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Electrochemical Membrane for CO_2 Capture and Power Generation

DE-FE0007634

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DE-FE0007634 Project Outline

Overall Project Objectives:

- Demonstrate ability of FCE's electrochemical membrane (ECM)-based system to separate ≥ 90% of CO_2 from a simulated PC flue-gas stream suitable for sequestration or beneficial use
- Demonstrate that 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) FuelCell Energy Ultra-Clean, Efficient, Reliable Power	**System design, GAP analysis, ECM fabrication, and bench-scale testing of an 11.7 m^2 area ECM system for CO_2 capture.**
Pacific Northwest National Laboratory (PNNL) Pacific Northwest NATIONAL LABORATORY	**Test effects of flue gas contaminants on ECM.**
URS Corporation URS	**Review ECM-based system design, equipment and plant costing, and flue gas clean-up system design.**

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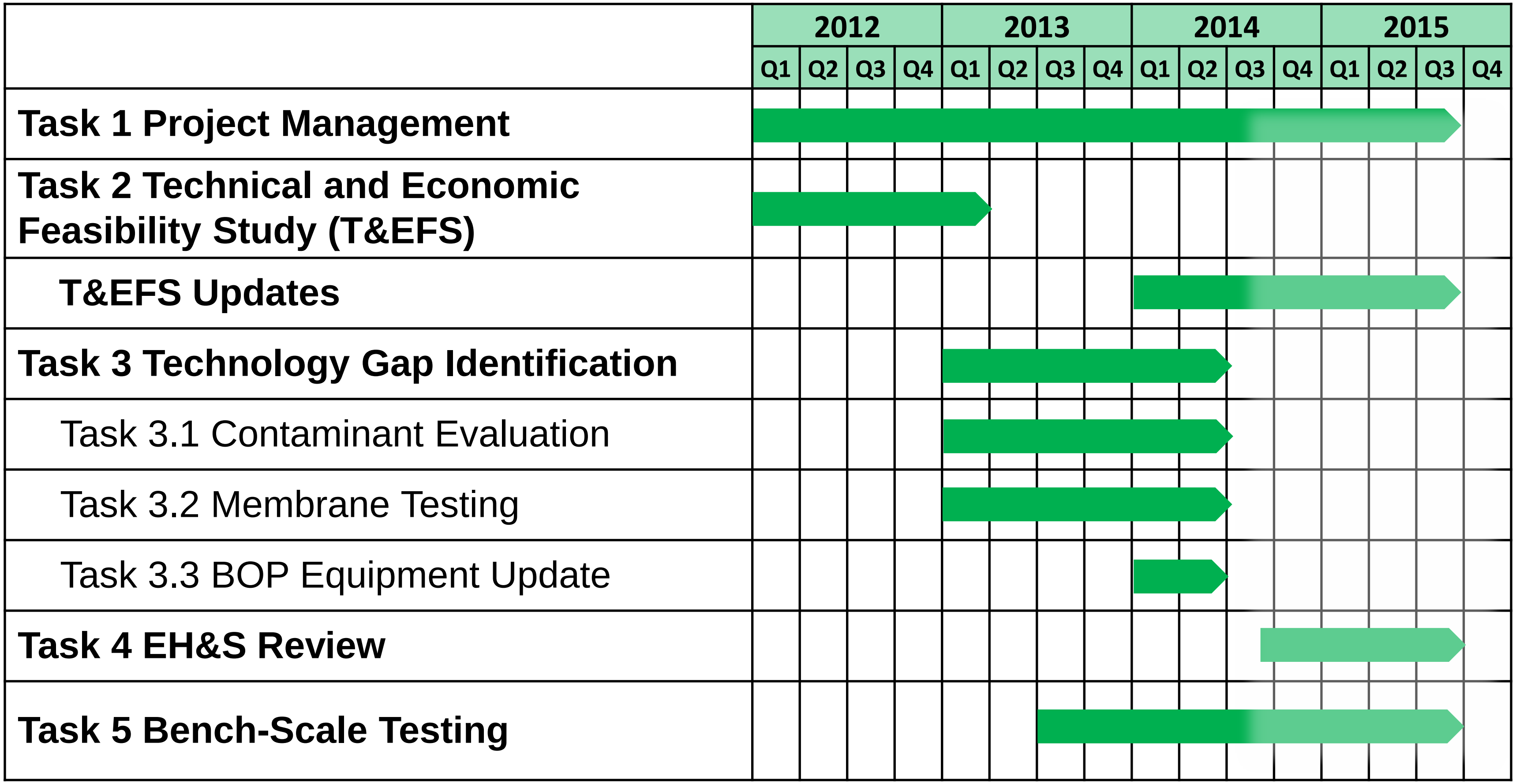
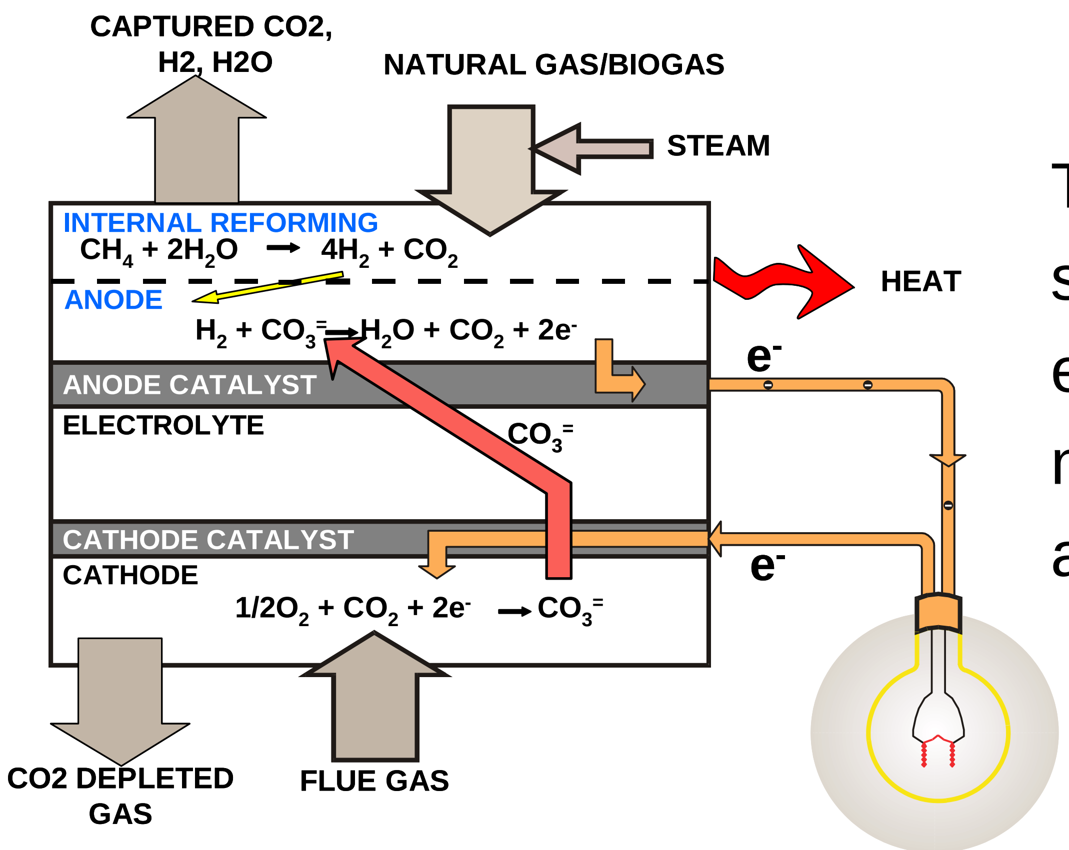
Project Tasks, Schedule and Funding



Project Funding		
DOE Share	FCE Cost Share	Project Total
$3,034,106	$758,527	$3,792,633

Electrochemical Membrane (ECM) Technology



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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ECM Stack Module Commercialization

- ECM utilizes the same technology as FCE's commercial stand-alone fuel cell power plants
- Current manufacturing ramp-up (>70 MW/year) is reducing ECM cost


World's largest fuel cell park located in Hwaseong City, South Korea

- 59MW power plant consisting of 42 stack modules adequate to power ~ 140,000 homes in S. Korea
- Supplying electric grid and district heating system
- Constructed in only 14 months

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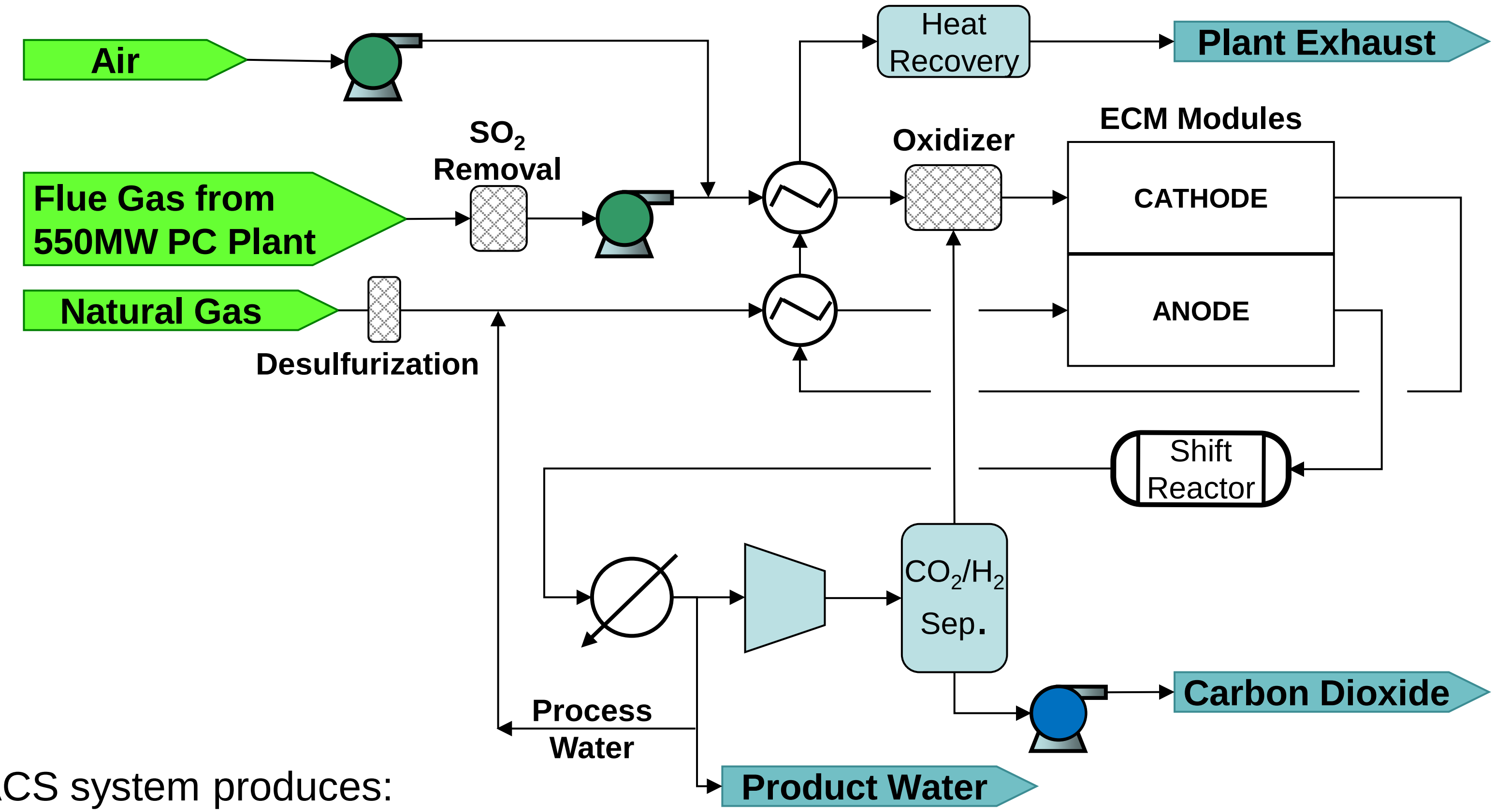
Techno-Economic Analysis

CEPACS System Block Flow Diagram

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

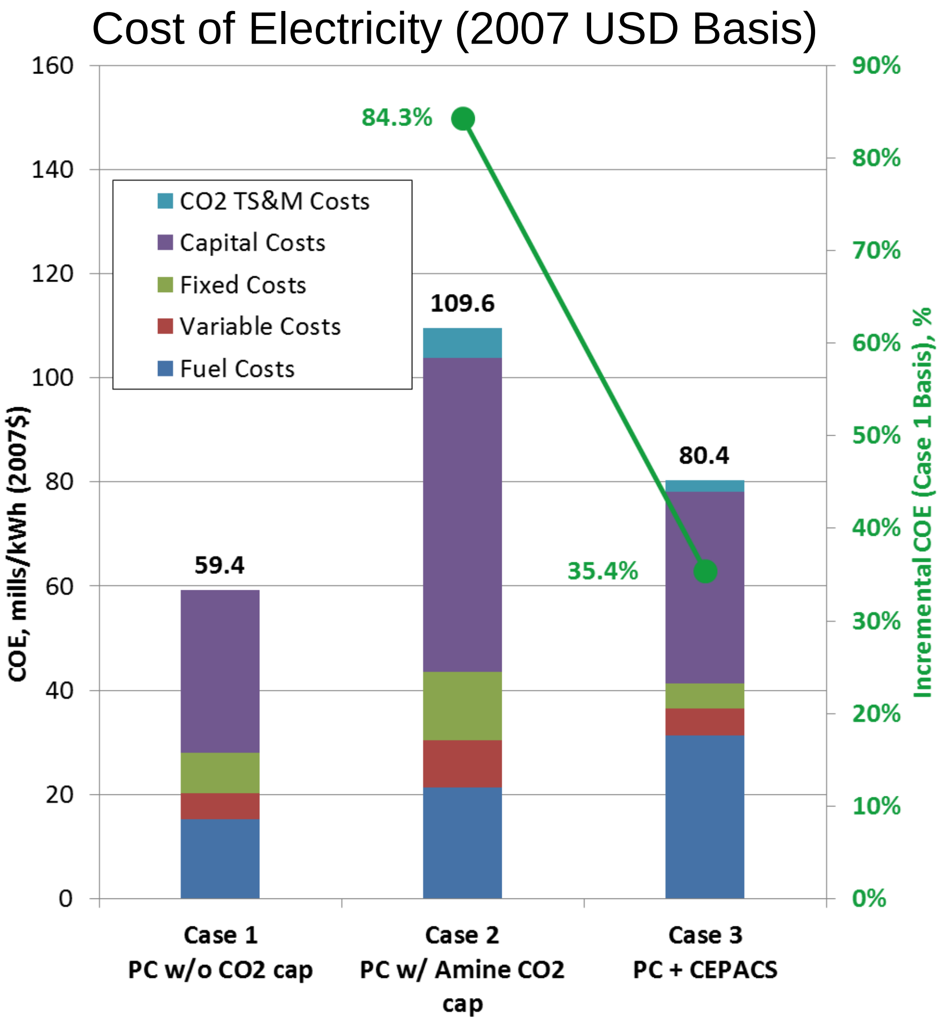


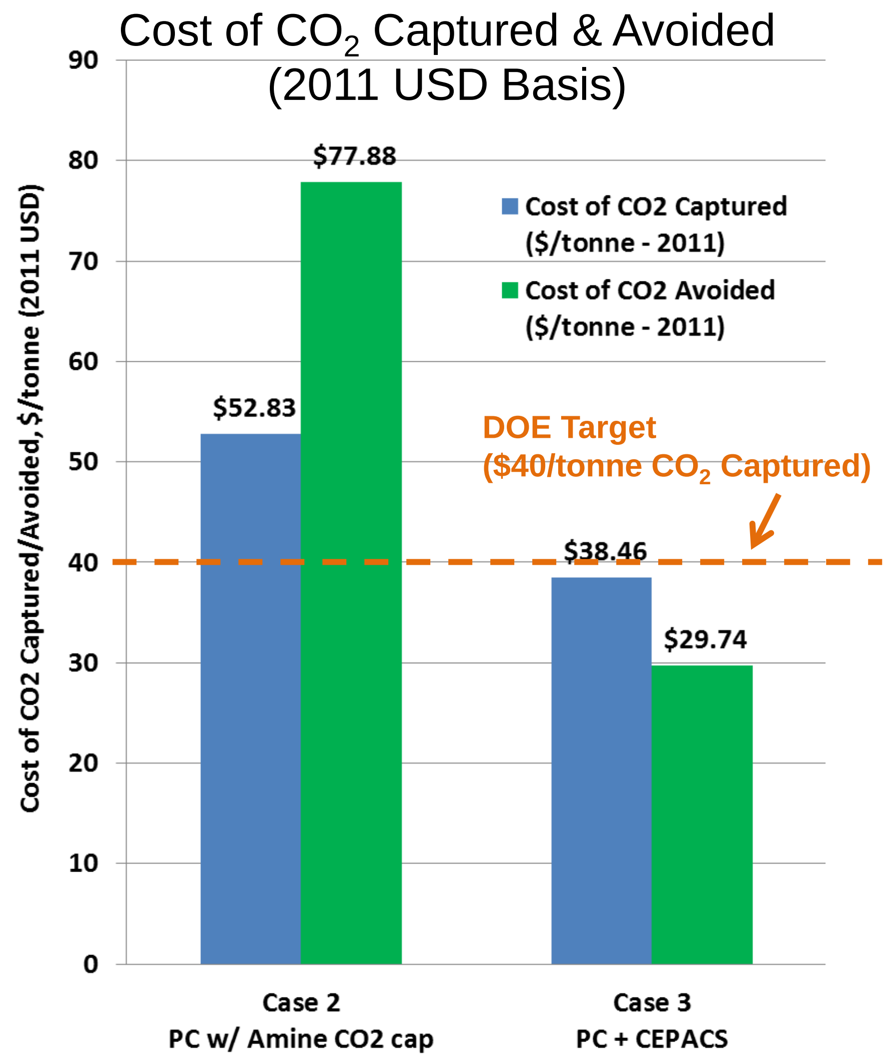
CEPACS system produces:

- Supercritical CO_2 (90% CO_2 capture from PC Plant)
- Excess Process Water
- Additional 421 MW of clean AC power @ 42.4% 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.

Techno-Economic Analysis Results

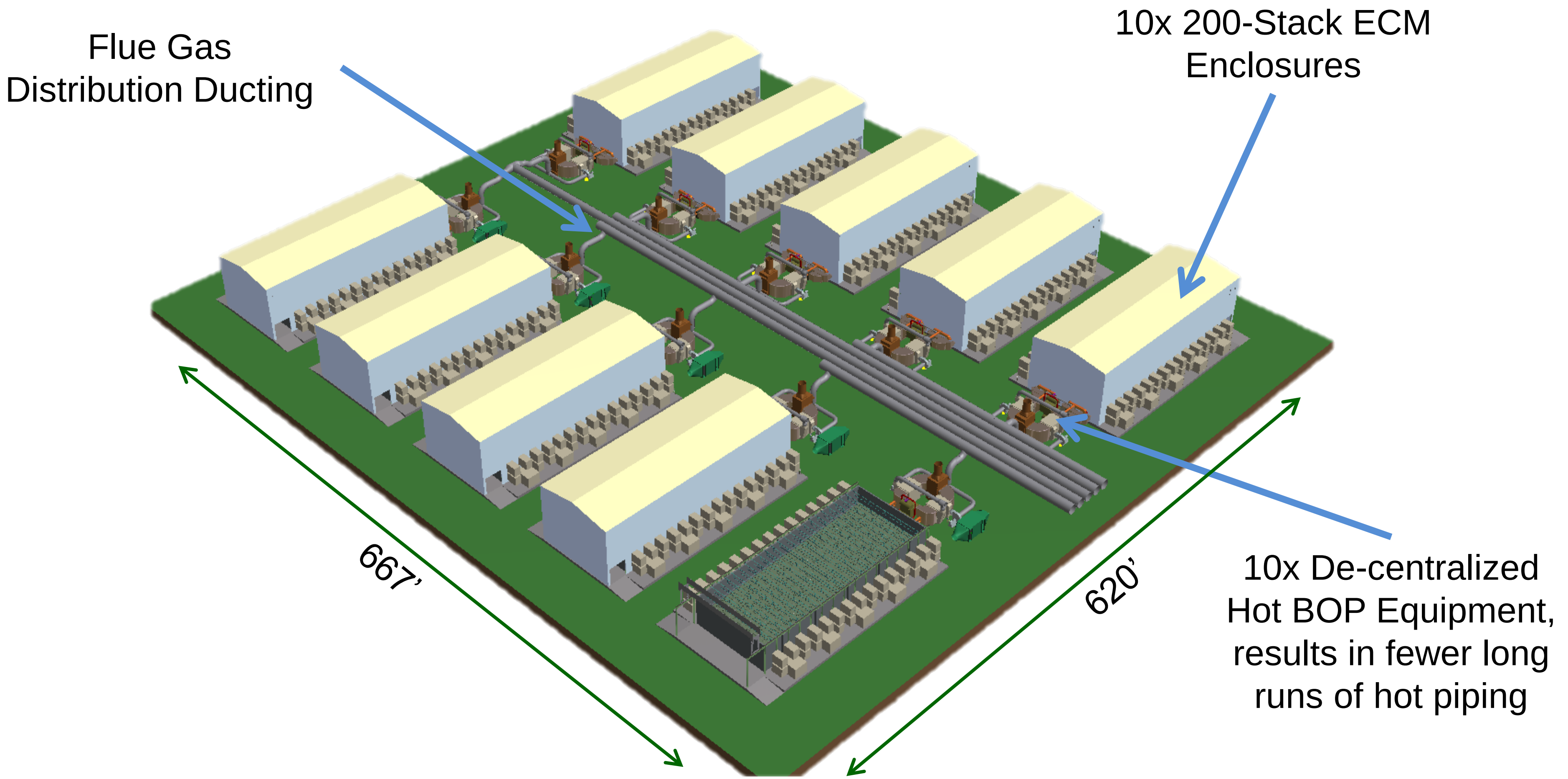




- CEPACS System incremental COE meets DOE target of <35%
- CEPACS System can meet DOE Target of <$40/tonne CO_2 captured (2011 USD)

CEPACS Plant Layout for Large Systems

421MWe CEPACS Plant for >90% Carbon Capture from 550MWe Reference PC Plant requires ~ 12 Acres



CEPACS System modularity allows for isolation of a single enclosure, resulting in near-100% availability with >90% capacity factor

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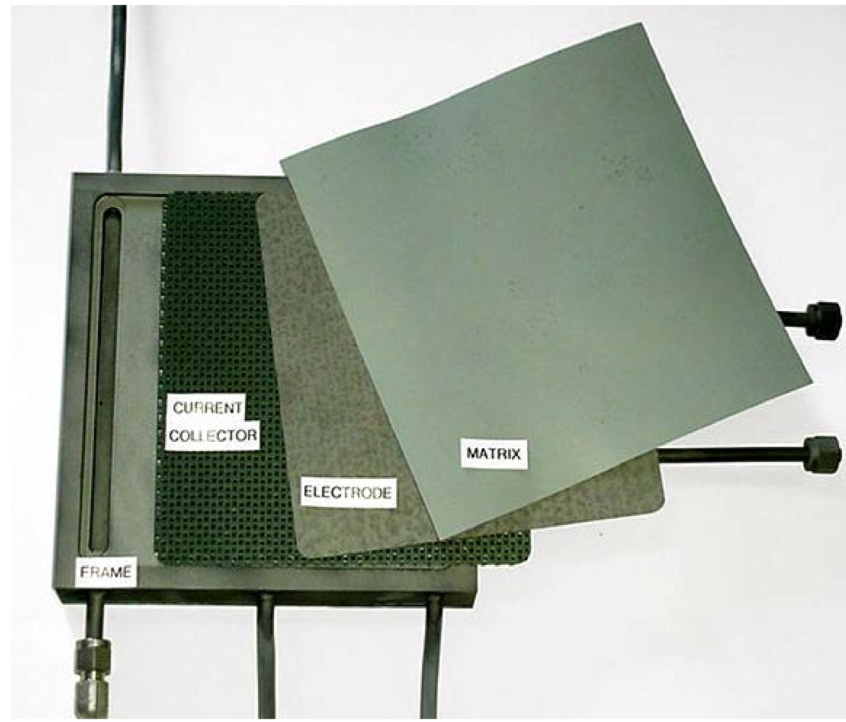
ECM Testing Results

ECM Components and Single-Cell Testing Facilities



- Laboratory facility for testing 250 cm^2 electrochemical membranes under a variety of system operating conditions.

Performance Comparison: Effect of Flue Gas Composition

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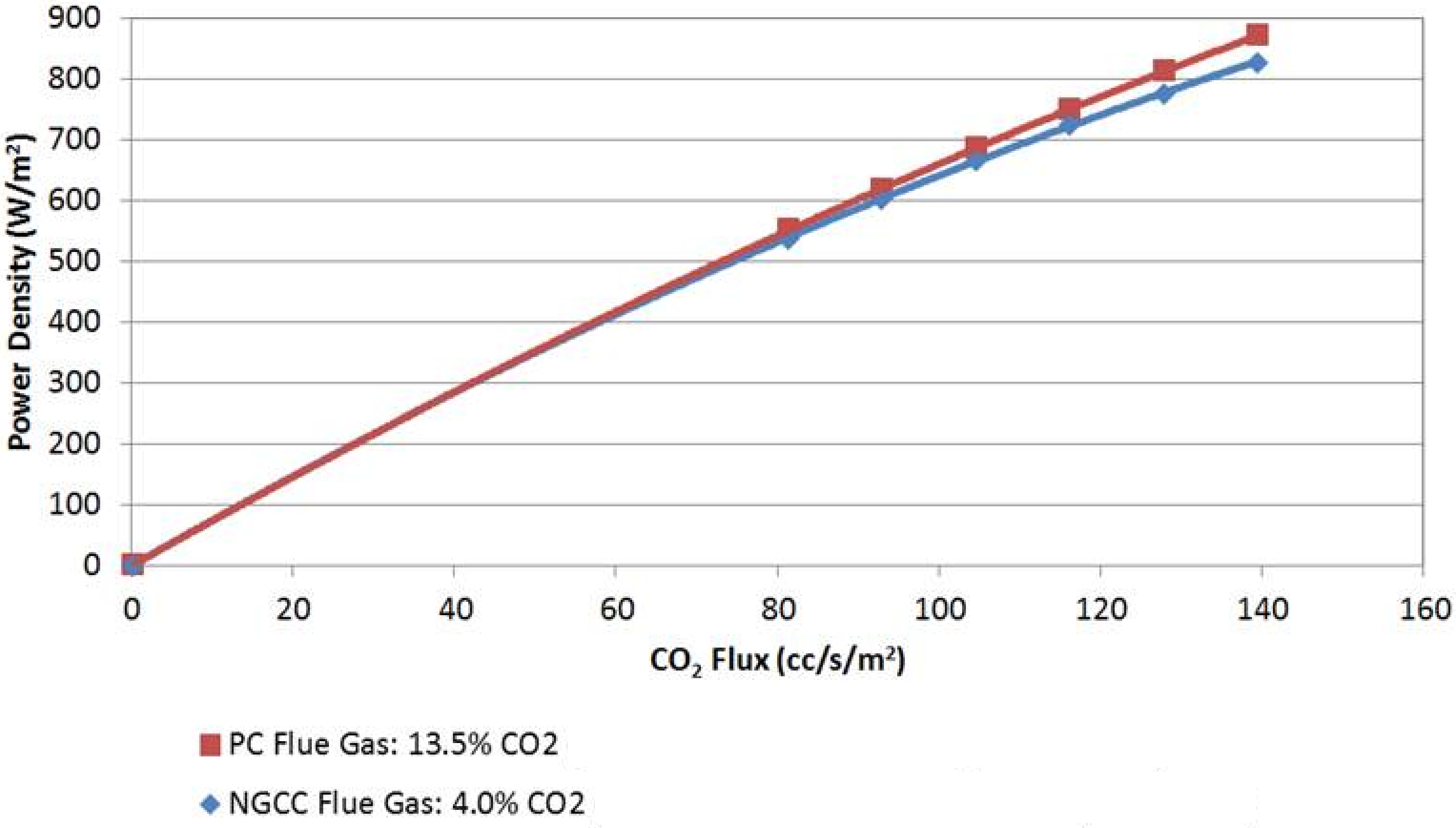
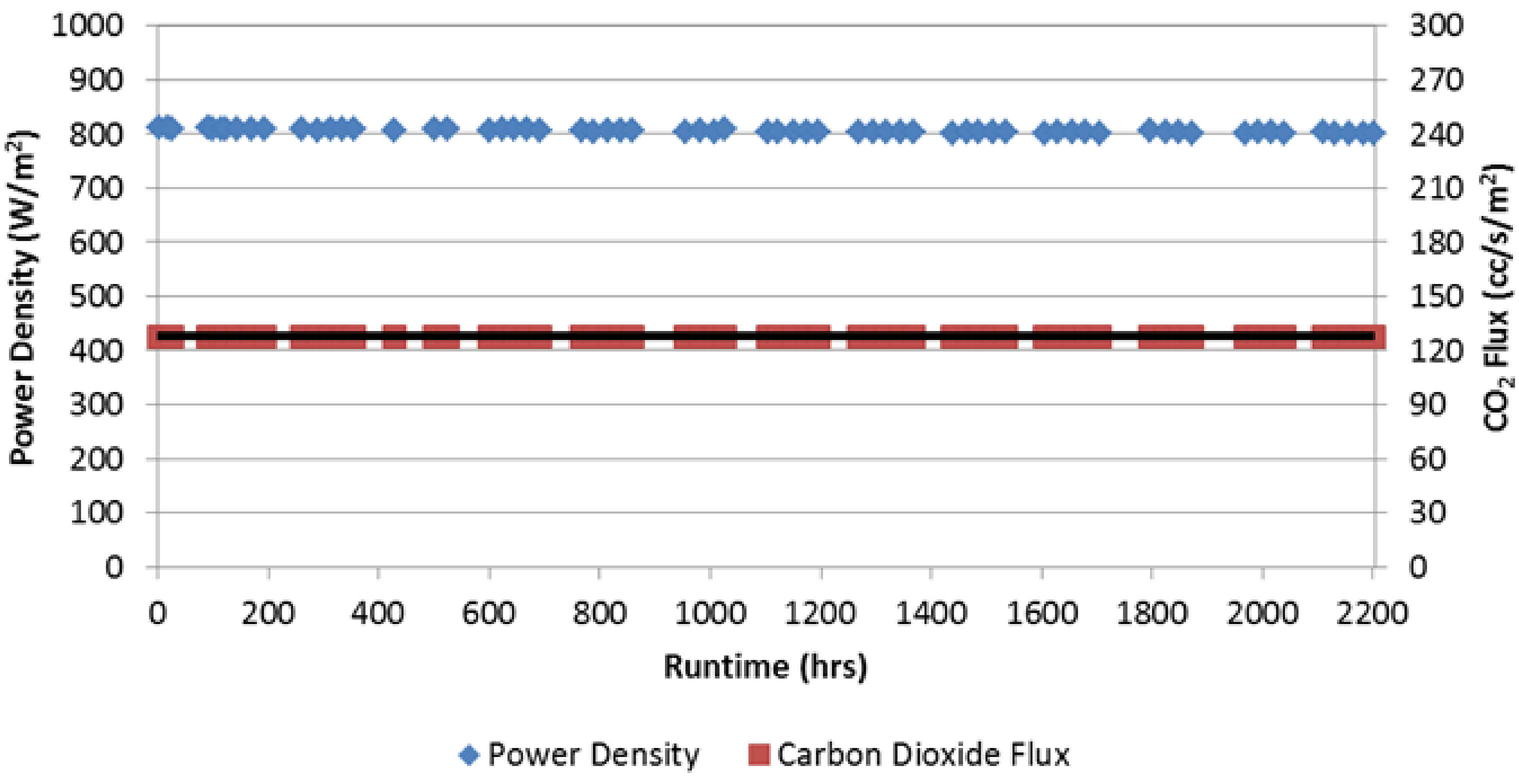
ECM cell performance data for NGCC and PC plant flue gases at 93% carbon capture:



- 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
- High cell power densities at high CO_2 flux is observed in ECM tests

ECM Endurance Testing Results

- ECM cell stability testing at steady state PC flue gas-based system conditions for over 2200 hours of operation:



- The CO_2 flux remained constant through over 2200 hours of testing of a subscale membrane assembly (250 cm^2 area), indicating constant 90+% CO_2 capture
- The power production remained stable during test duration

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Overview of ECM Contaminant Tolerance Testing

Testing Goals:

- Assess physical and chemical interactions of main flue gas pollutants with ECM via experiments and thermodynamic modeling
- Determine effects of most volatile species (S, Cl, Hg, and Se) in flue gases on ECM performance
- Enable selection of clean-up technology for CEPACS System

Approach:

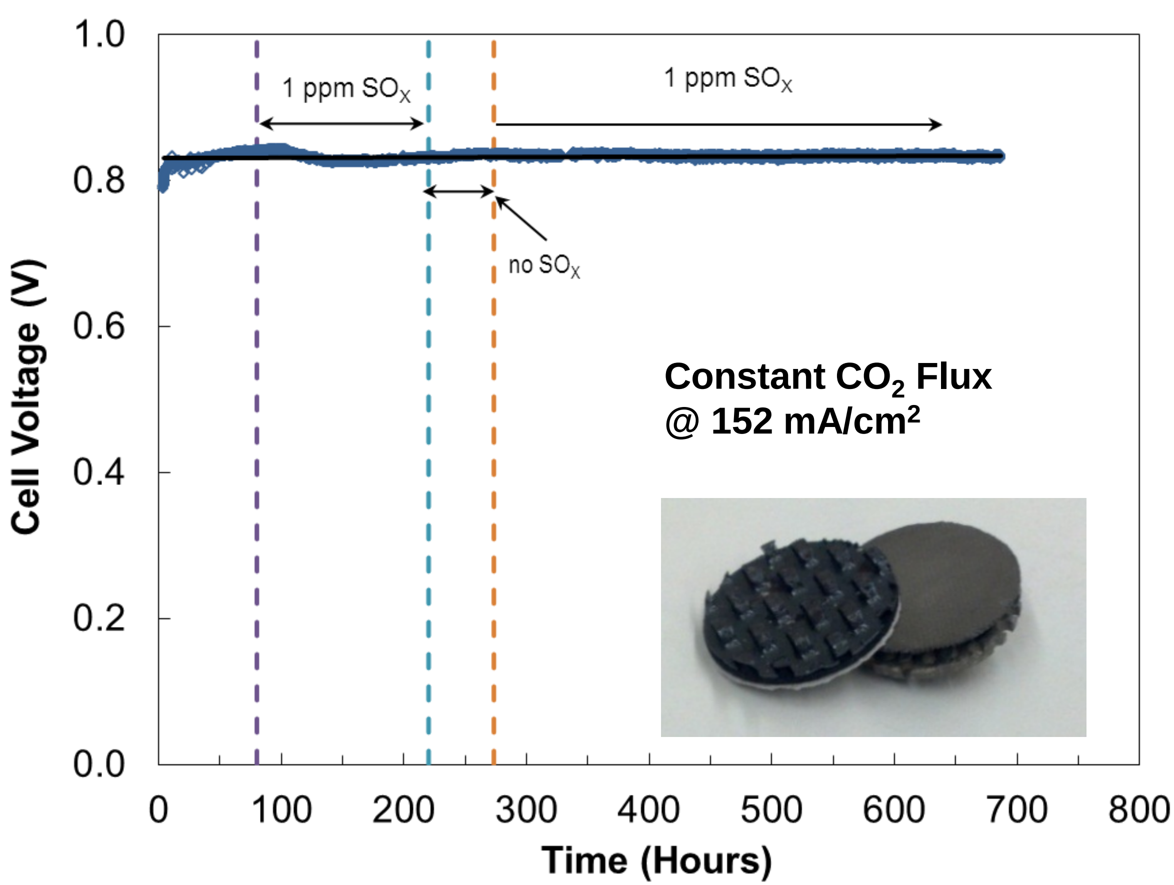
- Utilize ECM button cell tests to determine the effect of individual impurities on cell performance.
  - Maintain CO_2 flux
  - Measure ECM cell resistance and voltage
  - Analyze impurity effects on ECM using Electrochemical Impedance Spectroscopy (EIS)
- Perform post-test analyses using microscopy and surface analytical tools (SEM/EDS, TEM, FIB-SEM, AES, XPS, ToF-SIMS) to determine:
  - Nature of impurity-ECM interactions,
  - Presence of alteration phases formed from any reactions
  - Surface adsorption

Walk-in ventilated lab space and multiple work stations are used at PNNL

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

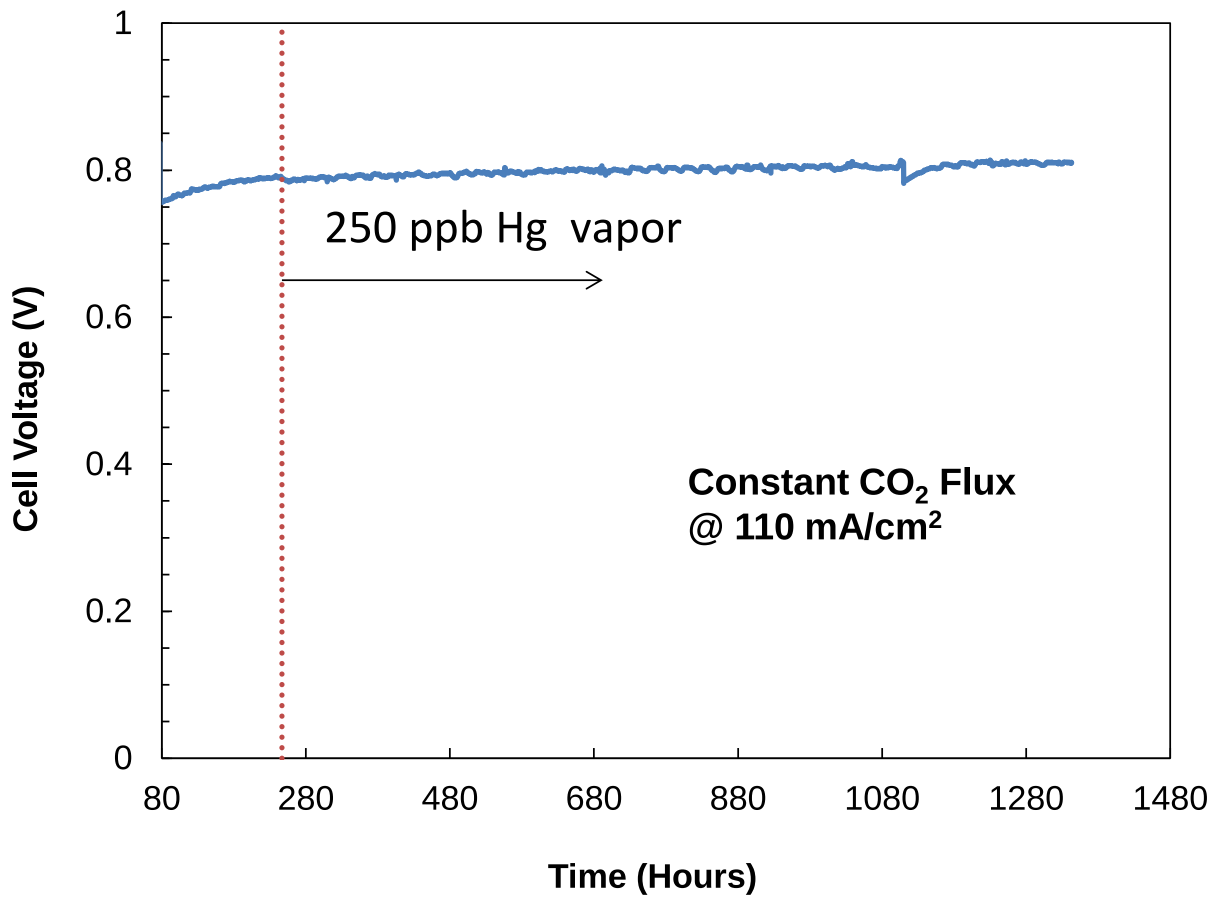
Pacific Northwest
NATIONAL LABORATORY

ECM Flue Gas Contaminant Tolerance: SO_2



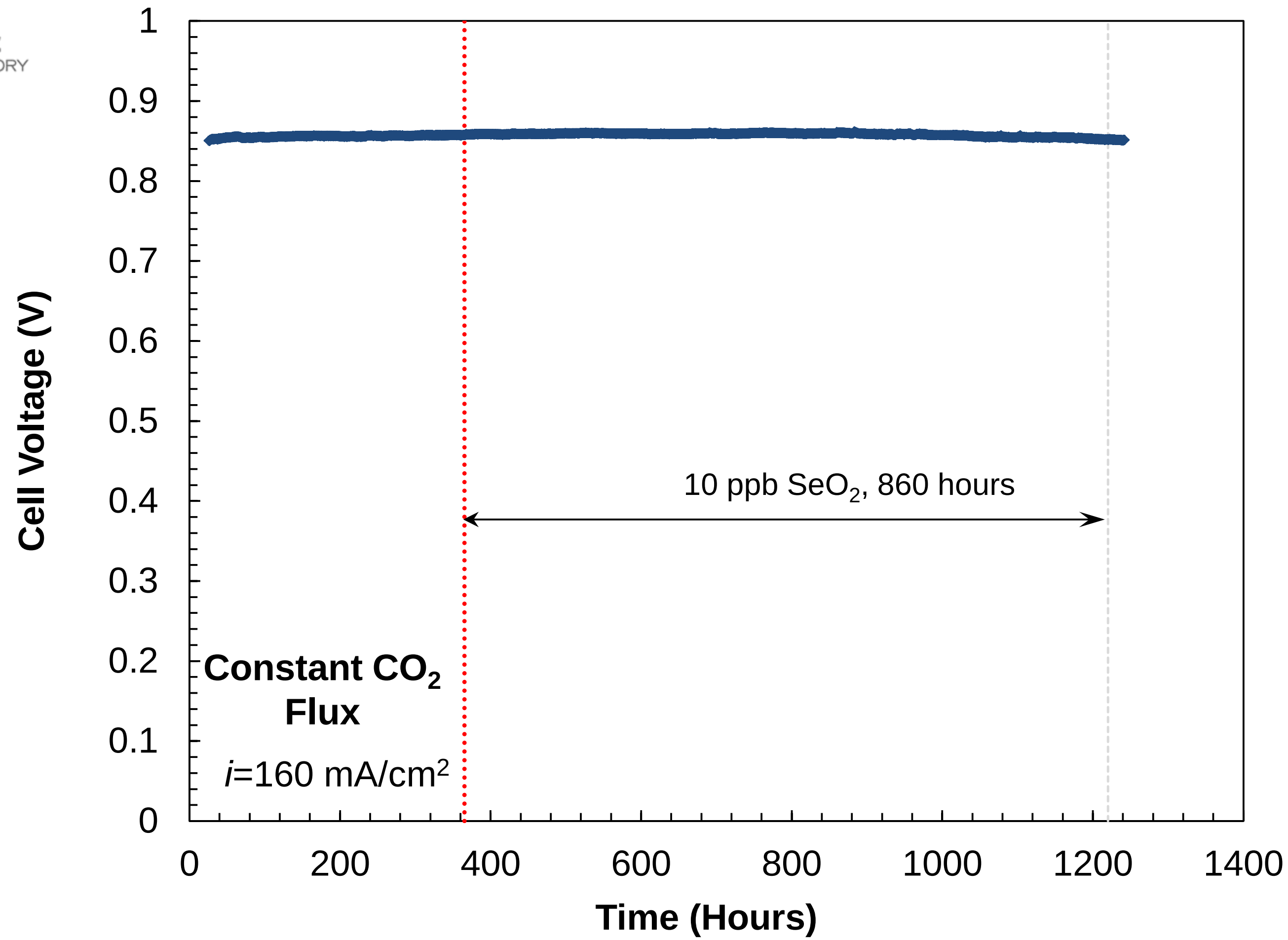
- Polishing equipment upstream of ECM reduces SO_2 concentration in the flue gas (cathode gas) to <1 ppm
- ECM stable operation has been verified with 0.4 - 1 ppm SO_2 in the cathode without significant performance loss in two 600+ hour tests

ECM Flue Gas Contaminant Tolerance: Hg



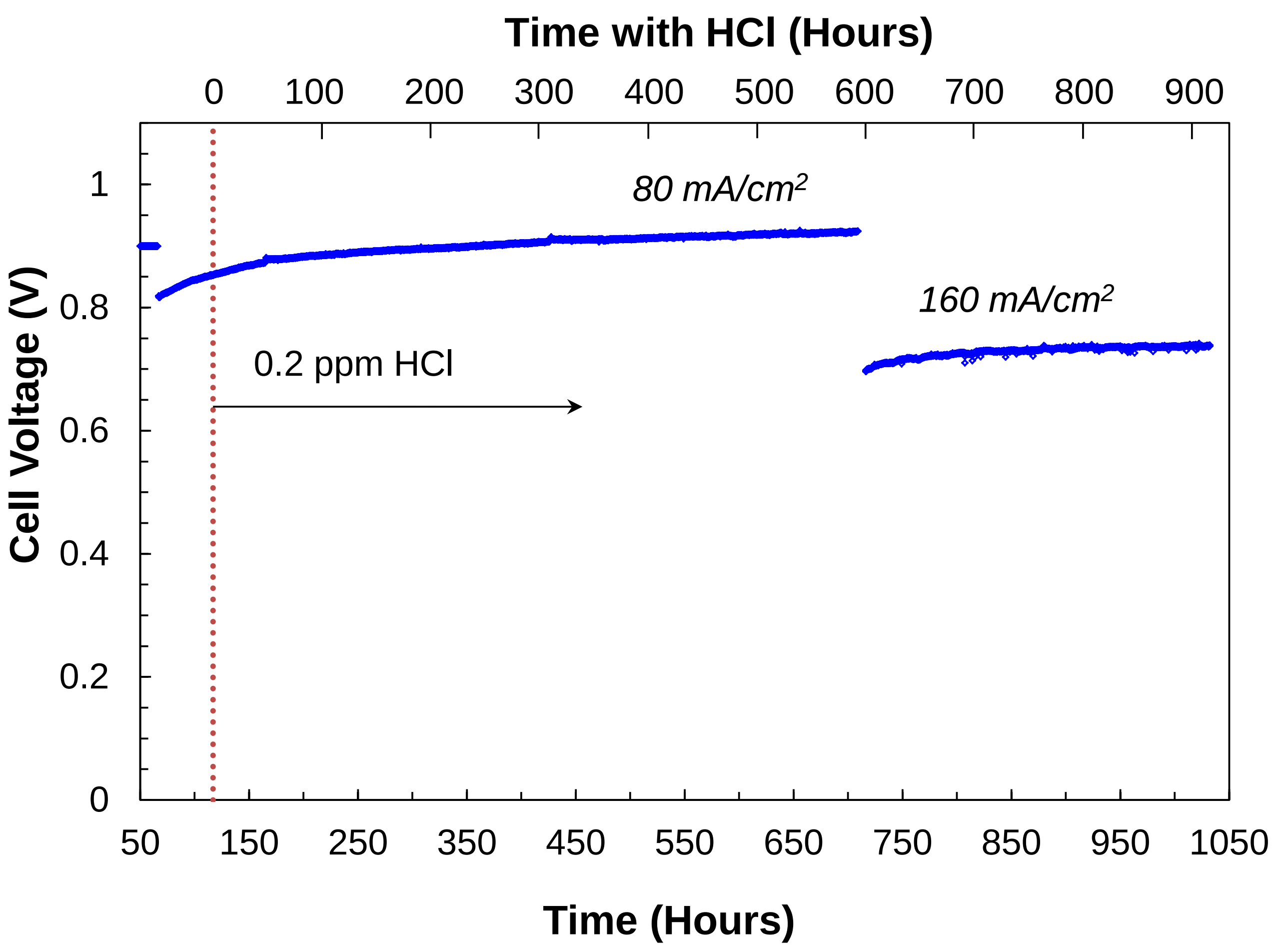
- Stable operation was observed with 250 ppb Hg in ECM cathode gas (500 times higher than typically present in coal plant flue gas) during ~1,100 hour test
- Test data analysis confirmed no accumulation of Hg in ECM components

ECM Flue Gas Contaminant Tolerance: Selenium



- ECM displayed stable operation with 10 ppb Selenium (20-30x higher than expected levels) for over 860 hours of exposure

ECM Flue Gas Contaminant Tolerance: Chlorine



- ECM displayed no performance loss with exposure to 200 ppb HCl (10-20x higher than expected levels) for over 900 hours

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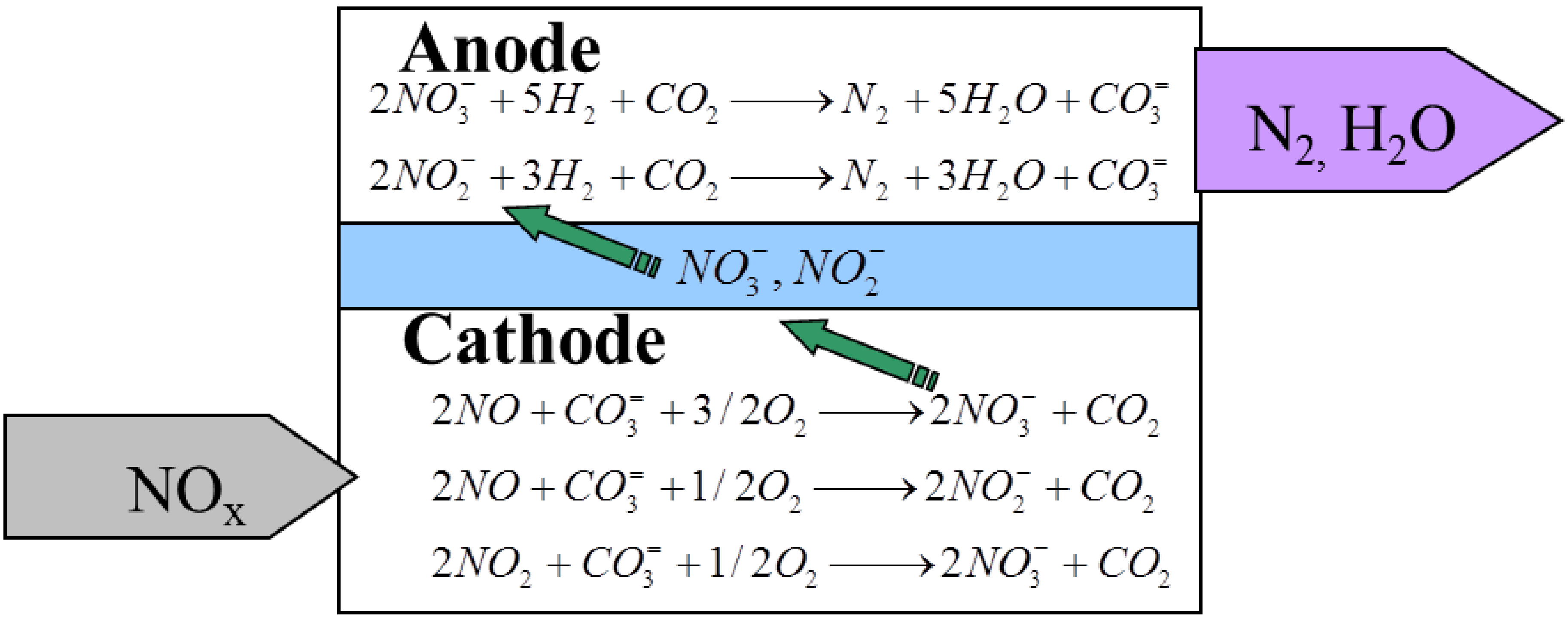
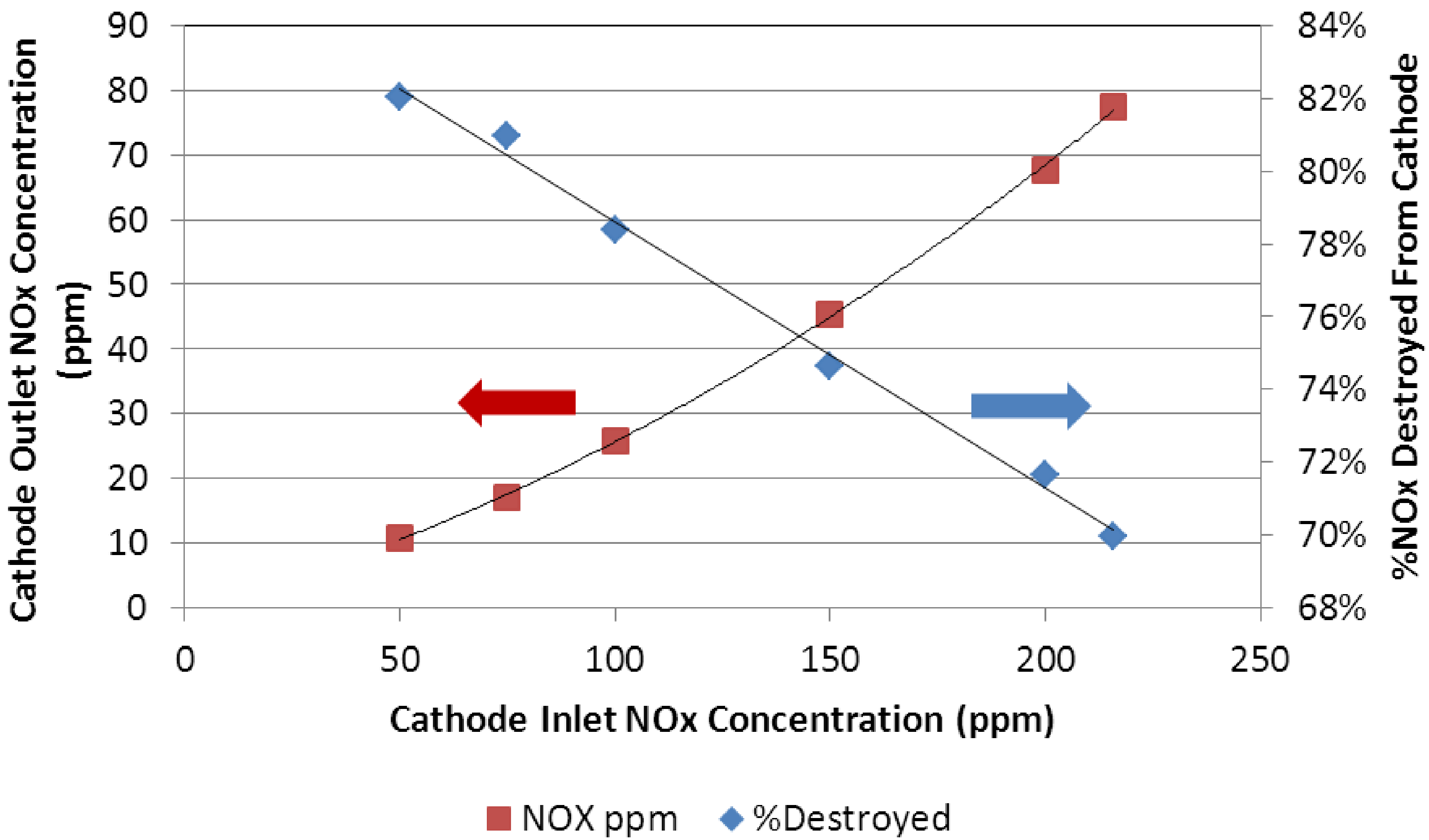
ECM NO_x Removal Mechanism

- Based on FCE's prior experience:
  - ECM materials are not expected to be degraded by NOx in flue gas
  - CEPACS system offers co-benefit of NOx reduction



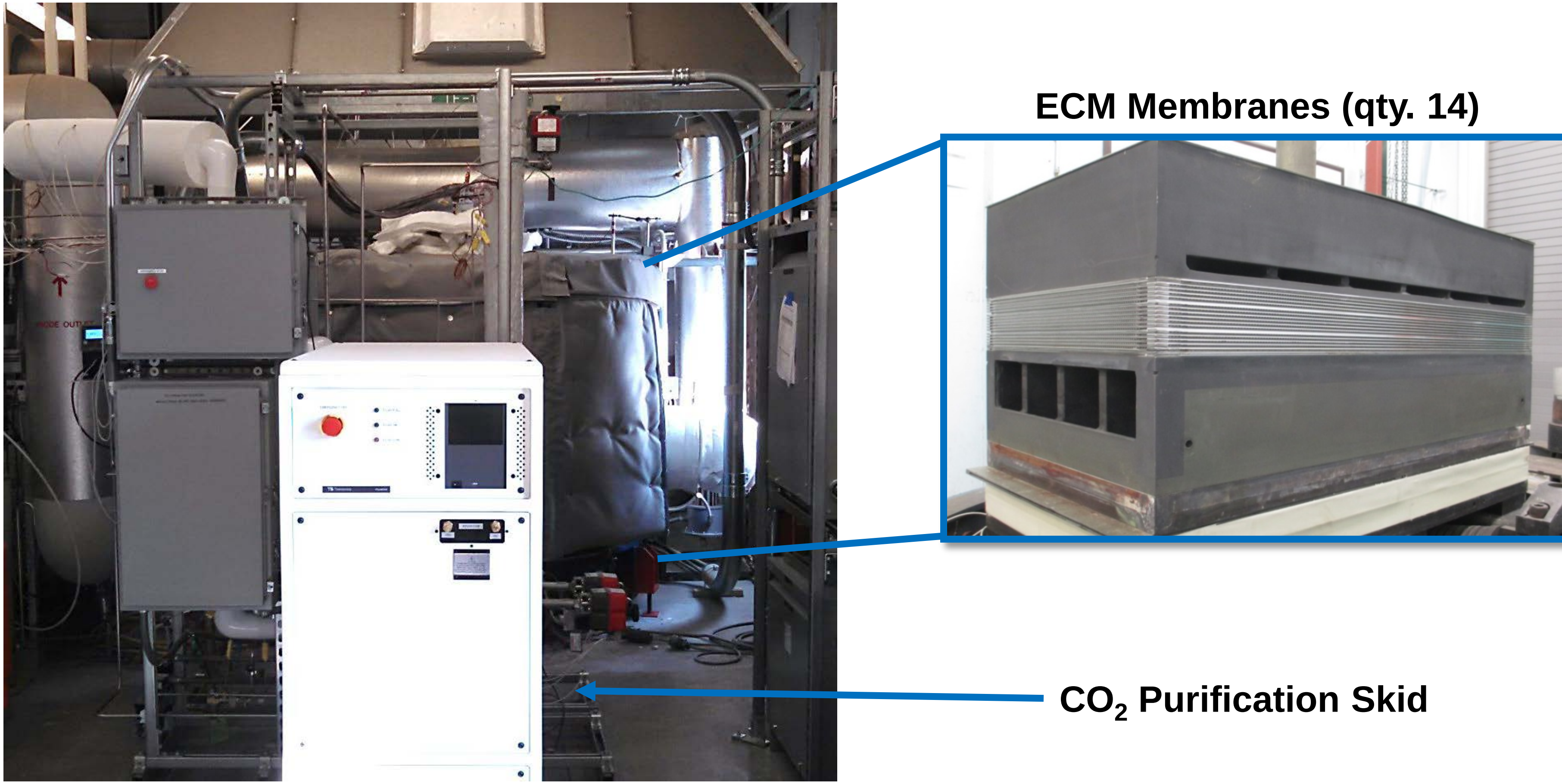
Reaction Mechanism by which NOx is removed from the Flue Gas (cathode-side), transferred to the anode-side along with CO_2, and subsequently destroyed

ECM NO_x Removal Capabilities



- ECM Capability for NO_x Destruction Remains > 70% at High Inlet NO_x Concentration (200 ppm) During Carbon Capture under System Conditions

Bench-Scale Demonstration System



CEPACS Demonstration system designed, assembled, and ready for testing

- 100 tons/year liquid CO_2 product
- Approximately 9 kW power production

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Accomplishments and Summary

- The Technical and Economic Feasibility Study (T&EFS) of a CEPACS system to separate 90% of CO_2 from the flue gas of a Reference Plant (550 MW PC) has verified:
  - Incremental cost of electricity (COE) of 35% and cost of CO_2 captured of $38/tonne CO_2 (2011 USD)
  - Excess water available for export
- Large-area ECM laboratory tests verified:
  - High CO_2 flux (>120 cc/m^2/s) while separating >90% of CO_2 from simulated PC or NGCC plant flue gas
  - Capability to destroy 70-80% of NO_x from flue gases
  - Stability of CO_2 flux as the membrane ages

Fuel Cell Manufacturing Facility, Torrington, CT

- Contaminants tests indicated ECM is stable in the presence of S, Se, Cl, and Hg levels expected from a conventional wet-FGD polisher
- The Technology Gap analysis indicated that available commercial equipment can be used in CEPACS system with no R&D needed for BOP
- ECM is suitable for a wide range of carbon capture applications: Enhanced oil recovery, SAGD Tar Sands, coal and natural gas power plants, and industrial sites (cement factory & refineries)
- Next step: Complete bench-scale CEPACS demonstration system for 100 tons/year carbon capture

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