9TH Annual SECA Workshop
Clean Economic Energy in a Carbon Challenged World

Wayne A. Surdoval
Technology Manager, Fuel Cells
Strategic Center for Coal
United States Department of Energy
FY 08 Fossil Energy Fuel Cell Program (SECA)

SECA
FY 09......$60,000,000

SECA Cost Reduction
Industry

SECA Coal Based Systems
Industry

National Laboratories

Universities,
Small Business

Request
Appropriation

<table>
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<th>Year</th>
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DOE’s Office of Fossil Energy
Advanced (Coal) Power Systems Goals

- **2010:**
  - 45-50% Efficiency (HHV)
  - 99% SO₂ removal
  - NOₓ< 0.01 lb/MM Btu
  - 90% Hg removal

- **2012:**
  - 90% CO₂ capture
  - <10% increase in COE with carbon sequestration

- **2015**
  - Multi-product capability (e.g., power + H₂)
  - 60% efficiency (measured without carbon capture)
Solid State Energy Conversion Alliance (SECA) 

Goals

- Stack Cost ~ $100/kW stack
- Capital Cost < 400/kW system

Maintain Economic Power Density with Increased Scale ~ 300mW/cm²

Mass customization – stacks used in multiple applications....large and small systems

Ref: 2002
How Big are the U.S. Markets?
Coal

SECA Fuel Cells available for installation in 2018
New Coal Capacity, 2018 – 2030……110 GW
Average SECA Fuel Cell Production ….. 9.2 GW/yr

EIA Annual Energy Outlook (AEO) for 2007 pp. 82-83
How Big are the U.S. Markets? Overnight Trucks

New Retail Truck Sales Class 8
Transportation Energy Data Book - Edition 26-2007 Table 5.3

Average Size of a Truck APU – 5kW
Average Annual Production – 200,000 units
Average SECA Fuel Cell Production… 1 GW/yr
SECA Fuel Cells in DOD Applications

- DOD Requirements
  - Extend mission length
  - Quiet
  - Combined functions – power, heat and water
  - **Volume and weight**
    - Operate with High Specific Energy Fuels – Liquids

- DOE’s power density targets (based on cost) minimize stack size and volume to diminishing returns. Specialized DOD designs will not increase gains.

- Further size and weight improvements – Focus on the Balance of Plant
Atoms for Peace
1953

October 22, 1953:
The Atomic Energy Commission announces that an AEC-owned demonstration power plant of 60 MW will be built at Shippingport, PA, jointly by Westinghouse Electric Corporation and Pittsburgh’s Duquesne Light Company under the direction of the U.S. Navy/AEC Naval Reactors Branch.

The more important responsibility of this atomic energy agency would be to devise methods whereby this fissionable material would be allocated to serve the peaceful pursuits of mankind. Experts would be mobilized to apply atomic energy to the needs of agriculture, medicine and other peaceful activities. A special purpose would be to provide abundant electrical energy in the power-starved areas of the world.

Dwight D. Eisenhower,
President of the United States of America,
to the 470th Plenary Meeting of the United Nations General Assembly
Tuesday, 8 December 1953

Photograph of the Shippingport Atomic Power Station in Shippingport, Pennsylvania, the first full-scale nuclear power generating station in the United States which began operating in 1957.
Clean Coal Power Initiative

"More than half of the electricity generated in America today comes from coal. If we weren't blessed with this natural resource, we would face even greater [energy] shortages and higher prices today. Yet, coal presents an environmental challenge. So our plan funds research into new, clean coal technologies."

President George W. Bush

May 17, 2001

"...we're creating the National Climate Change Technology Initiative...to fund demonstration projects for cutting-edge technologies, such as fuel cells."

President George W. Bush

June 11, 2001
Solid State Energy conversion Alliance (SECA)
Fuel Cells Technology Timeline


SECA R&D: Technology Solutions and Enabling Technology

SECA Cost Reduction: Validation test, Validation test

SECA Coal Based Systems: Operate Single Module (1 MW) Scale, Operate Multiple Module (5 MW) Scale with Turbines

SECA Manufacturing: $400/kW (Ref: 2002), 250 – 500 MW IGFC

Coal-Based Fuel Cell Objective
## Impact of Efficiency on COE

<table>
<thead>
<tr>
<th>Advanced Power Systems</th>
<th>With CO2 Capture, Compression and Storage</th>
</tr>
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<tbody>
<tr>
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<td>PC Baseline</td>
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<tr>
<td>Efficiency HHV (%)</td>
<td>27.2</td>
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<tr>
<td>Capital Cost $/kW</td>
<td>2,870</td>
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<tr>
<td>Steam Cycle % Power</td>
<td>100</td>
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<tr>
<td>Cost-of-Electricity $/kW-hr</td>
<td>11.6</td>
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</table>
SECA Coal Based Systems (IGFC)
Reduced Water Requirement
> 99% Carbon Capture

- Atmospheric SOFC with conventional coal gasification
- Separate Fuel and Air Streams > 99% CO₂ Capture
- Steam cycle – reduced external water requirement
- Cycle Efficiency (HHV)
  - ~42% with CO₂ Compression
  - ~46% w/out CO₂ Compression

• Coal
   • Air Separation
   • Gasification
   • Gas Cleaning
   • Sulfur Recovery
   • Marketable Ash/Slag By-product
   • Marketable Sulfur By-product

• CO₂, CO, H₂, H₂O
• CO₂, CO, H₂, H₂O
• Anode
• Cathode
• Atmospheric SOFC
• Heat Recovery e.g., Steam Turbine

• CO₂
• CH₄

• CO₂
• CH₄
• H₂O

• Enhanced Oil Recovery
• Unmineable Coal Beds
• Deep Saline Aquifer
• Depleted Oil & Gas Reservoirs
Advanced SECA Coal Based Systems
Minimal Water Requirement
> 99% Carbon Capture

- Pressurized SOFC with catalytic coal gasification
- Separate Fuel and Air Streams
- No steam cycle – minimal external water requirement
- Cycle Efficiency (HHV)
  - ~56% with CO2 Compression
  - ~60% w/out CO2 Compression
Integrated Gasification Fuel Cell (IGFC)

System Efficiencies

- Plant Eff (% HHV)
- Rectifier Eff Increased from 96% to 98%

- CO2 compression
- w/o CO2 compression

- conv. IGCC
- IGFC BASE Cat. Gasifier (28%)
- HT Cell (1000°C cathode/325°C)
- Utilization: 70% (28%)
- Dry gas cleaning (DGC) (10%)
- TRIG gasifier (3.0%)
- TRIG, DGC (3.2%)
- BGL gasifier, DGC (1.8%)
- Am-SOFC (28%)
- Atm-SOFC, HT cell (28%)
- TRIG, Atm-SOFC (10%)
- Am-SOFC: 70% util, DGC, no CO2 (30%)
- Atm-SOFC, 70% util, DGC, recycle, DGC (28.7%)
- Reduced CH4, Atm SOFC, recycle, DGC (19.5%)
- TRIG, Am-SOFC, Recycle, DGC, 2-Stage Meth (19.3%)
- TRIG, Am-SOFC, Recycle, DGC, 3-Stage Meth (17.1%)
- TRIG, Am-SOFC, Recycle, DGC, 3-Stage Meth (17.5%)
System includes 100% carbon capture and CO\textsubscript{2} compression to 2,215 psia

System includes 90% carbon capture and CO\textsubscript{2} compression to 2,215 psia

- Higher fuel cell cycle efficiency reduces water use per unit of coal feed
- Separate fuel and oxidant streams in fuel cell permits use of substantially less cooling water to condense, recycle and reuse process H\textsubscript{2}O

From NETL Bituminous Baseline Study

1 System includes 100% carbon capture and CO\textsubscript{2} compression to 2,215 psia
2 System includes 90% carbon capture and CO\textsubscript{2} compression to 2,215 psia

Gallons/MWh (net)
IGFC Plant Water Makeup

**gal/ MWh**

- **PC plants:** 1000 - 1200
- **IGCC:** 600-700
- **Nuclear:** 1600
- **NGCC:** 500

**Note:** Title shows Dry Syngas Methane Content [vol%]

With all water-cooled components
With selected air-cooled components
# Current Priorities: SECA Core Technology Program

<table>
<thead>
<tr>
<th></th>
<th>Gas Seals</th>
<th>Cathode Performance &amp; Stability</th>
<th>Structural Analysis</th>
<th>Interconnect</th>
<th>Anode / fuel processing</th>
<th>Heat Exchangers/ High Temperature Blowers</th>
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<tr>
<td>1</td>
<td>Compliant Seal - Self-Healing Materials</td>
<td>Surface Dissociation – Mobility-Surface Modification</td>
<td>Design Basis – Material Data, Analysis &amp; Failure Modes</td>
<td>Alloy – Composition – Cost</td>
<td>Purity Requirements - Fuel</td>
<td>Cost and reliability</td>
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<td>High Temperature Seal – Monolithic Structure</td>
<td>In-Situ/Ex-Situ Correlation</td>
<td>Design Tools – Engineering Design</td>
<td>Coatings</td>
<td>Characterize thermodynamics/kinetics - Contaminants</td>
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<td>Impact of Potential</td>
<td>Transients- Control System</td>
<td>Electrode to Interconnect Interface - Contact Material</td>
<td>Multi-component catalysts</td>
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<td>Solid-State Understanding - Mechanism</td>
<td>Manufacturing Tolerances- Cost</td>
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<td>Carbon &amp; Sulfur Strategy</td>
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<td>Integrated Cathode Studies</td>
<td>Thermal Profile and Gradients – Structure</td>
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<td>2</td>
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<td>Electrode to Interconnect Interface – Contact Material</td>
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</table>
Electrical Performance of Surface Treated 441

LSM cathode, LSM contact paste, 800°C, air
Improved Scale Adherence with Modified MC Coatings

850°C, 900 hours, air

Original MC spinel

Ce-MC spinel – No spallation observed
## SECA Industry Teams
### FY 2001 – FY 2007
### Complete

<table>
<thead>
<tr>
<th>SECA Industry Team</th>
<th>Location</th>
<th>Prototype</th>
<th>NETL Validation</th>
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<tr>
<td>General Electric</td>
<td>Torrance, CA</td>
<td>Complete</td>
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<tr>
<td>Delphi</td>
<td>Rochester, NY</td>
<td>Complete</td>
<td>Pass</td>
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<tr>
<td>Fuel Cell Energy</td>
<td>Calgary, BC</td>
<td>Complete</td>
<td>Pass</td>
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<tr>
<td>Acumentrics</td>
<td>Westwood, MA</td>
<td>Complete</td>
<td>Pass</td>
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<tr>
<td>Siemens Power Group</td>
<td>Pittsburgh, PA</td>
<td>Complete</td>
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<tr>
<td>Cummins Power Gen.</td>
<td>Minneapolis, MN</td>
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<tr>
<th>Size</th>
<th>Efficiency</th>
<th>Degradation</th>
<th>Availability</th>
<th>Cost</th>
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<td>Target 3 – 10 kW</td>
<td>35 (LHV)</td>
<td>4%/1,000 hrs</td>
<td>90%</td>
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<tr>
<td>Aggregate Team</td>
<td>3.54 – 41 %</td>
<td>2%/1,000 hrs</td>
<td>97%</td>
<td>$724 - $775/kW</td>
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SECA Industry Teams & Major Subcontractors
2008 SECA Core Technology & Innovative Concepts

Pacific Northwest National Laboratory
U.S. Department of Energy

MONTANA STATE UNIVERSITY

ACOMAC

ARCIMAC

NETL

NEXTECH MATERIALS

Acumentrics Technologies

CellTech Power

Carnegie Mellon

MIT

BOSTON UNIVERSITY

R&D Corporation

United Technologies

FuelCell Energy

NIST

PADT

Sanda National Laboratories

Virginia Tech

Georgia Institute of Technology

2008 SECA Core Technology & Innovative Concepts

NATIONAL ENERGY TECHNOLOGY LABORATORY

00076-6-30-08 WAS
## 2008 Peer Review

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<th>Project Type</th>
<th>Score (0 – 5.0)</th>
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<td>1 Fuel Cell Energy</td>
<td>Jody D. Doyon</td>
<td>Industry</td>
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<td>2 Delphi Automotive Systems</td>
<td>Steven R. Shaffer</td>
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<td>3 Santa Clara County</td>
<td>Caroline Judy</td>
<td>Congressional</td>
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<td>4 Siemens Power Generation</td>
<td>Joseph F. Pierre</td>
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<td>6 GE Global Research</td>
<td>Mathew Alinger</td>
<td>Advanced Research</td>
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<td>7 Allegheny Technologies, Inc.</td>
<td>James Rakowski</td>
<td>Interconnects</td>
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<td>Material Properties</td>
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<td>Cathodes</td>
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<td>12 Lawrence Berkeley National Laboratory</td>
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<td>18 Virginia Tech Polytechnic Institute</td>
<td>Jason Lai</td>
<td>Power Electronics</td>
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For More Information About the DOE Office of Fossil Energy Fuel Cell Program

- **NETL website:**
  - [www.netl.doe.gov](http://www.netl.doe.gov)

Reference Shelf

**CDs available from the website**

- FE Fuel Cell Program Annual Report _2007_
- 8th Annual SECA Workshop Proceedings (Coming Soon)
- Fuel Cell Handbook (7th ed.)

Wayne A. Surdoval  
Technology Manager, Fuel Cells  
National Energy Technology Laboratory  
U. S. Department of Energy  
(Tel) 412 386-6002  
(Fax) 412 386-4516  
wayne.surdoval@netl.doe.gov

**Office of Fossil Energy website:**
- [ww.fe.doe.gov](http://ww.fe.doe.gov)