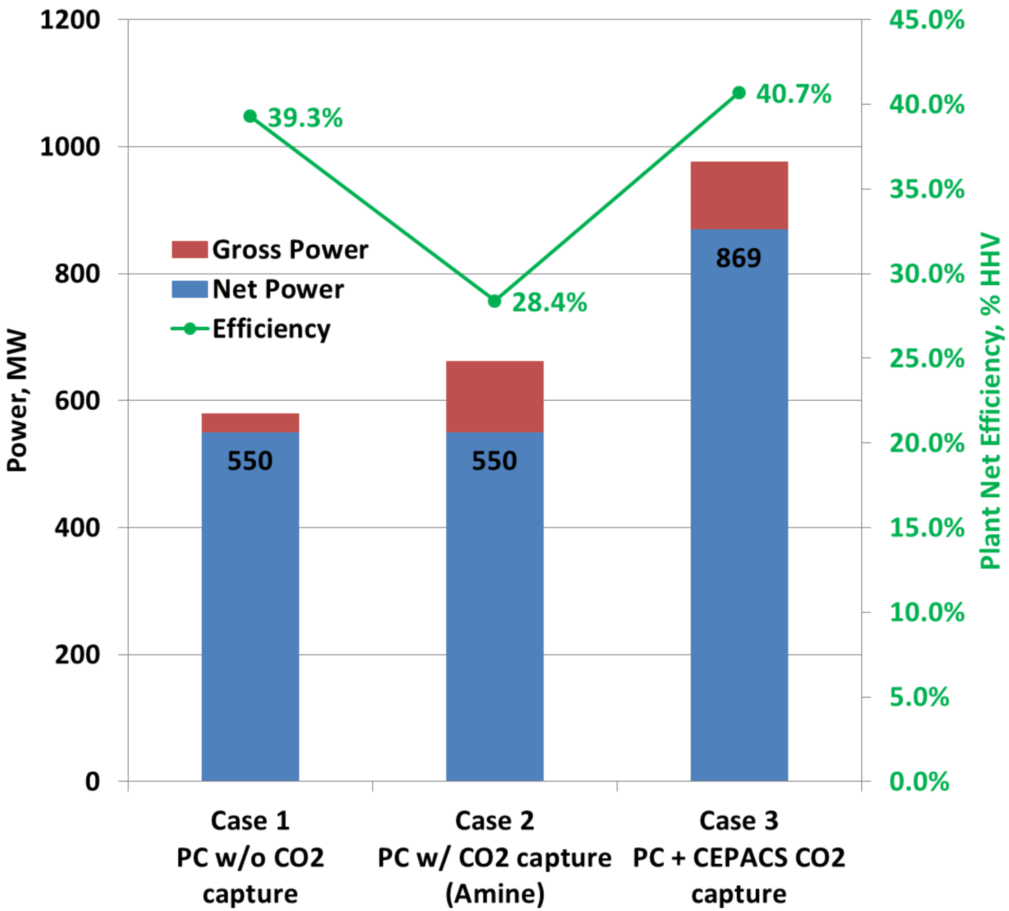
* Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 2a, DOE/NETL-2010/1397, September 2013.

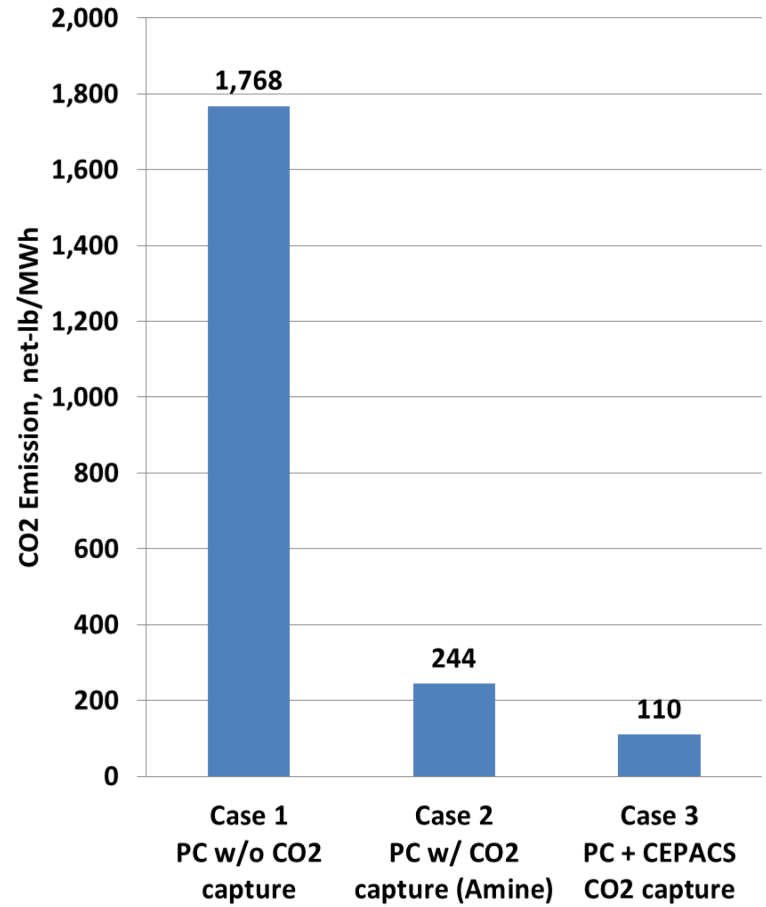
CEPACS System Performance



- CEPACS System increases power output of Baseline PC plant by 58%
- PC plant retrofitted with CEPACS system is 43% (12.3 percentage points) more efficient than amine scrubbing for carbon capture

CEPACS System Performance

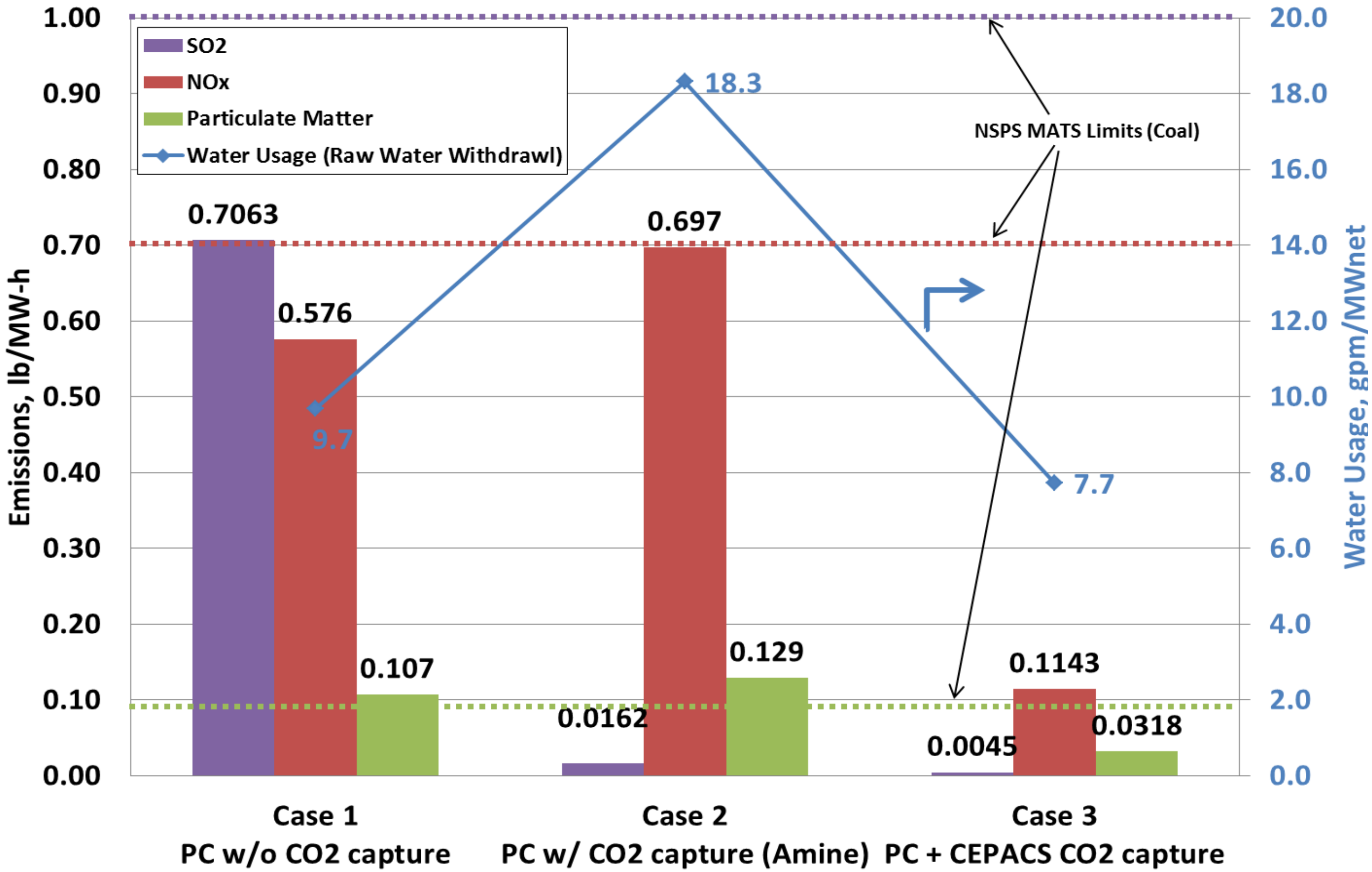




- CEPACS System increases power output of Baseline PC plant by 58%
- PC plant retrofitted with CEPACS system is 43% (12.3 percentage points) more efficient than amine scrubbing for carbon capture

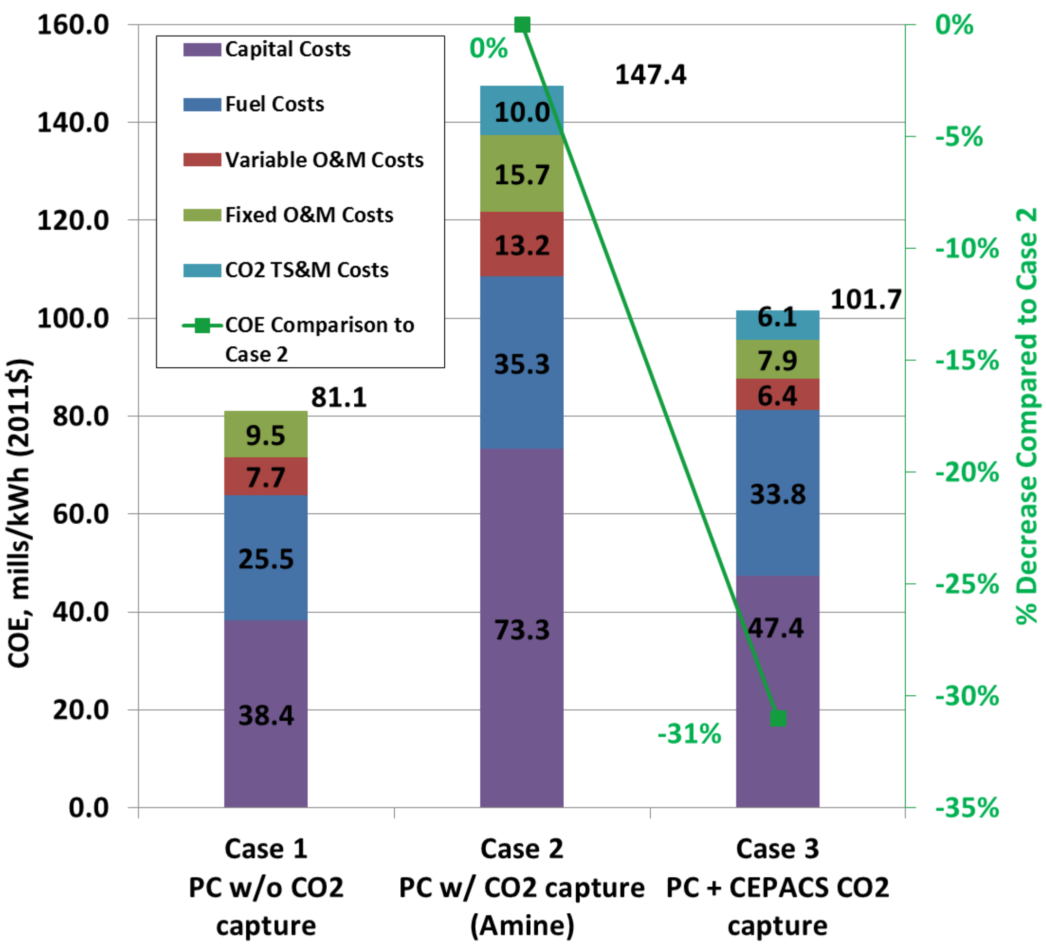
- PC + CEPACS System CO_2 Emissions are 55% lower than PC w/ Amine due to power generation (vs. consumption) @ 90% capture level

CEPACS System Performance: Emissions and Water Usage



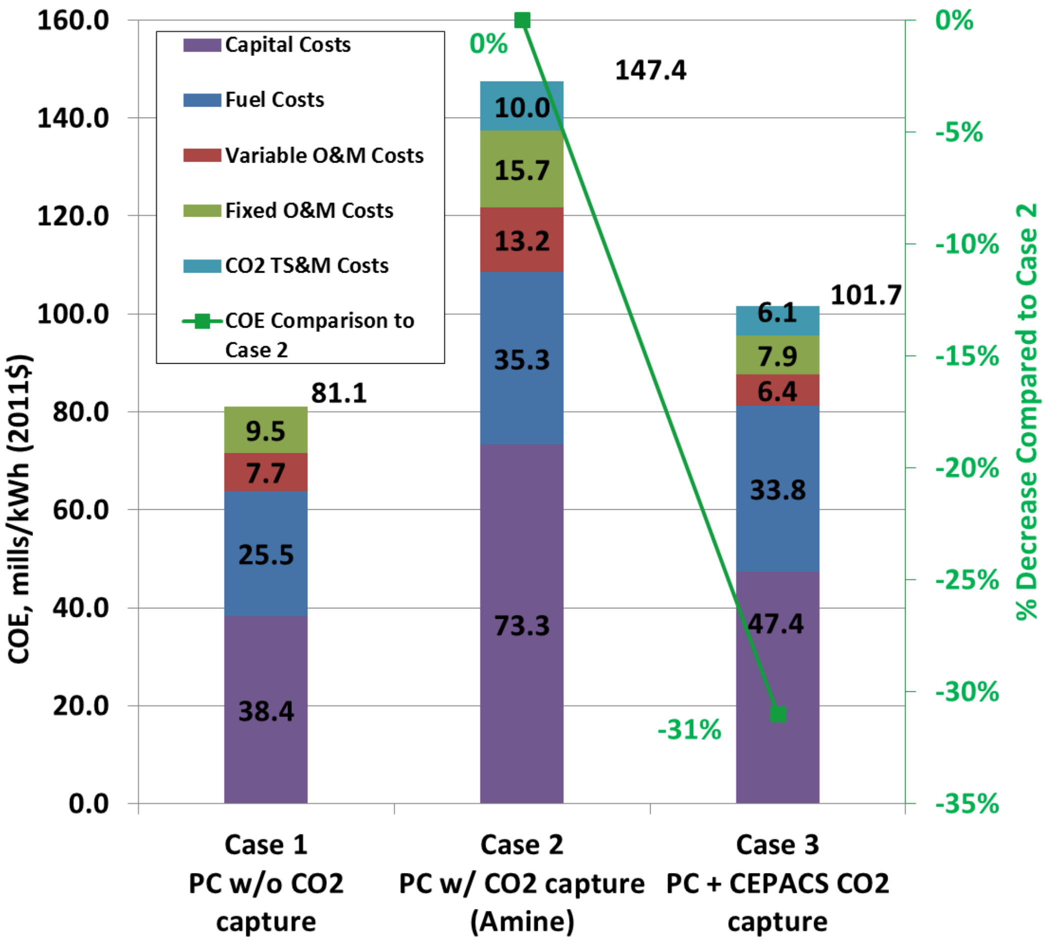
- PC plant retrofitted with CEPACS system has lower emissions of NO_x, SO_x, and Particulate Matter (PM) than a PC plant retrofitted with Amine scrubber for CO_2 capture, below MATS limits
- CEPACS system produces excess process water, resulting in:
  - 58% less raw water withdrawal than with amine scrubbing
  - 20% less raw water withdrawal compared to baseline plant *without* CO_2 capture

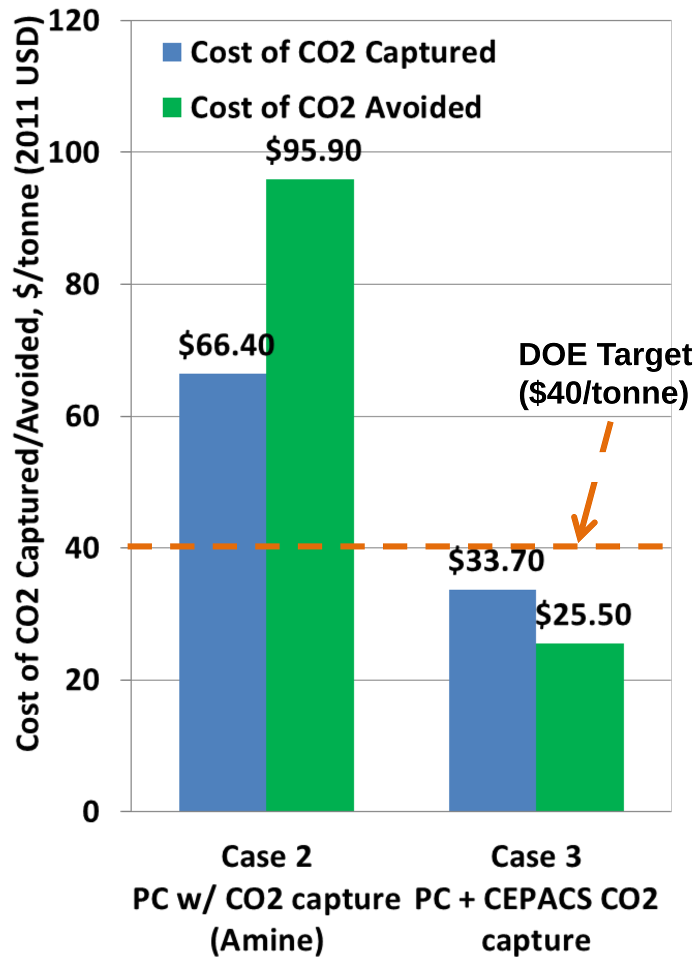
CEPACS System Economics



- PC plant retrofitted with CEPACS system has 31% lower COE than amine scrubbing

CEPACS System Economics





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

ECM Testing Results (DE-FE0007634)

- ***ECM Tolerance to Flue Gas Contaminants***
- ***Bench-scale (11.7m^2) ECM System***

ECM Flue Gas Contaminants Tolerance: Summary

Flue Gas Contaminant	Highest Concentration Tested by PNNL, with Negligible Power Degradation		Concentration in Cathode Inlet Gas after Polishing FGD, Estimated by AECOM		Notes
SO_2	1	ppmv	0.18	ppmv	Performance losses due to short-term SO_2 exposure up to 40ppm were fully reversible
Se	10	ppbv	0.30	ppbv	No apparent degradation over 860 hours.
Hg	250	ppbv	0.08	ppbv	Expected form is predominantly elemental Hg. No apparent degradation over 1100 hours.
HCl	200	ppbv	12.7	ppbv	No apparent degradation over 900 hours.

- Tests of ECM with simulated trace contaminants in the flue gas were performed at Pacific Northwest Laboratory (PNNL)
- Based on trace contaminants tests and AECOM performance estimates, a polishing wet-FGD scrubber was designed to sufficiently clean flue gas for ECM operation

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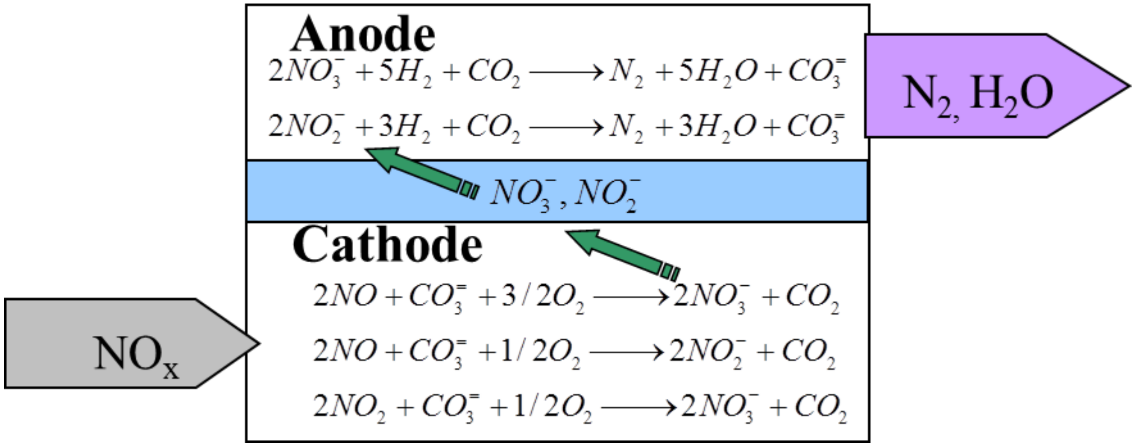
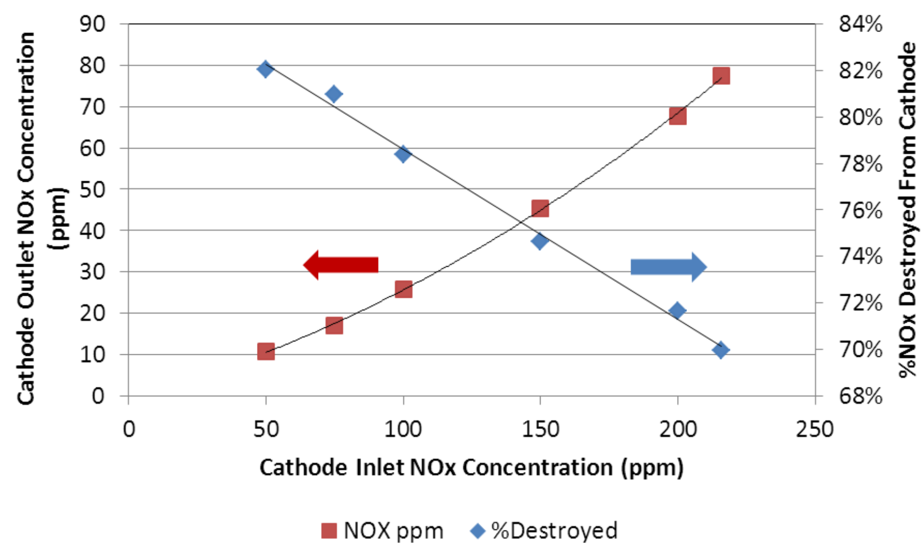
ECM NO_x Removal Tests



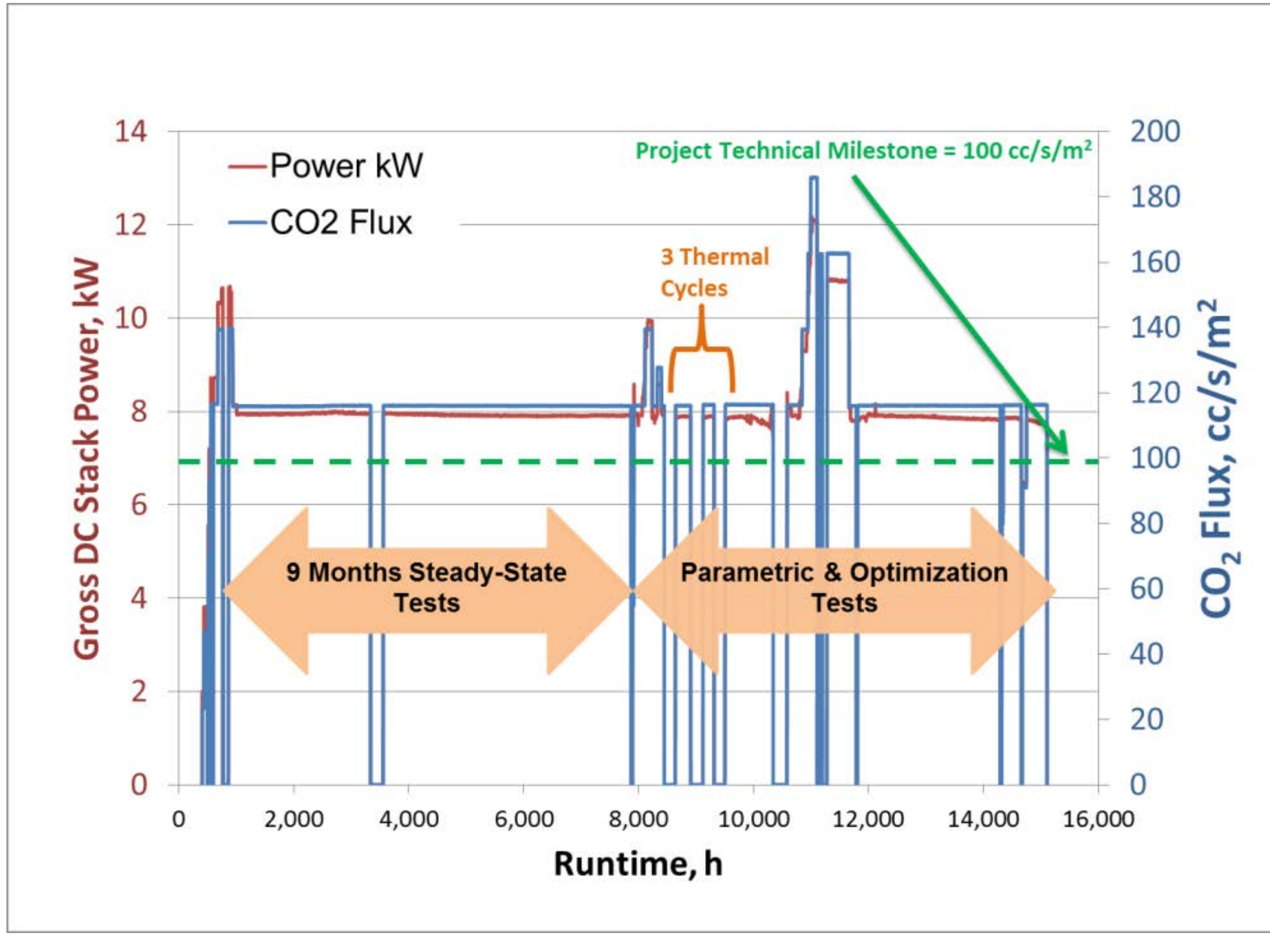


- ECM Provides a Co-benefit for NO_x Destruction
- Test results have shown > 70% at High Inlet NO_x Concentration (200 ppm) During Carbon Capture under System Conditions

Bench-Scale Demonstration Test Results

14-cell ECM stack assembly

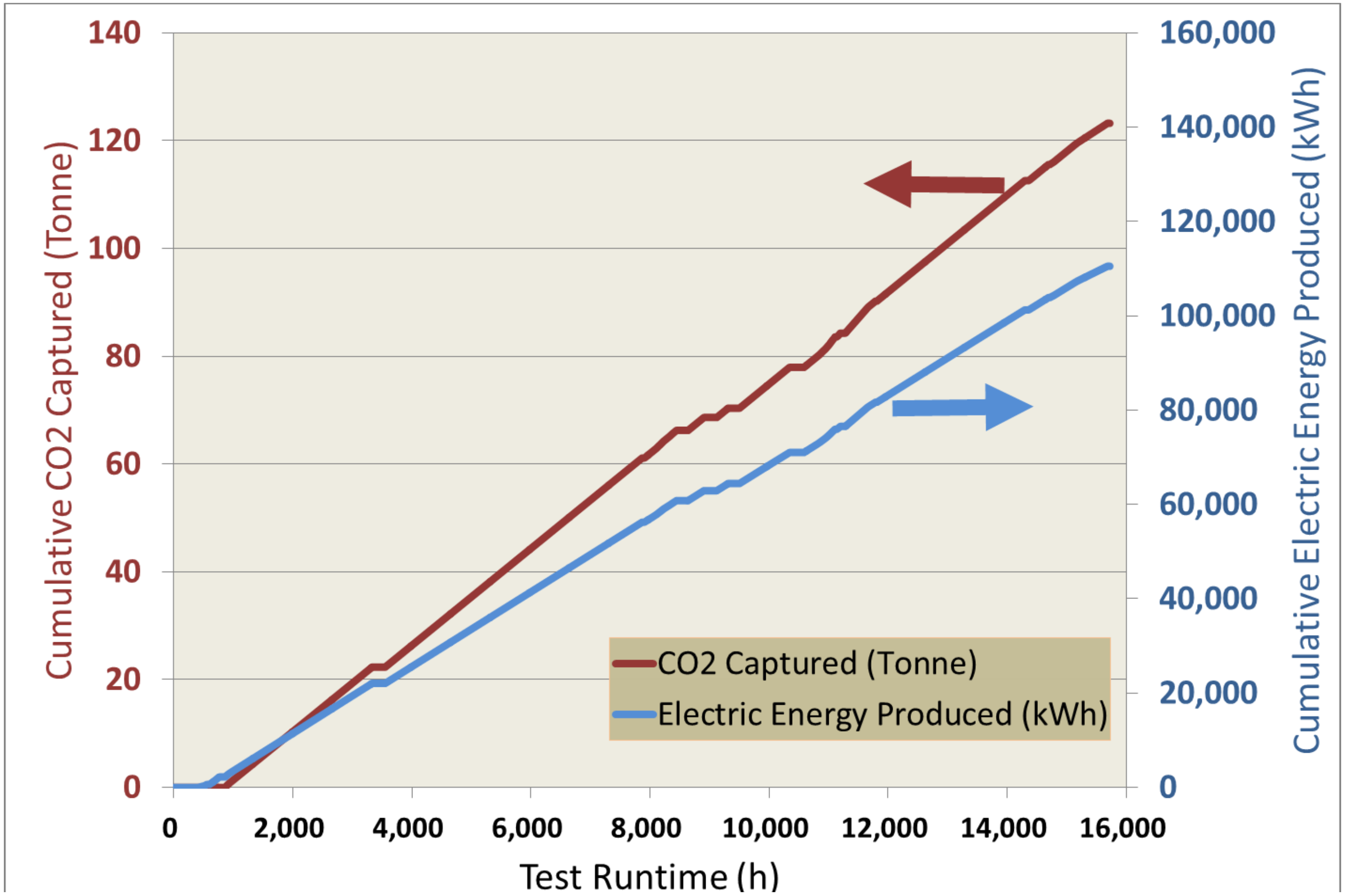
Bench-Scale Test Facility



Completed testing of CEPACS demonstration system using simulated PC flue gas:

- >100 ton/year CO_2 capture capability
- >10 kW peak power production
- 15,715 hours total runtime

Bench-Scale ECM Test Summary



Net CO_2 captured >120 Tonnes and net DC electric power generated >110MWh

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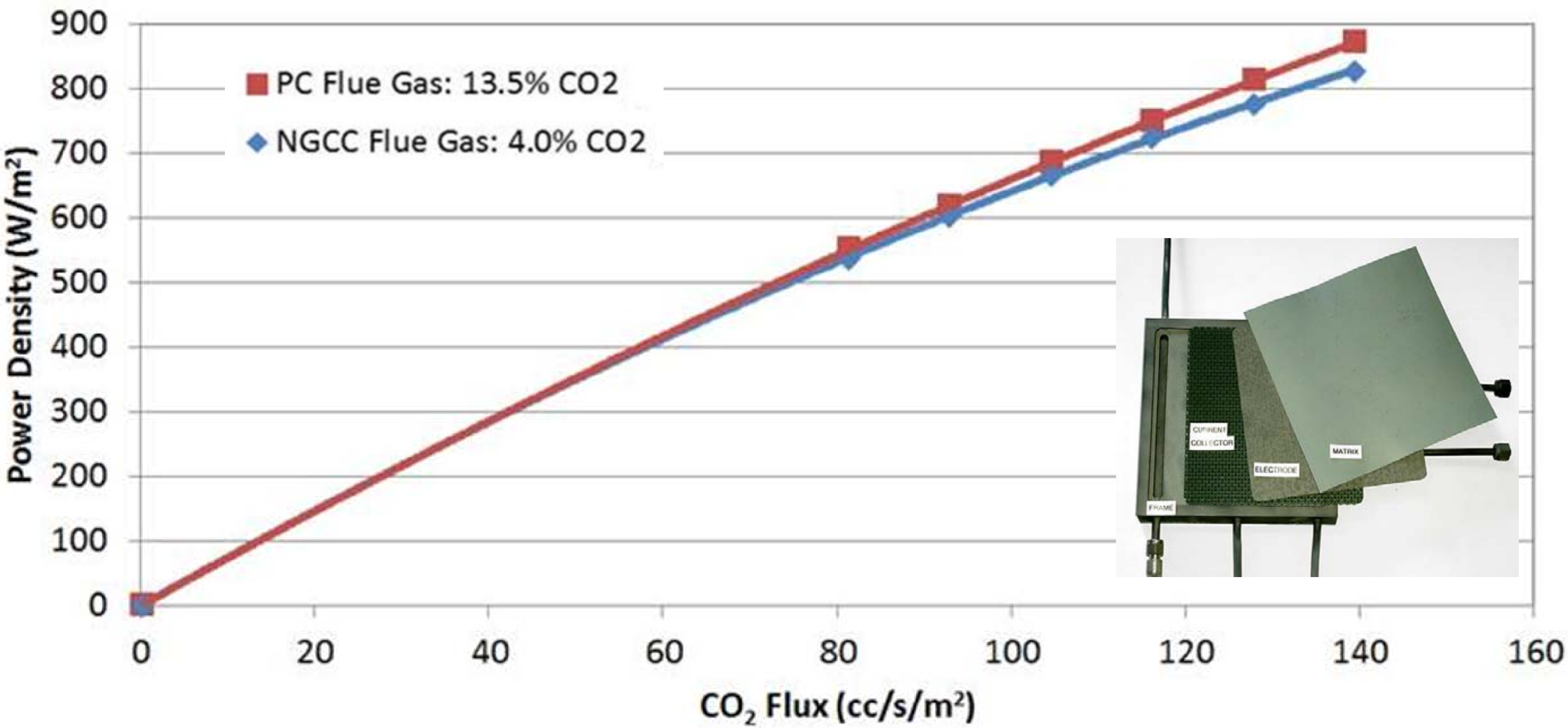
ECM Single-Cell Testing: Effect of Flue Gas Composition

ECM cell performance data for NGCC and PC plant flue gases at 93% carbon capture:



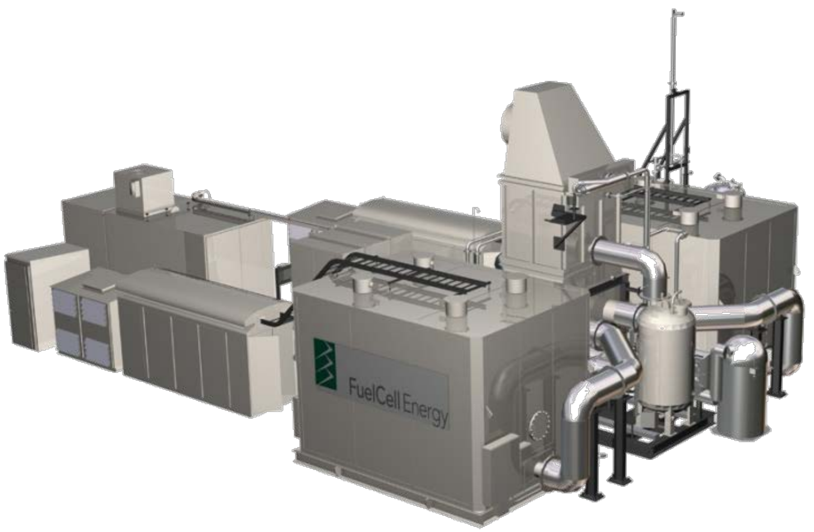
- ECM is capable of operating on flue gases with a wide range of CO_2 partial pressure
- System features (e.g. supplemental air addition, product recycle) allow tuning of cathode-side composition to optimize ECM performance

Pilot Plant Design

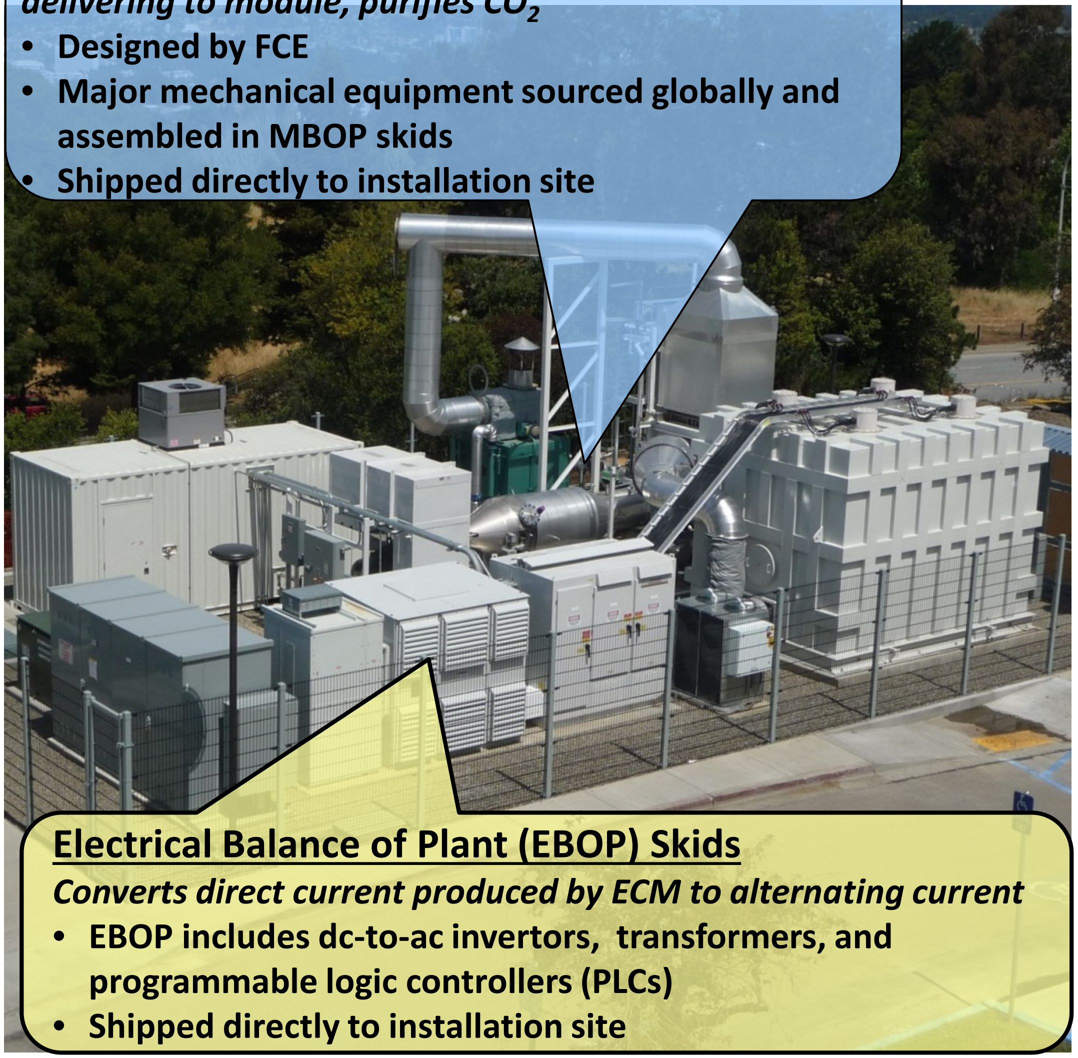
Preliminary Pilot System Performance Estimate

MW-Class Pilot CEPACS System Performance Summary

ECM Gross Power	Rated Power	
DC Power	**2015.7**	**kW**
Energy & Water Input		
Natural Gas Fuel Flow	216.8	scfm
Fuel Energy (LHV)	3759.3	kW
Water Consumption @ Full Power	0	gpm
Consumed Power		
AC Power Consumption	(450.3)	kW
Inverter Loss	(100.8)	kW
Total Parasitic Power Consumption	**(551.1)**	**kW**
Net Generation & Efficiency		
CEPACS Plant Net AC Output	**1464.6**	**kW**
Electrical Efficiency (LHV)	**39.0**	**%**
Carbon Capture		
Total Carbon Capture %	**92**	**%**
CO_2 Captured, Tons per Day	**64**	**T/D**
CO_2 Purity	**99.6**	**%**



Pilot System Fabrication



Mechanical Balance of Plant (MBOP) Skids

Preheats flue gas, conditions & humidifies fuel prior to delivering to module, purifies CO_2

- Designed by FCE
- Major mechanical equipment sourced globally and assembled in MBOP skids
- Shipped directly to installation site

Electrical Balance of Plant (EBOP) Skids

Converts direct current produced by ECM to alternating current

- EBOP includes dc-to-ac invertors, transformers, and programmable logic controllers (PLCs)
- Shipped directly to installation site

Vendor-Supplied Equipment Skids

CO_2 Compressors, Chiller, Flue Gas Polishing

- Specified by FCE / AECOM
- FCE / AECOM QC oversight
- Shipped directly to installation site

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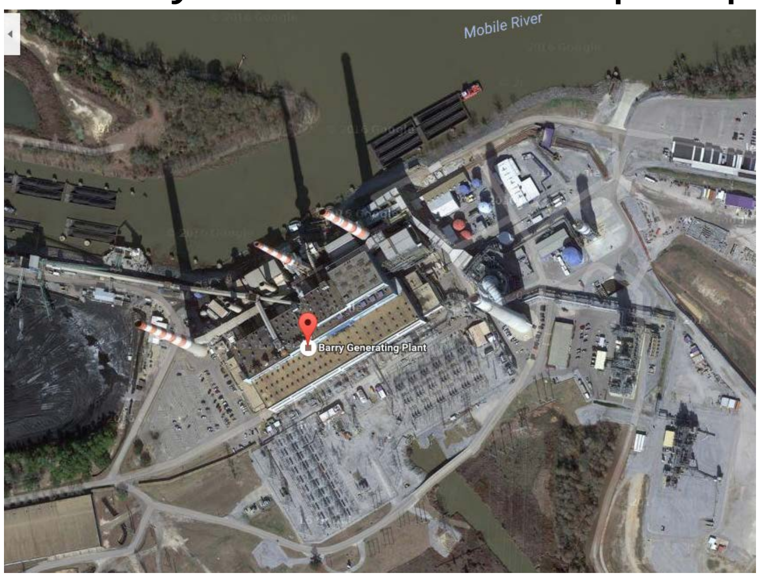
Pilot Demonstration Site Selection Process

- Initial screening of several coal based power generating sites were conducted
- Two sites were investigated for detailed analysis
- Site selection criteria includes implementation cost and accessibility of the necessary infrastructure for pilot plant tests



- James M. Barry Electric Generating Station, Alabama Power/Southern Co.
- Location: Bucks, Al
- Nameplate Capacity: 1,771 MWe, Mix of Coal and Natural gas

- Abbott Power Plant, University of Illinois
- Location: Champaign, Ill
- Nameplate Capacity: 84 MWe, Mix of coal and natural gas

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ECM Carbon Capture Summary

Captures and Concentrates Exhaust from:
- Coal power plant
- Natural gas power plant
- Industrial process

Proven Technology:
- Leverages commercial fuel cell technology
- Project underway to demonstrate MW-class pilot plant for capture from coal flue gas

Economical:
- Produces additional power vs power reduction
- Generates return on capital vs operating expense

Additional Benefits:
- 70% reduction in NOx
- Clean water production

JDA with ExxonMobil

- **Collaboration partner with extensive resources**
  - o World's largest energy company & public gas producer
  - o Leading expert & experience with sequestration
- **Opportunity**
  - o Integration with combined cycle gas plants
  - o Global market opportunity measured in Gigawatts

Hwaseong, South Korea
59 MW Fuel Cell System

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Acknowledgements

ECM Carbon Capture from Coal Plants supported by DOE/NETL (Co-operative Agreements: DE-FE0007634 & DE-FE0026580)

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Thank You

Hossein Ghezel-Ayagh
Director, Advanced Technology Programs
203.825.6048
hghezel@fce.com

FuelCell Energy, Inc.
3 Great Pasture Rd
Danbury, CT 06810
www.fuelcellenergy.com