FuelCell Energy

Electrochemical Membrane for CO_2 Capture and Power Generation

No. DE-FE0007634

Hossein Ghezel-Ayagh
FuelCell Energy, Inc.

2012 NETL CO_2 Capture Technology Meeting

July 9, 2012

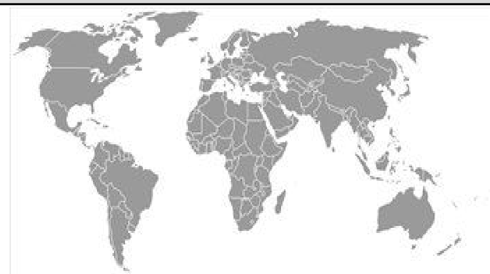
Pittsburgh, PA

Ultra-Clean, Efficient, Reliable Power

FuelCell Energy

FuelCell Energy, Inc.

Manufacture	**Sell** (direct & via partners)	**Install**	**Services**



- Premier developer of stationary fuel cells with >40 years of experience
- Headquarters and R&D in Danbury, CT (USA), manufacturing facility in Torrington, CT (USA)
- Delivering Direct FuelCell® (DFC®) power plants for On-Site Power and Utility Grid Support
- Over 80 Direct FuelCell plants generating power at more than 50 sites globally
- Established commercial relationships with major distributors in the Americas, Europe, and Asia

Delivering ultra-clean baseload distributed generation globally

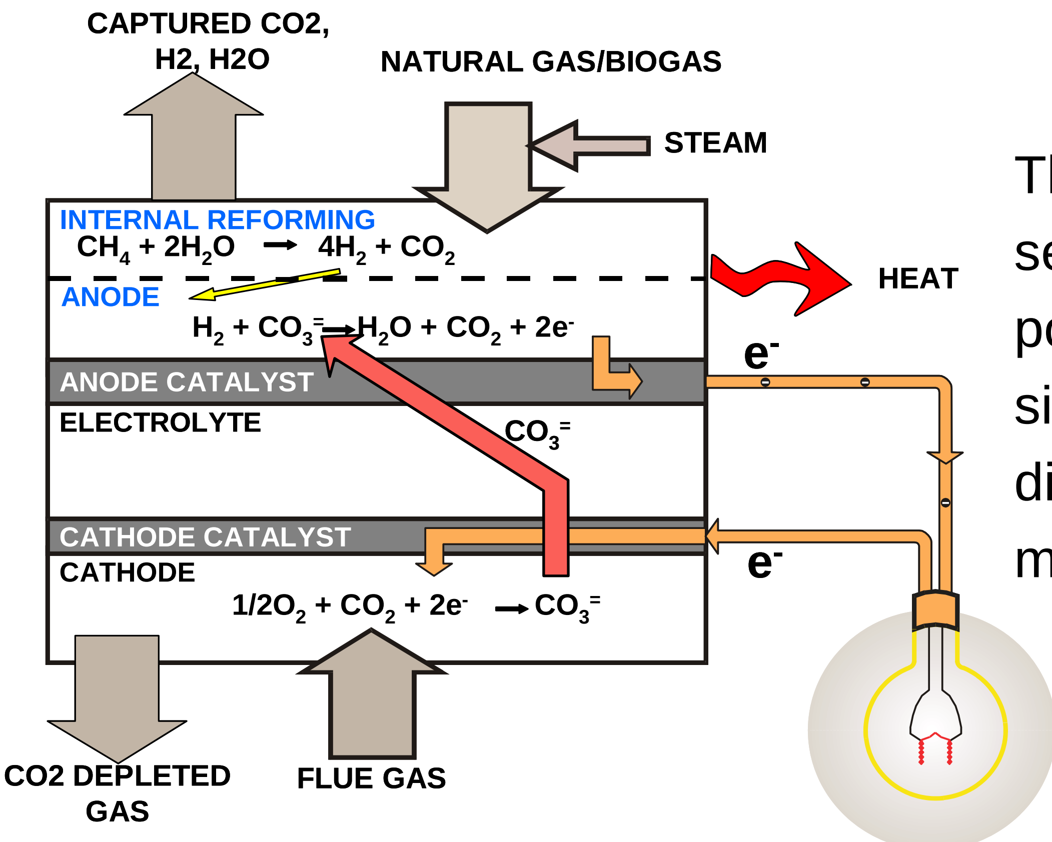
600 kW plant at a food processor

1.4 MW plant at a municipal building

2.4 MW plant owned by an Independent power producer

11.2 MW plant - largest fuel cell park in the world

Electrochemical Membrane (ECM) Technology



The driving force for CO_2 separation is electrochemical potential of fuel on the anode side versus pressure differential across the membrane

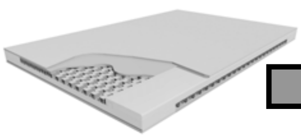
Net Result

- 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 (CO_2/N_2 Selectivity = ∞)

FuelCell Energy

ECM Module Assembly

Planar Electrochemical Membrane Assemblies Are Stacked and Incorporated into MW-scale Modules.



ECM Assembly

ECM Stack

Four-Stack Module

Enclosed Module

ECM is a modular technology:

- **Ease of scale up and transport**
- **Suitable for incremental phased applications to almost any type of CO_2-emitting plant**

FuelCell Energy

DE-FE0007634 Project Outline

Overall Project Objectives:

- Demonstrate the ability of FCE's electrochemical membrane (ECM)-based system to separate ≥ 90% of the CO_2 from a simulated PC flue-gas stream and to compress the CO_2 for sequestration or beneficial use
- Demonstrate that the ECM system is an economical alternative for post-combustion CO_2 capture in PC-based power plants, and that it meets DOE objectives for incremental cost of electricity (COE)

Project Participants:

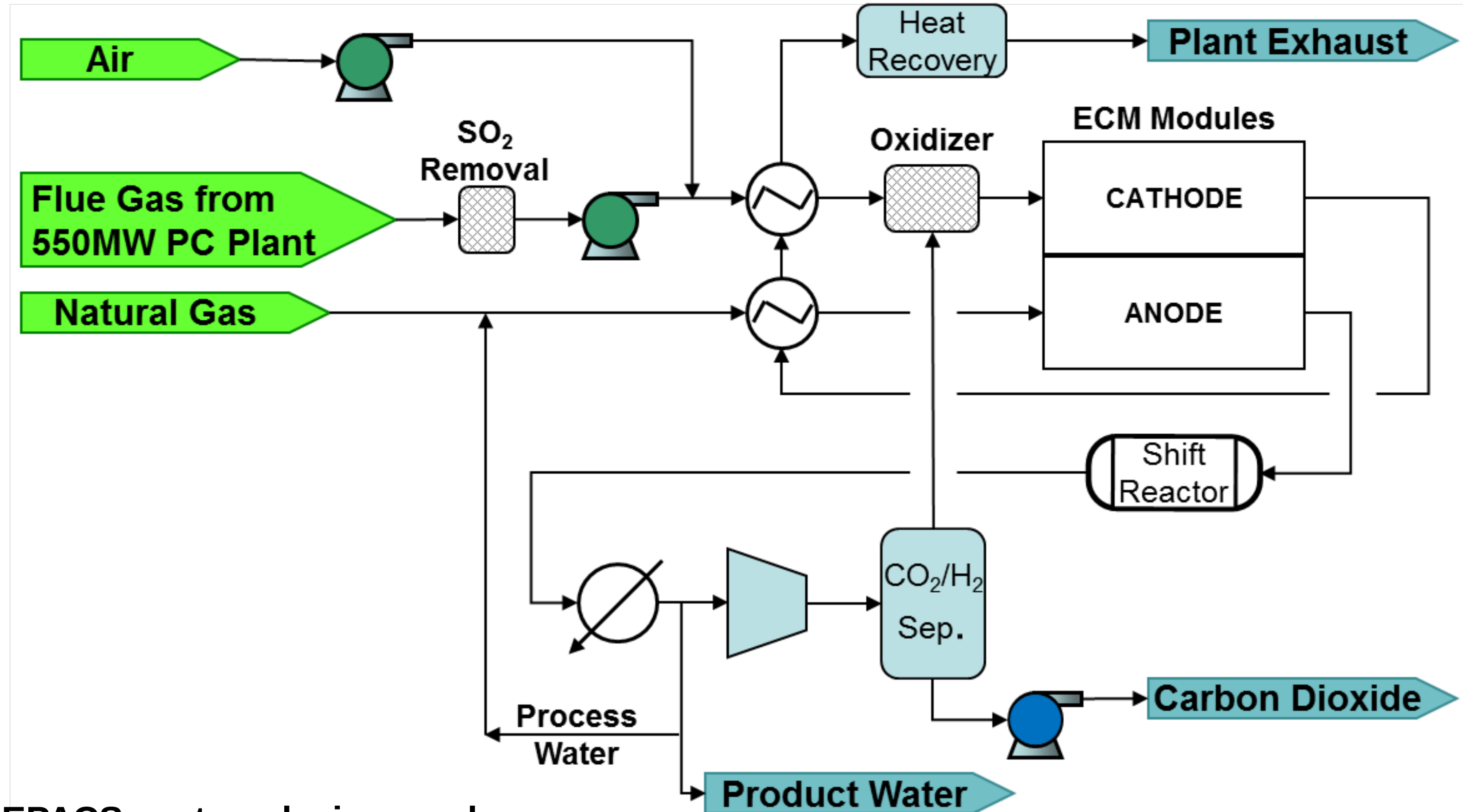
FuelCell Energy Inc. (FCE)	**System design, GAP analysis, ECM fabrication, and bench-scale testing of an 11.7 m^2 area electrochemical membrane system for CO_2 capture.**
Pacific Northwest National Laboratory (PNNL)	**Test effects of flue gas contaminants on ECM.**
URS Corporation	**Review ECM-based system design, equipment and plant costing, and flue gas clean-up system design.**

Project Performance Dates: 10/01/2011 to 12/31/2014

Funding: Government Share = $2,434,106, FCE Cost Share = $758,527

CEPACS System Block Flow Diagram

Combined Electric Power and Carbon-dioxide Separation (CEPACS) System Concept Implementation for 550 MW Reference PC Plant (Case 9)*

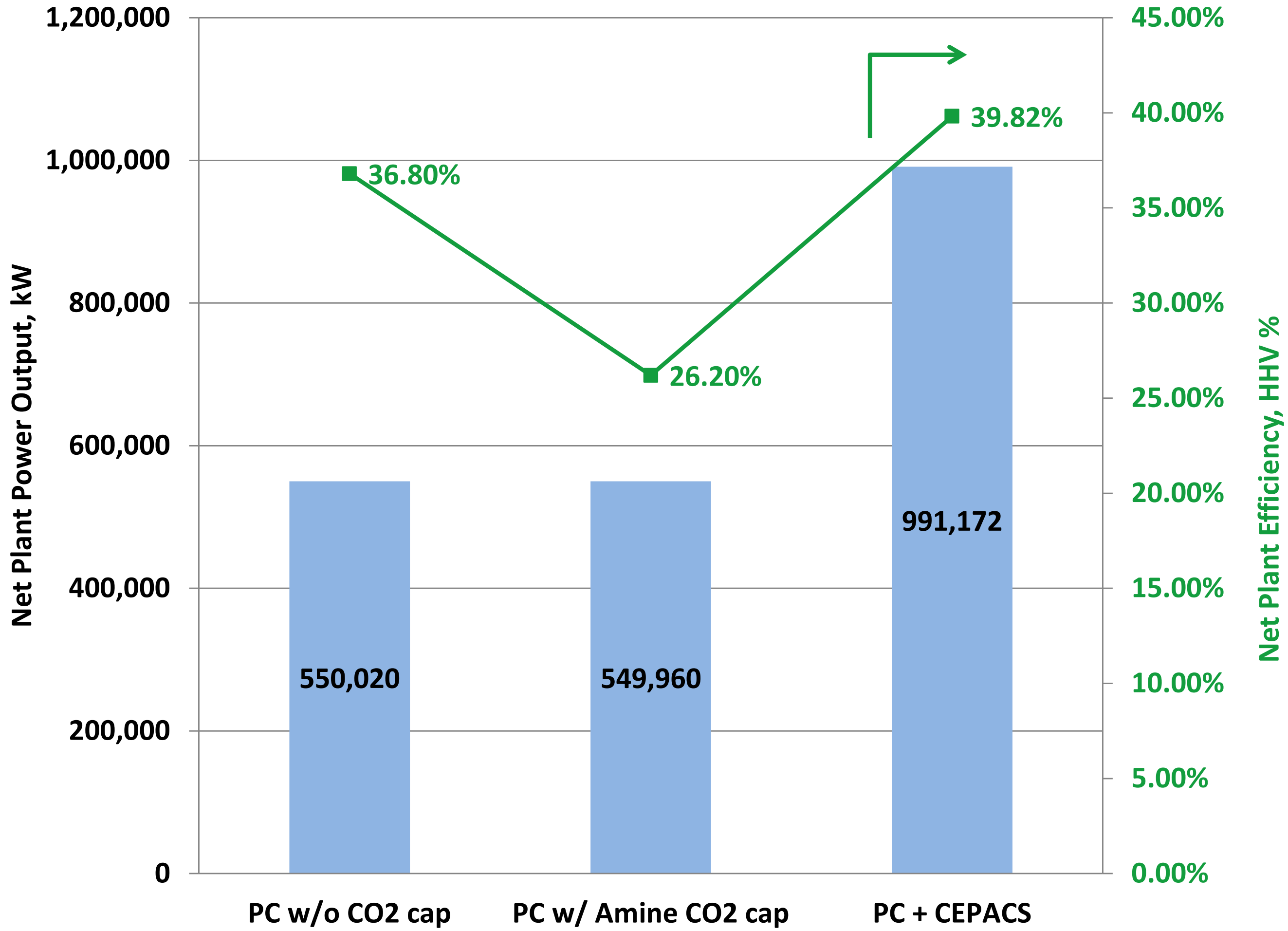


CEPACS system design produces:

- **Supercritical CO_2 (90% Carbon capture from PC Plant)**
- **Excess Process Water**
- **Additional 441 MW of clean AC power @ 44.4% Efficiency (based on LHV Natural Gas)**

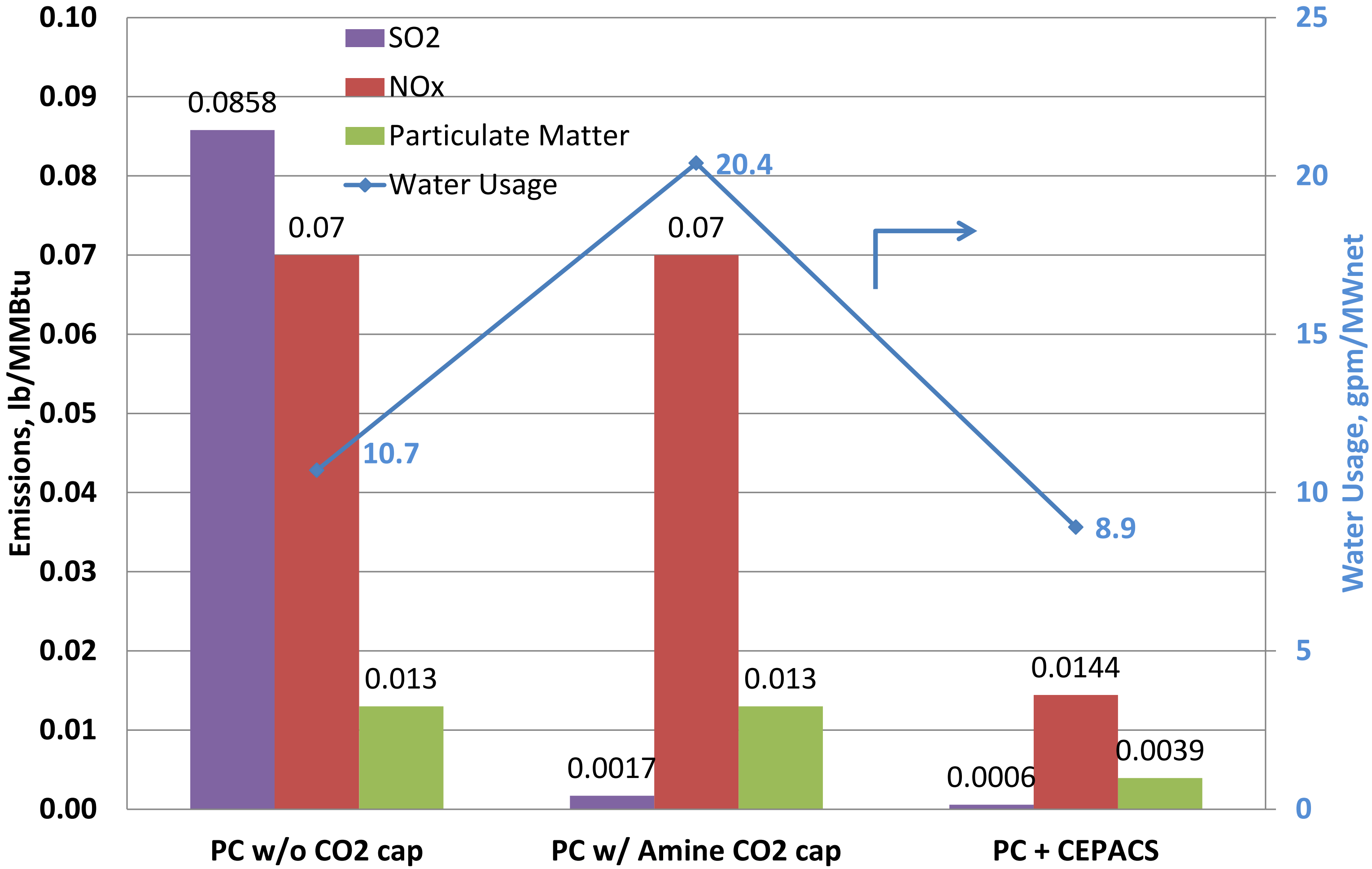
* Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 2, DOE/NETL-2010/1397, November 2010.

CEPACS System Performance



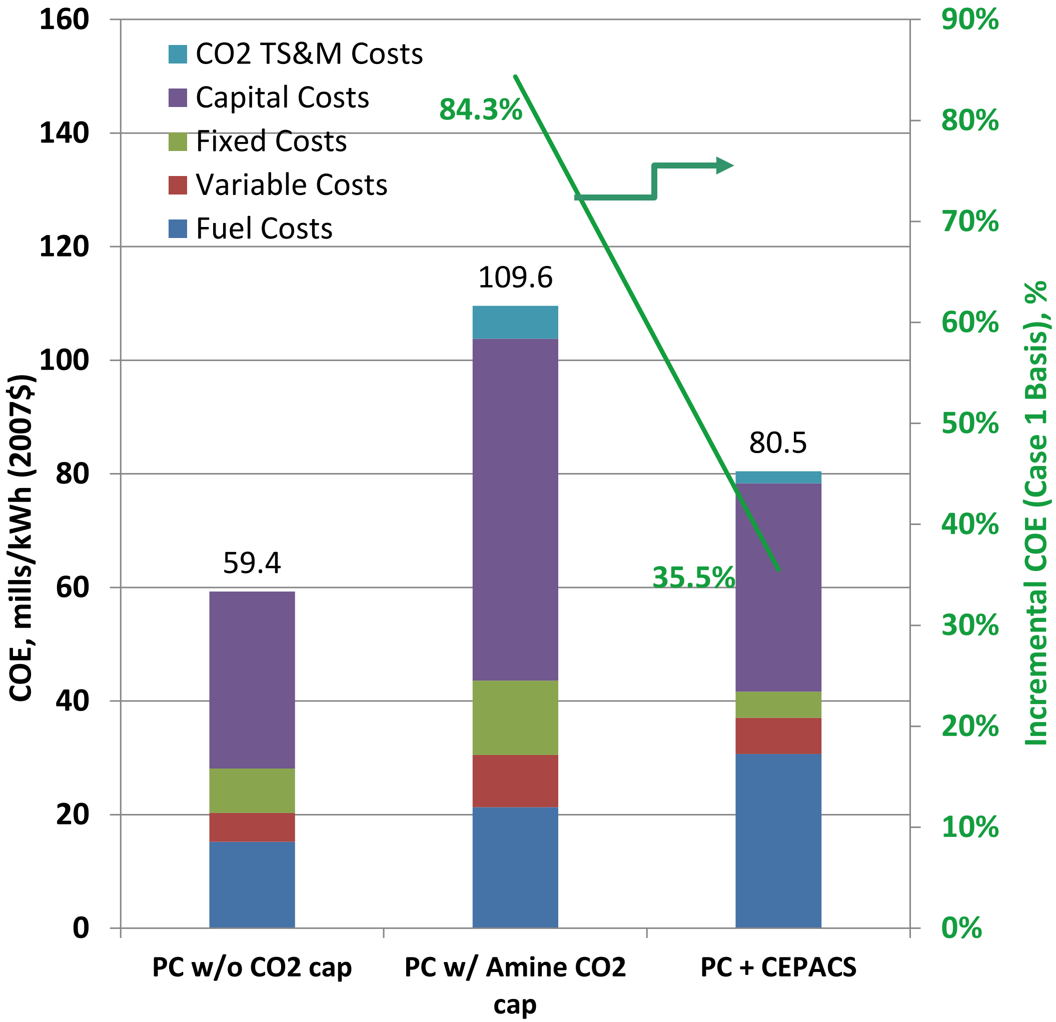
- CEPACS System increases power output of Baseline PC plant by 80%
- PC plant retrofitted with CEPACS system is 3 percentage points more efficient than Baseline PC Plant without carbon capture

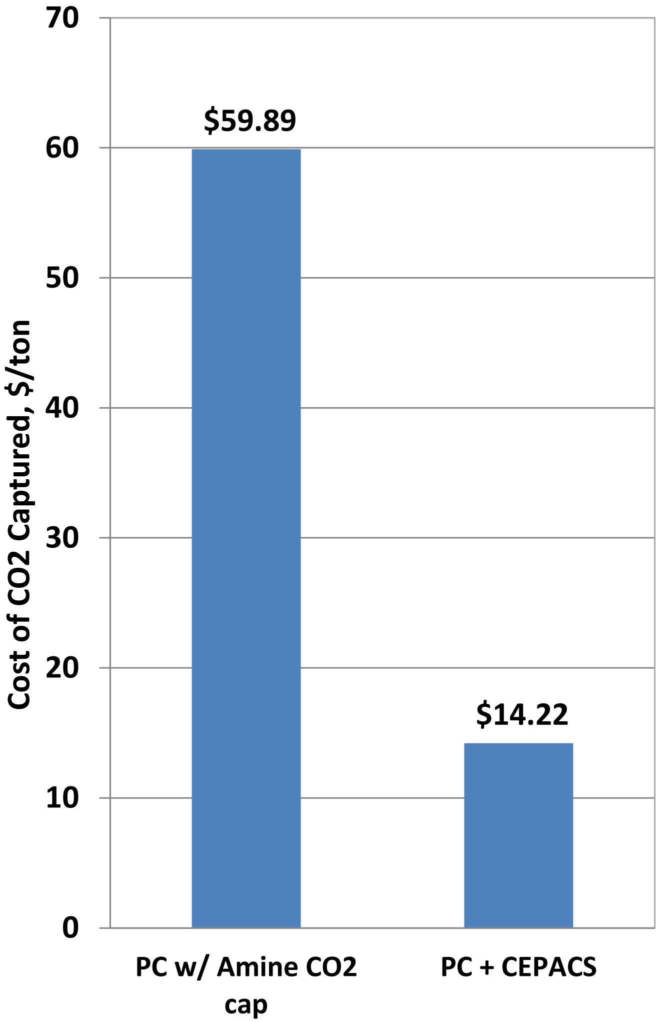
CEPACS System Performance: Emissions and Water Usage



- PC plant retrofitted with CEPACS system has lower emissions of NOx, SOx, and Hg than a PC plant retrofitted with Amine scrubber for CO_2 capture
- CEPACS system produces excess process water, reducing the total plant water usage

CEPACS System Economics



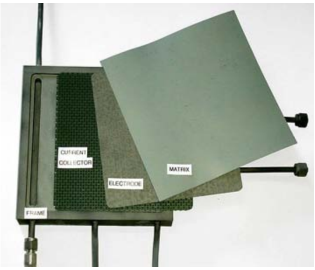


- PC plant retrofitted with CEPACS system can meet the DOE incremental COE target of 35%
- Cost of CO_2 capture for PC plant retrofitted with CEPACS system is 4x lower than for Amine scrubber case

FuelCell Energy

Future Project Work

Membrane Testing to Optimize System Performance

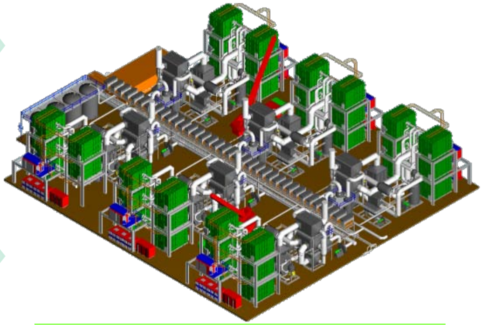


250 cm^2 ECM test cell

Evaluate Effects of Contaminants on ECM Performance

Multiple button cells in furnace each with individual gas flow and electrical controls

Detailed Thermo-Economics and GAP Analyses



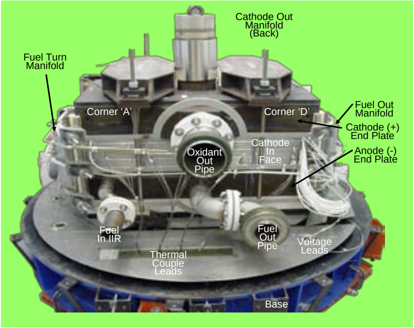
<u>44 MW ECM cluster</u>

930 ton CO_2/day

Power Generation: ~1150 kWh/ton CO_2

Technical EH&S review to assess the environmental friendliness

Fabricate bench-scale 11.7m^2 membrane module capturing carbon dioxide and producing ~10kW



10 kW ECM stack installed on a base

FuelCell Energy

Summary & Commercialization Prospects

- **ECM, derived from commercially proven Direct FuelCell® technology, provides a unique alternative for CO_2 capture.**
- **ECM cost is coming down with the growth in manufacturing:**
  - > **Growing annual production: From 4 MW in 2003 to 56 MW in 2011.**
- **Utilization of ECM technology in large scale fuel cell systems demonstrates the viability of carbon capture for centralized PC and NGCC plants.**

Fuel Cell Manufacturing Facility, Torrington, CT

Hwaseong, South Korea 60MW system in Development

Thank You!

Acknowledgement

DOE/NETL support, with special thanks to: Jose Figueroa, Lynn Brickett, and Shailesh Vora