Fourth Annual Conference on
Carbon Capture & Sequestration

***Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date***

# Combined Power Generation and Carbon Sequestration Using Direct FuelCell

**Hossein Ghezel-Ayagh, Robert Sanderson, Dilip Patel**

**and Mohammad Farooque**

**FuelCell Energy, Inc.**

**Danbury, CT**

FuelCell Energy

**May 2-5, 2005, Hilton Alexandria Mark Center, Alexandria Virginia**





# FuelCell Energy Profile

- Delivering commercial products now with advanced Direct FuelCell® technology
- Established strong commercial relationships with major companies in the U.S., Germany, Japan and Korea
- #1 high temperature stationary fuel cell manufacturer and developer including carbonate and solid oxide applications
- A leading fuel cell technology developer for over 30 years – over $450 million invested
- Headquarters in Danbury, CT
  Manufacturing in Torrington, CT
- Strong balance sheet with more than $230 million

FuelCell Energy

# FuelCell Energy Core Products : 250kW-10MW

DFC® 300

DFC® 1500

DFC® 3000

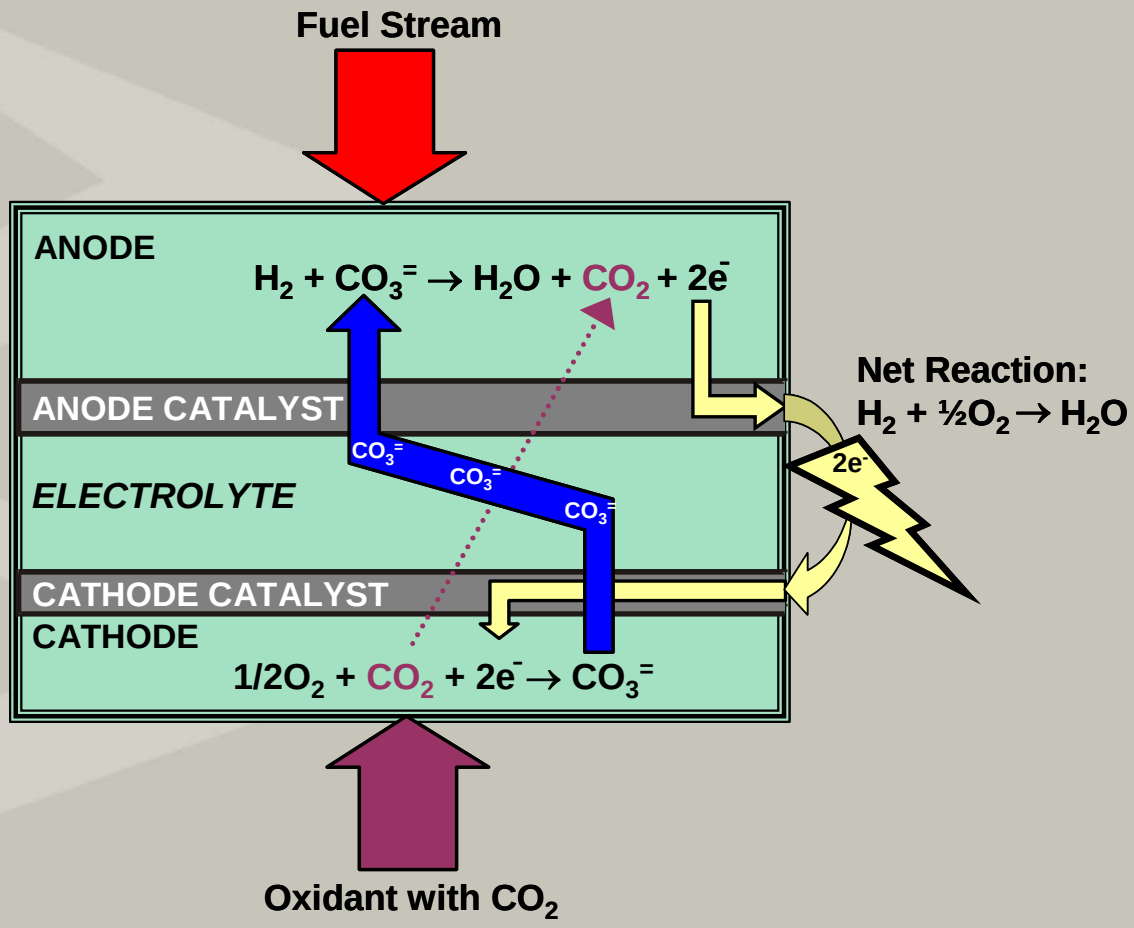
## Product Characteristics

- High temperature, high efficiency, carbonate fuel cell power plants for base load commercial and industrial applications
- High value waste heat by-product for cogeneration
- Internally generated hydrogen from readily available fuels such as natural gas –***operating at customer sites today***
- Certifications for product safety, interconnection, performance and installation
- Meeting current customer expectations

Multi-MW Grid Support

FuelCell Energy

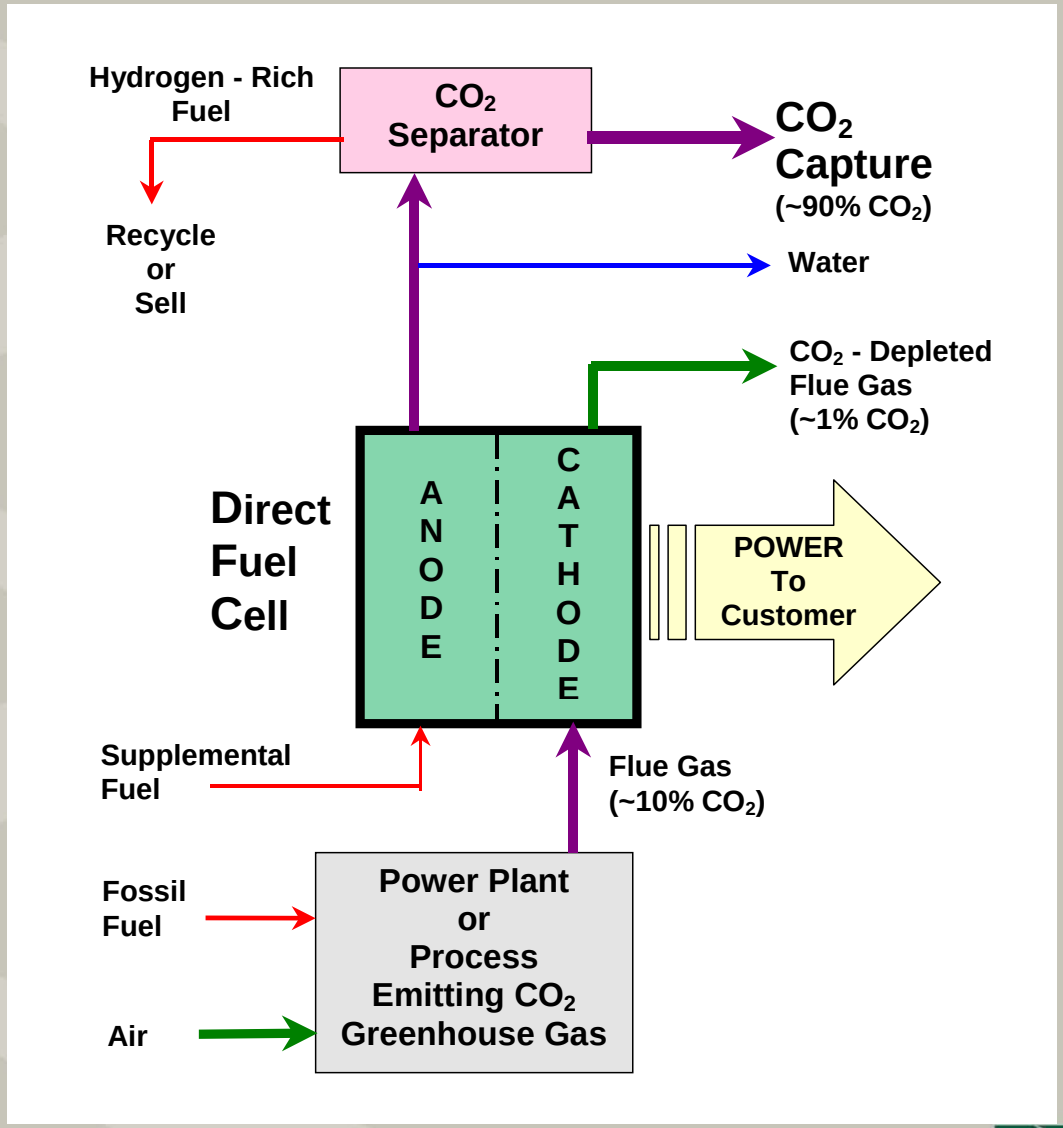
# $CO_2$ Transfer Mechanism in Direct FuelCell (DFC)




**Carbon Dioxide is transferred from cathode to anode via carbonate ions.**

FuelCell Energy

# DFC-Based $CO_2$ Sequestration System Concept




FuelCell Energy

# DFC-Based $CO_2$ Separation System

**Objectives:**

- **Cost-effective carbon dioxide separation systems utilizing Direct FuelCell technology**
- **Separation of at least 90% of carbon dioxide from the greenhouse gases (GHG) generated by coal fired power plants**
- **Less than 10% increase in the cost of energy services for long-term deployment**

FuelCell Energy

# Ongoing R&D Activities

- Develop System Design Configurations
- Perform Process Simulation including Mass and Energy Balances
- Conduct Fuel Cell Tests using Simulated Greenhouse Gas
- Identify Equipment Requirements and Specifications
- Perform Economic Analysis

FuelCell Energy

# Plant Design Basis

- System designed for carbon dioxide removal from 200MW (nominal) coal fueled power plant exhaust
- Types of coal fired plants under study:
  - Pulverized Coal (PC) Steam Cycle Plant
  - Integrated (coal) Gasification Combined Cycle (IGCC) Power Plant
  - Atmospheric Circulating Fluidized Bed (ACFB) Boiler Steam Cycle Plant

# Coal Fueled Power Plant Exhaust Streams (From Database Compiled)

| | Pulverized Coal Boiler Steam Cycle Plant [1] | Atmospheric Circulating Fluidized Bed Boiler Steam Cycle Plant [2] | Integrated (coal) Gasification Combined Cycle Power Plant [2] | |
|---|---|---|---|---|
| | | | Existing Plant | Commercially Offered Future Plant |
| **Gas Composition (mole %)** | | | | |
| $CO_2$ | 12.06 | 14.40 | 7.49 | 7.85 |
| $O_2$ | 4.47 | 3.32 | 11.95 | 11.76 |
| $N_2$ + Ar | 70.32 | 74.81 | 65.73 | 72.55 |
| $H_2O$ | 13.13 | 7.45 | 14.84 | 7.83 |
| **Temperature (deg F)** | 129 | 291 | 280 | 280 |
| **Pressure (psia)** | 14.7 | 14.7 | 14.7 | 14.7 |
| **Flow Rate (lbmole/h)*** | 69,269 | 63,032 | 100,563 | 115,573 |

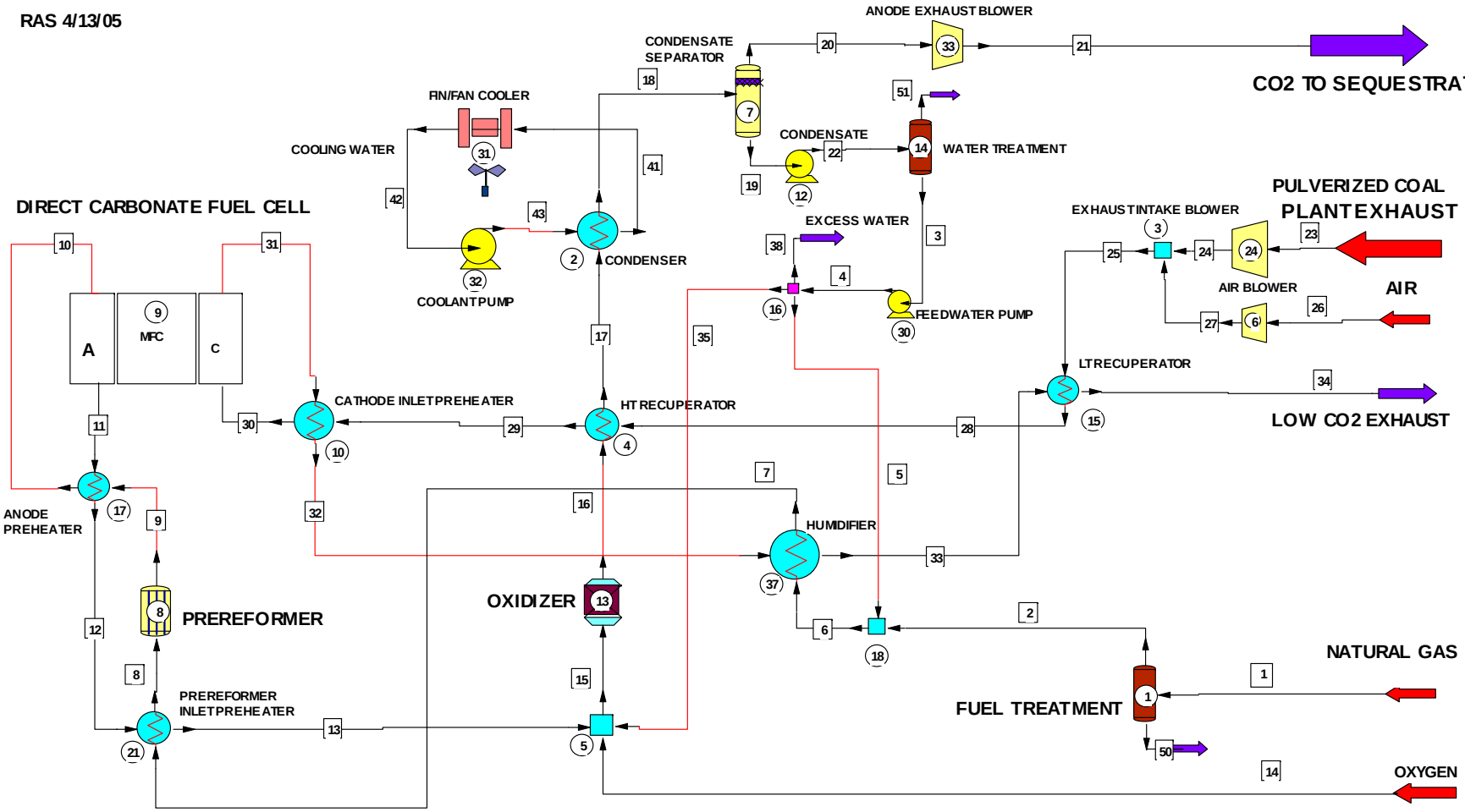
*** Scaled to 200 MW net plant size**


**[1] E. Parsons (NETL) and W. Shelton (EG&G), "Advanced Fossil Power Systems Comparison Study," Final Report, Dec 2002, Prepared for: National Energy Technology Laboratory (NETL)**

**[2] "Greenhouse Gas Emissions Control by Oxygen Firing in Circulating Fluidized Bed Boilers: Phase I – A Preliminary Systems Evaluation," Final Report (Volume I), May 2003, Prepared for: National Energy Technology Laboratory, By: Alstom Power, Inc., Windsor, CT**


FuelCell Energy

# DFC System Process Flow Sheet (Baseline Configuration)




FuelCell Energy

# $CO_2$ Separation by DFC-Based System

**DFC-based system is very effective in separating $CO_2$ from greenhouse gases**

| | Gas Compositions (mole%) | | |
|---|---|---|---|
| | PC Plant Flue Gas (GHG) | Plant Exhaust Using DFC System | Stream to Sequestration |
| CO2 | 12.1 | 1.0 | 88.8 |
| H2O | 13.1 | 11.4 | 9.1 |
| N2+Ar | 70.3 | 82.6 | 1.0 |
| O2 | 4.5 | 5.0 | 1.2 |

# DFC System Performance Summary

**DFC system has shown excellent performance in separation of carbon dioxide in the study of various types of coal fueled power plants**

| PLANT TYPE | Net Power MW | | CO2 to Environment lbs/MWhr | |
|---|---|---|---|---|
| | w/o DFC | with DFC | w/o DFC | with DFC |
| Pulverized Coal (PC) Steam Plant | 200 | 341 | 1838 | 108 |
| ACFB Steam Plant | 200 | 353 | 1997 | 113 |
| IGCC Plant | 200 | 327 | 1657 | 101 |

**DFC provides additional power**

**~ 90% $CO_2$ separation from the greenhouse gas**

FuelCell Energy

# Anode Exhaust Post-Treatment Options

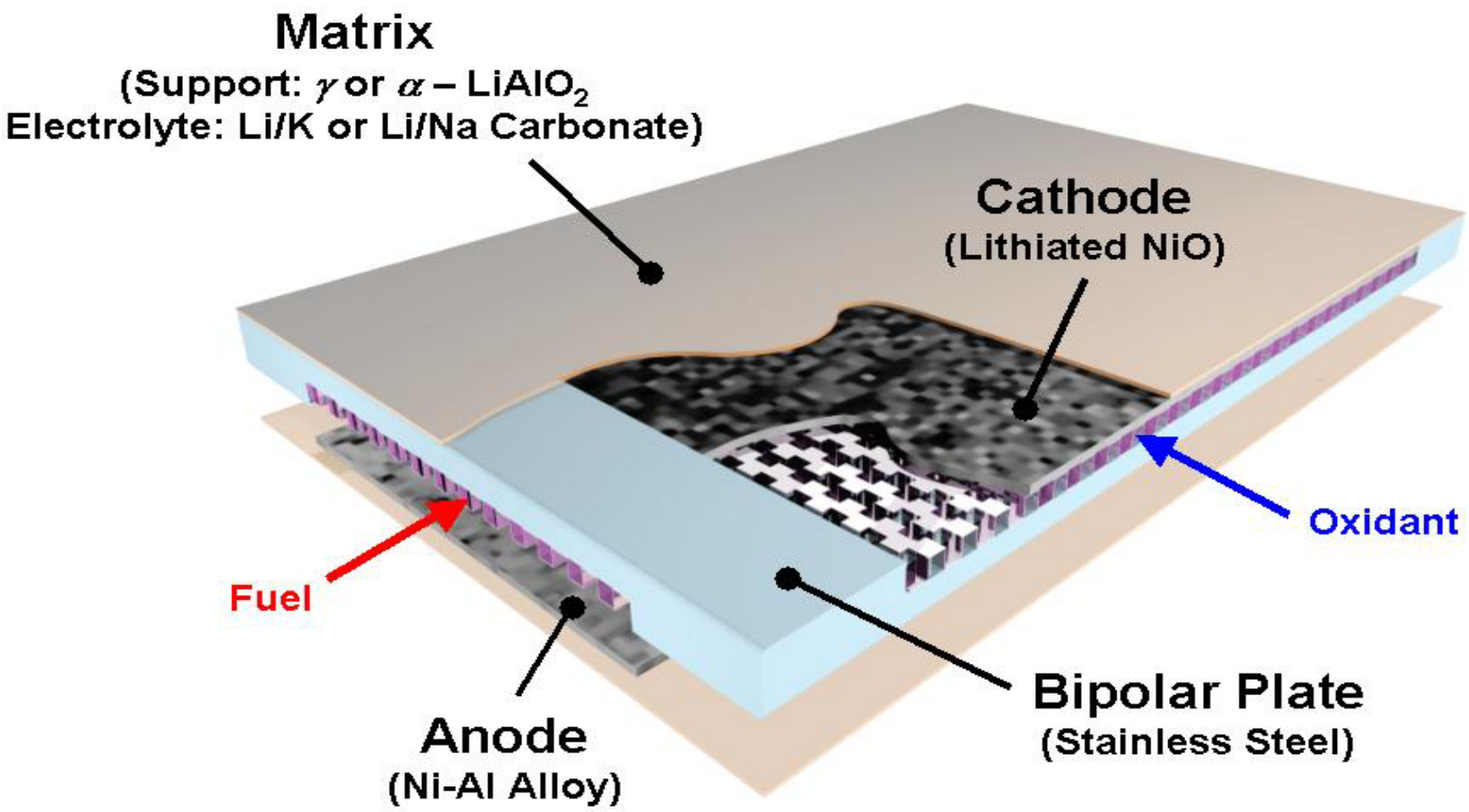
- **Design of water condensation**
- **Utilization of hydrogen at the site:**
  - Recycle as power plant fuel
  - Oxidation for heat recovery
- **Recovery of hydrogen as byproduct:**
  - Pressure swing adsorption (PSA)
  - Electrochemical separations (hydrogen pump)

# Fuel Cell Tests

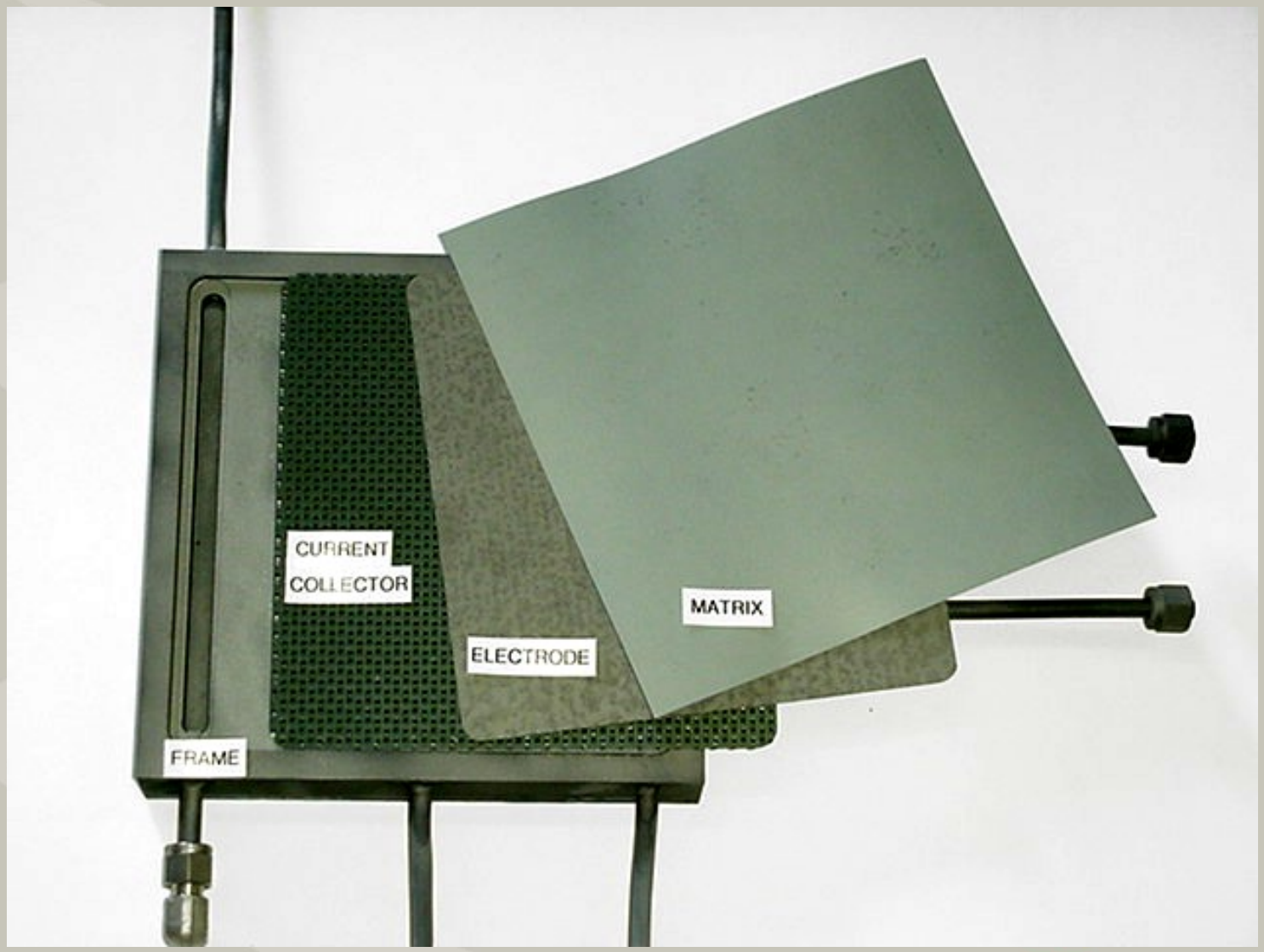
- Support system design task
- Perform tests of a lab-scale fuel cell
- Conduct tests with simulated GHG compositions as fuel cell cathode gas
  - Characterize fuel cell performance
- Optimize fuel cell performance for $CO_2$ transfer to anode
- Perform detailed data analysis
  - Utilize to improve the computer model by revising the fuel cell performance characteristics

FuelCell Energy

# Single Cell Schematic



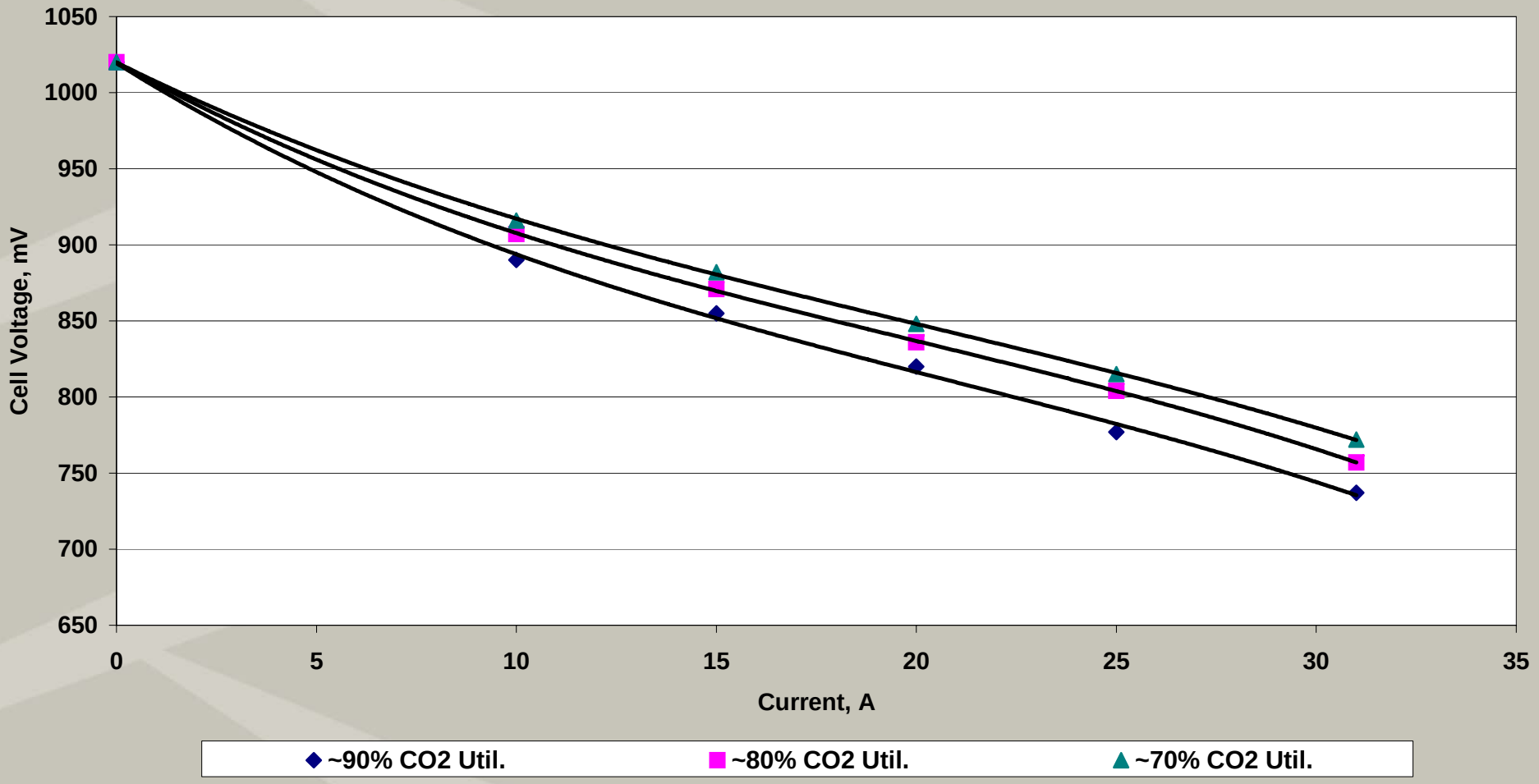
# Lab-Scale Fuel Cell Components




FuelCell Energy

# Fuel Cell Test Results

## Fuel Cell Performance on Simulated PC Boiler Exhaust Gas




FuelCell Energy

# Summary

- The Direct FuelCell technology offers a unique and attractive alternative for $CO_2$ sequestration
- The R&D efforts are focused on applications with greater needs for GHG mitigation (coal fired plants)
- DFC based sequestration system cost is expected to be low due to the on-going commercialization of the technology and high volume manufacturing for power plant applications
- Results of the fuel cell tests with simulated PC plant flue gas have verified the potential application of the Direct FuelCell technology for carbon dioxide separation

# Acknowledgement


- This research and development program is performed as a FCE cost-shared project supported by the US Department of Energy through the National Energy Technology Laboratory (NETL) under the Award No. DE-FC26-04NT42206.
- The DOE Contracting Officer's Representative is Mr. David A. Lang of NETL.