SOFC Program Overview

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Clean Coal Research Program

CLEAN COAL RESEARCH PROGRAM

CCS AND POWER SYSTEMS R&D

SUBPROGRAMS

Advanced Energy Systems
Carbon Capture
Carbon Storage
Crosscutting Research

TECHNOLOGY AREAS

Gasification Systems
Advanced Combustion Systems
Advanced Turbines
Solid Oxide Fuel Cells
SOFC Power Systems - COE

* Advanced IGCC system includes: coal feed pump, warm gas cleanup, H₂ membrane, advanced H₂ turbine, and ITM

** Advanced IGFC system includes catalytic gasifier, 0.2% degradation rate, and internal reforming

*** Advanced NGCC system features a J-class turbine with a state-of-the-art carbon capture system

Source: NETL Systems Analysis
SOFC Power Systems - Efficiency

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*** Advanced NGCC system features a J-class turbine with a state-of-the-art carbon capture system

Source: NETL Systems Analysis
Solid Oxide Fuel Cell Program

Budget History

Year: 2000 to 2014

- Request
- Appropriation

$M

0 10 20 30 40 50 60 70

FE SOFC Program Mission

- Enable the generation of efficient, low-cost electricity from domestic coal and natural gas with near-zero emissions of CO$_2$ and air pollutants and minimal use of water in central power generation applications.
- Increase reliability, robustness, and durability of cell and stack technology.
- Provide the technology base to permit grid-independent distributed generation applications.

- 60% Efficiency (Coal HHV)
- ≥ 97% CO$_2$ Capture
- <0.5ppm NOx, low H$_2$O use
- Low Cost, similar footprint to IGCC
- Modular Technology
- Fuel-Flexible: Syngas, NG, H$_2$, Diesel, etc.
SOFC Program Structure

R &D Needs
Research Topics

Industry Teams

Core Technology Program
(Universities, NLs)

Technology Transfer
The SOFC program maintains a diversified portfolio of more than 20 short-, mid-, and long-term R&D projects.
Since its inception in 1999 as SECA, the SOFC Program has funded approximately 175 projects.
SOFC Program Core Technology Program

• Focus on:
  - Technologies critical to the commercialization of SOFC technology
  - Cost reduction, improved performance, reduced degradation
  - Computational tools and modeling
  - Novel cell and stack concepts, advanced processing techniques, and novel fuel cell power systems

The Core Technology Program, made up of universities, national laboratories, small businesses, and other R&D organizations, addresses applied technological issues common to all Industry Teams.
SOFC Program Industry Teams  
**FY13 Status**

- **LG Fuel Cell Systems**  
  - Pressurized Technology  
  - 18 kWe stack test; 3,000 hrs  
  - Degradation rate ~1.1% /1,000 hrs  
  - TRL 5

- **Delphi**  
  - Atmospheric Pressure Technology  
  - 9 kWe stack test; 3,500 hrs  
  - Degradation rate <0.5% /1,000 hrs  
  - TRL 5

- **Fuel Cell Energy**  
  - Atmospheric Pressure Technology  
  - 60 kWe stack test; 1,130 hrs  
  - Degradation rate <1% /1,000 hrs  
  - TRL 6
SOFC Program Industry Teams

- Developing unique and proprietary SOFC technology
- Scope includes cells to fully integrated SOFC power systems
- Pilot-scale and first-of-a-kind commercial demonstrations
- Held to a common set of performance and cost metrics
  - Stack cost: $225/kWe
  - System cost: $900/kWe
  - System degradation: 0.2% /1000 hrs

The multi-team approach provides technology diversification, offers insurance against business environment risk, and reduces program dependency on single developer.
SOFC Program Technology Progress

- Core R&D
  - 1st Industry Teams
  - Natural Gas
  - 5 kWe modules

- Successful Prototype Test
  - Coal-based Industry Teams

- 10 kWe Stack Test
  - \( \eta = 35 \text{ } - \text{ } 41\% \)
  - <2%/1000 hr degradation

- 60 kWe Stack Test
  - \( \eta = 64\% \)
  - <1%/1000 hr degradation
  - Cost target at high volume achieved (extrapolated)

- >125 kWe POC Module
  - (Planned)

- MWe-Class
  - (Planned)
SOFC Program Timeline

2015
- 60-kWe Stack Test
  Thermally self-sustaining
  Commercial-scale

- 125-kWe Module Test
  Proof-of-concept
  Multiple stacks
  Commercial-scale

- 250-kWe Field Test
  Carbon capture
  Partial compression
  Venting

2020
- MWe Demonstration(s)
  Multiple deployments
  CCS
  Delivery to existing infrastructure

- Commercial DG Systems
  Natural-gas fueled
  Privately funded

2025
- IGFC/NGFC Demonstration
  Multi-MW
  Slipstream
  CCS

2030
- IGFC/NGFC Utility Scale
  First-of-a-kind
  Central station
  CCS
SOFC is a Transformational CCS Technology

**Trends / Drivers / Benefits**

- Green technology
  - Low emissions
  - >97% CO₂ capture potential
  - Renewable fuel
- High quality heat & power
- High efficiency
- High reliability/availability
- Low O&M cost, minimal moving parts
- Low degradation
- No water consumption (except startup)
- Quiet (65 DBA @ 10 m)
- Recyclable at the end of useful life
- Siting flexibility, easily permitted
- Enhances energy independence and security

**Technology Attributes**

<table>
<thead>
<tr>
<th>IGFC</th>
<th>T &amp; D</th>
<th>End User</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg η=35%</td>
<td>Avg loss: 10-15%</td>
<td>Avg η = 30-35%</td>
</tr>
<tr>
<td>BAT η=60%</td>
<td>Reliability risk</td>
<td>BAT η = 45-50%</td>
</tr>
<tr>
<td></td>
<td>Significant investment</td>
<td>No available heat</td>
</tr>
</tbody>
</table>

- η > 55% electricity
- η > 30% thermal
- η > 85% total
- > 97% carbon capture
- Water neutral
- > 60% efficiency
- < $400/kW
SOFC: Meets DG Market Need
Path to Utility Scale Power Generation w/o CO₂ Emissions

• Distributed generation market opportunity: electric power (5 kWe to MWe-class units)

• SOFC DG electric power application
  – Provides > 20 percentage point gain in efficiency
  – Results in significant CO₂ emission reduction

• Commercial, cost-competitive, high efficiency SOFC DG product by 2025
  – Consistent with technology development plan
  – ~30 MWe installed capacity to achieve competitive cost; assumes R&D reduces system cost to ~$6,000/kWe

• Projected learning to achieve competitive cost is consistent with similar technology commercialization experience

SOFC DG applications provide pathway to utility scale coal and natural gas-fueled power plants with efficiencies >60% and >97% carbon capture
Summary

• SOFC offers a potential pathway to low cost CCS for fossil based systems

• Near term opportunities for commercial demonstration and deployment exist in the distributed generation market

• SOFC offer other benefits, e.g., high efficiency, deep turndown, fuel flexibility, sulfur tolerance, modular design, high grade waste heat
Back-Up
For More Information on the SOFC Program

Office of Fossil Energy:  
www.energy.gov/fe/office-fossil-energy

NETL Website:  www.netl.doe.gov/

SOFC Program:  
www.netl.doe.gov/technologies/coalpower/fuelcells/index.html

Reference Shelf:  
- SOFC Program FY13 Project Portfolio  
- SOFC Technology Program Plan  
- Technology Readiness Assessment  
- Past SECA Workshop Proceedings  
- Systems Analysis  
- Fuel Cell Handbook
Fuel Cells 2014 FOAs

1. Improved Reliability of Solid Oxide Fuel Cell Systems
   Focused on Industry
   Estimated Funding: $15 M (2-3 awards)
   Period of Performance: 18 months

2. Solid Oxide Fuel Cell Core Technology Program
   Focused on R&D in Support of Industry
   Estimated Funding: $6.4 M (5-8 awards)
   Period of Performance: 36 months

Issued: February 14, 2014
Close: March 31, 2014
## CCS & Power Systems

The budget request takes into consideration the need for budget restraint across all research and development (R&D) program areas.

The majority of the reduction is from Advanced Energy Systems. The request continues development of pressurized oxy-combustion and chemical looping combustion systems. Funding for fuel cells is narrowed to materials research essential to commercial viability.

Carbon Capture and Carbon Storage are reduced but maintaining priority activities associated with capture for fossil fuel-fired plants and large-scale injection and monitoring operations.

The NETL Coal R&D budget reflects a $16M reduction from FY2014; however, the funding is consistent with levels prior to FY 2014. The FY2014 enacted amount included extra funding to perform a special assessment of recovering rare earth elements.

<table>
<thead>
<tr>
<th>CCS AND POWER SYSTEMS</th>
<th>FY 2014 Enacted</th>
<th>FY 2015 Congressional Request</th>
<th>FY 2015 vs FY 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Capture</td>
<td>92,000</td>
<td>77,000</td>
<td>(15,000) -16%</td>
</tr>
<tr>
<td>Carbon Storage</td>
<td>108,766</td>
<td>80,084</td>
<td>(28,682) -26%</td>
</tr>
<tr>
<td>Advanced Energy Systems</td>
<td>99,500</td>
<td>51,000</td>
<td>(48,500) -49%</td>
</tr>
<tr>
<td>Crosscutting Research</td>
<td>41,925</td>
<td>35,292</td>
<td>(6,633) -16%</td>
</tr>
<tr>
<td>NETL Coal R&amp;D</td>
<td>50,011</td>
<td>34,031</td>
<td>(15,980) -32%</td>
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<tr>
<td><strong>TOTAL CCS AND POWER SYSTEMS</strong></td>
<td><strong>392,202</strong></td>
<td><strong>277,407</strong></td>
<td><strong>(114,795) -29%</strong></td>
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The Advanced Energy Systems (AES) mission is to increase the availability and efficiency of fossil energy systems integrated with CO₂ capture, while maintaining the highest environmental standards at the lowest cost.

Due to funding priority, the Solid Oxide Fuel Cells funding was reduced to focus on the development of CCS technologies. Materials research will continue.

Coal and Coal Biomass to Liquids will continue collaboration with the DOD, but no funds are requested in FY 2015.

Gasification Systems will maintain priority development of advanced oxygen production, dry feed technologies, warm-gas cleanup, and hydrogen separation.

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<th>FY 2014 Enacted</th>
<th>FY 2015 Congressional Request</th>
<th>FY 2015 vs FY 2014 $</th>
<th>%</th>
</tr>
</thead>
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<tr>
<td>Advanced Combustion Systems</td>
<td>18,500</td>
<td>15,000</td>
<td>(3,500)</td>
<td>-19%</td>
</tr>
<tr>
<td>Gasification Systems</td>
<td>36,000</td>
<td>22,000</td>
<td>(14,000)</td>
<td>-39%</td>
</tr>
<tr>
<td>Hydrogen Turbines</td>
<td>15,000</td>
<td>11,000</td>
<td>(4,000)</td>
<td>-27%</td>
</tr>
<tr>
<td>Coal and Coal Biomass to Liquids</td>
<td>5,000</td>
<td>-</td>
<td>(5,000)</td>
<td>-100%</td>
</tr>
<tr>
<td>Solid Oxide Fuel Cells</td>
<td>25,000</td>
<td>3,000</td>
<td>(22,000)</td>
<td>-88%</td>
</tr>
<tr>
<td><strong>TOTAL ADVANCED ENERGY SYSTEMS</strong></td>
<td><strong>99,500</strong></td>
<td><strong>51,000</strong></td>
<td><strong>(48,500)</strong></td>
<td><strong>-49%</strong></td>
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