Fuel Cell Based Carbon Capture

April 19, 2017

fuelcellenergy

- >50 sites operating on 3 continents
- > 5 billion kWh's ultra-clean power generated
- Global manufacturing
- Robust intellectual property portfolio

Design & Manufacture

Project Development

Turn-key Project Delivery

Plant Operation

Energy **Supply**

$22 billion estimated market

Micro-grid CHP

Utility Grid Support

Distributed Hydrogen Tri-Gen

Energy **Recovery**

$28+ billion estimated market

Coal   Gas
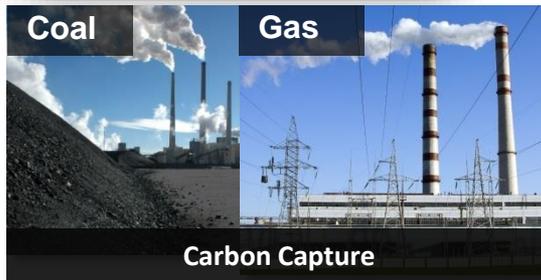
Carbon Capture

Gas Pipeline

H₂ Recovery *(EHS)*

Energy **Storage**

Tens of $ billions of estimated market
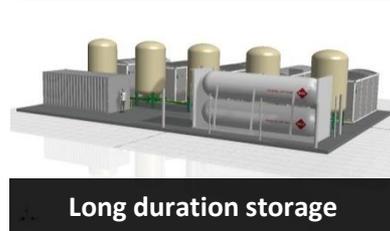
Long duration storage

Power-to-Gas

NASDAQ: FCEL
www.fuelcellenergy.com

N. America

Europe

Asia

Strategic Investors

POSCO ENERGY — Largest IPP in S. Korea, Owns 6% FCEL stock

nrg — Largest IPP in USA, Owns 3% FCEL stock

Finance Providers

nrg — Extends $40 million project finance facility

Manufacturing: Connecticut, USA; Global sales and service

**Individual fuel cell
&
350 kW fuel cell stack**

**Four-Stack Module
1.4 megawatts**

**Completed module
1.4 megawatts**

**1.4 MW
SureSource1500®**
- *Utilizes one module*
- *47% Electrical Eff, up to 90% Total Eff.*

**2.8 MW
SureSource3000®**
- *Utilizes two modules*
- *47% Electrical Eff, up to 90% Total Eff.*

**3.7 MW
SureSource4000®**
- *Utilizes three modules*
- *60% Electrical Eff. Up to 80% total Eff*

**59MW fuel
cell park**

SureSource Fuel Cell Principle

Hydrocarbon Fuel

Steam

INTERNAL REFORMING
$$CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$$

ANODE
$$4H_2 + 4CO_3^= \rightarrow 4H_2O + 4CO_2 + 8e^-$$

CATALYST

ELECTROLYTE

CATALYST

CATHODE
$$2O_2 + 4CO_2 + 8e^- \rightarrow 4CO_3^=$$

Air
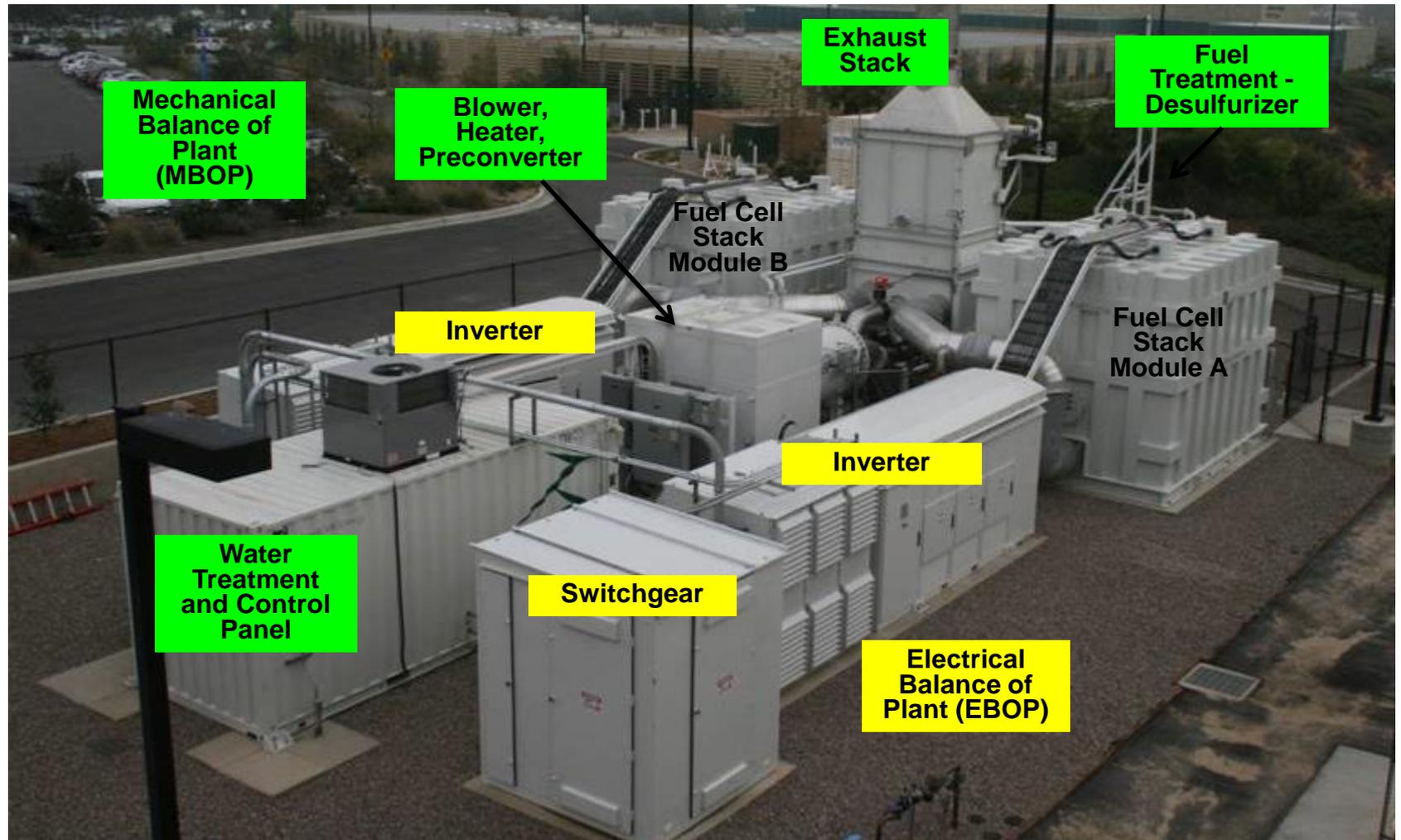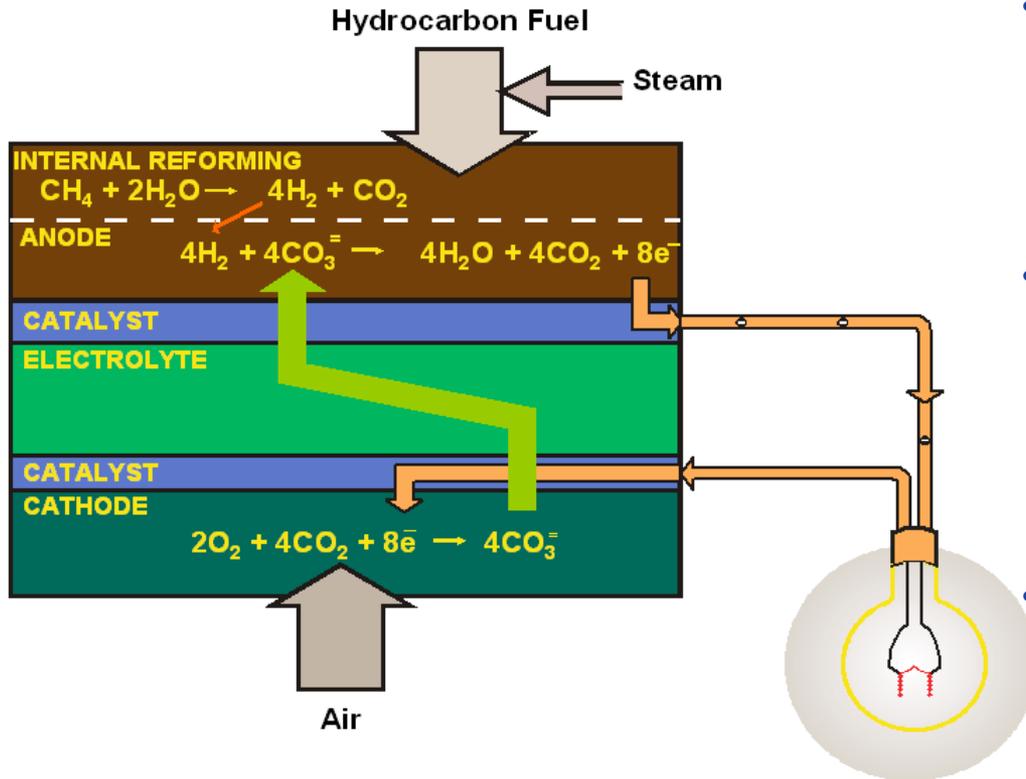
- SureSource carbonate fuel cell electrochemistry involves transfer of CO_2 from cathode (air electrode) to anode (fuel electrode)

- This aspect can be exploited to use carbonate stack for CO_2 separation, with concentration in anode gas allowing for easy capture and use or sequestration

- Additional benefits: NOX destruction and water production

Fuel Cell CO_2 capture uses the same electrochemical process at work in more than 100 powerplants operating around the world

- **Carbonate electrochemical process transfers CO_2 from Air Electrode (Cathode) to Fuel Electrode (Anode)**

- **CO_2 is easily separated from Anode exhaust gas because it is no longer diluted with air**

Clean Power

CATHODE

ANODE

Fossil Plant Exhaust with 5% to 15% CO_2

CO_2

Fuel

CO_2 Depleted Flue Gas

Depleted Fuel with ~70% CO_2

CO_2 Separation

Conventional Coal or Natural Gas Plant

Natural Gas Fuel to Fuel Cell

SureSource Powerplant
30 to 75% of Conventional Plant Rating

CO_2 to sequestration or industrial use
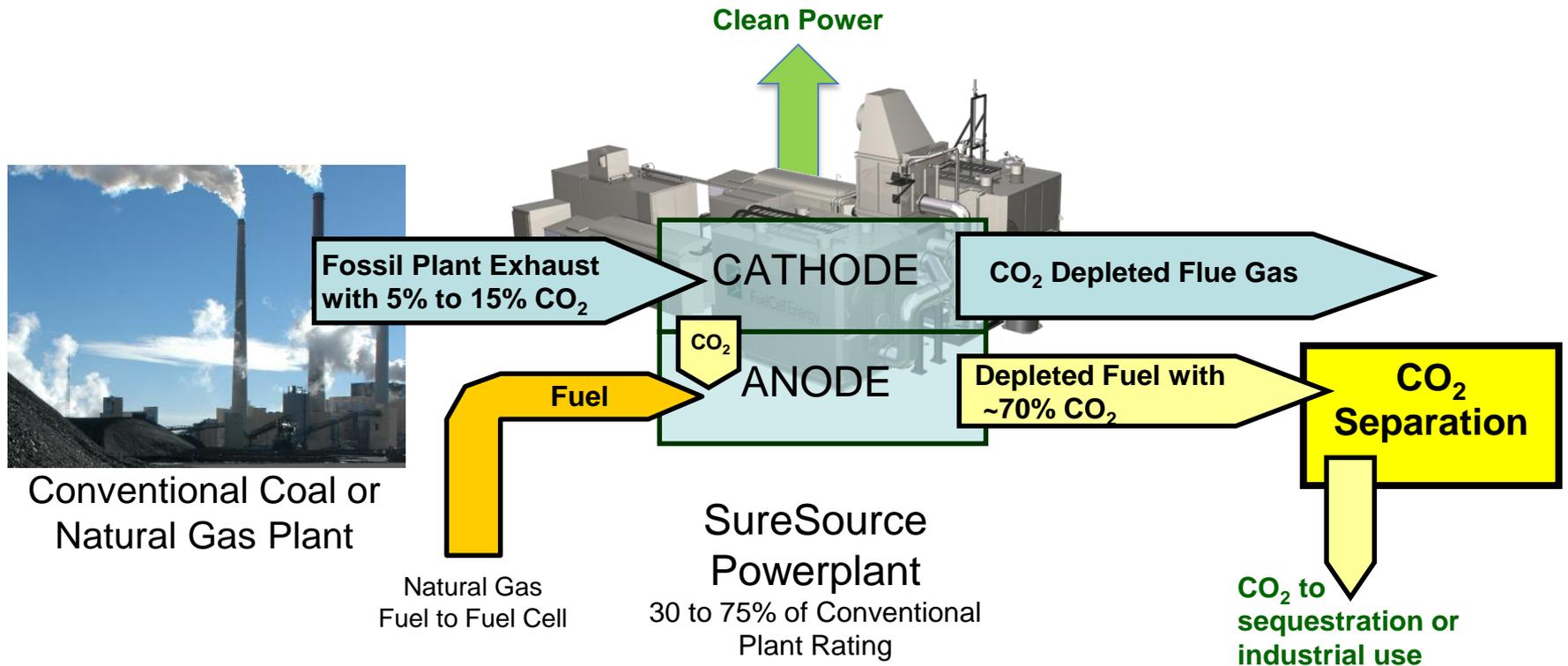
CO_2 is concentrated by fuel cell process as a side reaction of power generation. Co-production of power during carbon capture enhances capture economics

- **Large-scale CC from coal-fired plants**
  - Ultimate objective of DOE-supported development

- **CC from distributed natural gas plants**
  - Provide low-carbon baseload or peaking Plants.

- **CC from industrial processes**
  - Reduced carbon footprint from processes such as cement production

- **CC and Enhanced Oil Recovery (EOR)**
  - On-site generation from associated gas with CO_2 capture for EOR

- **DOE funded project to demonstrate capture from coal power generation**

- **Opportunity to use pilot to demonstrate natural gas capture under ExxonMobil Joint Development program**

- **Southern selected Plant Barry as best site choice**
  - Coal and natural gas power generation
  - Plot space availability
  - Existing flue connection supporting past carbon capture projects
  - Supportive management and staff

- **Project will be single SureSource 3000-based capture system**
 - 90% capture from 3MW of coal exhaust

James M. Barry Electric Generating Station Alabama Power/Southern Co.
- **Location**: Bucks, AL
- **Nameplate Capacity:** >2 GW
- **Fuel:** Mix of Coal and Natural gas

Large Scale Coal Capture System

- **4.9 Million tons of CO_2 capture per year**

- Future system specifically designed for 90% CO_2 capture from large scale coal plants

- 350 MW carbonate-based system would capture 90% of CO_2 from 550MW plant

- 2.6 GWh ultra-clean power generated per year

- Cost of CO_2 capture in low power value coal regions targeted to meet DOE goal of less than $40/ton, or less than $0.02/kWh. Cost of capture is significantly less in high power cost areas, where higher power value drives additional revenue to project
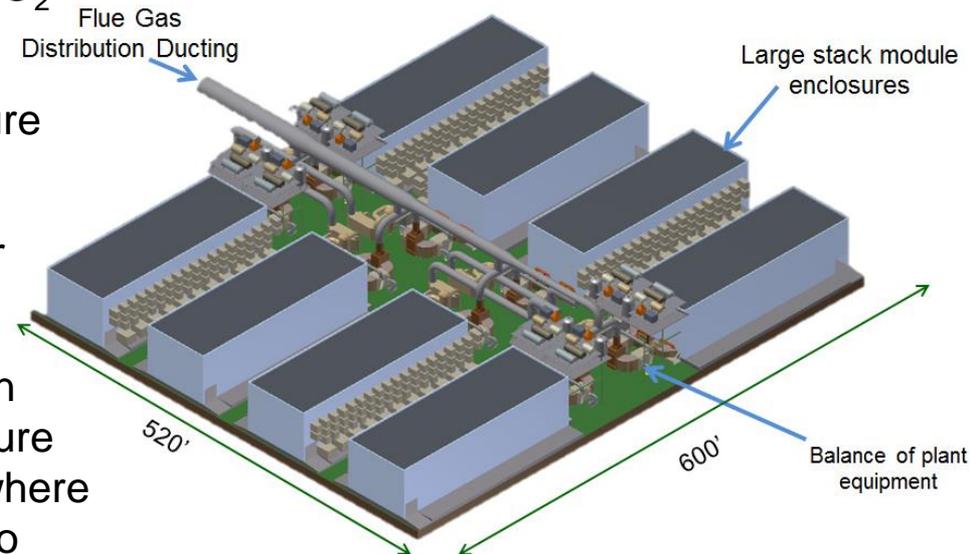
Future long term development for 90% capture of CO2 from large coal power plants

- **Carbon Capture Fuel Cell Farm with 12 SureSource 3000^{tm}-based capture systems**
    - 18 MW at 90% capture (500 tons/day from coal flue plus 200 tons/day from fuel cell ng)
- **3 acres total site**
- **Potential to expand incrementally as needed**

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Fuel Cell Carbon Capture Summary

- **Utilizes commercially proven fuel cell technology with modified balance of plant systems**
- **Modular and lower cost, enhanced economics from power co-production**
- **Additional benefits of NOX destruction and water production**
- **Invented in America, Manufactured in America**
- **DOE-supported program builds on earlier DOE support for core fuel cell technology**

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Guidance from NETL team: José Figueroa, Elaine Everitt, Lynn Brickett, John Litynski, and others at NETL/DOE