Office of Fossil Energy’s Solid Oxide Fuel Cell (SOFC) Program Overview

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DOE's Clean Coal R&D Program is focused on developing and demonstrating advanced power generation and Carbon Capture and Storage (CCS) technologies.
FE SOFC Program Mission

• Enable the generation of efficient, low-cost electricity from domestic coal and natural gas with near-zero emissions of CO₂ and air pollutants and minimal use of water in central power generation applications.

• Increase reliability, robustness, and durability of solid oxide fuel cell and stack technology.

• Provide the technology base to permit natural gas fueled distributed generation (DG) applications.

60% Efficiency (Coal HHV)  
≥ 97% CO₂ Capture  
<0.5ppm NOx, low H₂O use  
Low Cost, similar footprint to IGCC  
Modular Technology  
Fuel-Flexible
SOFC power systems offer a pathway to low cost, high efficiency electric power generation – with CCS – from fossil fuels.
SOFC Program Structure

Systems Development
- Multiple teams developing unique and proprietary SOFC technology
- Scope includes cells to fully integrated SOFC power systems
- Pilot-scale and prototype system testing
- Held to a common set of performance and cost metrics

Core Technology
- Applied R&D focused on technologies critical to the commercialization of SOFC technology
- Evaluate, develop and implement advanced technologies to reduce costs and improve performance, reliability and endurance
  - Materials
  - Manufacturing processes
  - Computational tools and modeling

The multi-team approach provides technology diversification and reduces program dependency on a single developer
The SOFC Program has a portfolio of more than 30 projects, ranging from bench-scale R&D to system-scale testing.
The SOFC Program has a geographically diverse roster of participants.
Where we were ... Where we are ...

**Cell Development**

<table>
<thead>
<tr>
<th>Component</th>
<th>2000</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interconnect</strong></td>
<td>Dense La-chromite Expensive, requires high sintering temp.</td>
<td>Stamped Ferretic SS + Coating Low-cost, post-processing possible</td>
</tr>
<tr>
<td><strong>Cathode</strong></td>
<td>LSM High Resistance</td>
<td>LSM+YSZ, LSCF-doped-Ceria Low Resistance</td>
</tr>
<tr>
<td><strong>Electrolyte</strong></td>
<td>Thick YSZ High Resistance, mechanical support</td>
<td>Thin YSZ + doped-Ceria Barrier Layer Low Resistance</td>
</tr>
<tr>
<td><strong>Anode</strong></td>
<td>Thin Ni-YSZ Screen-printed Functional Layer</td>
<td>Medium Thickness (~500 mm) Ni-YSZ Tape-cast, mechanical support</td>
</tr>
</tbody>
</table>

- Developed planar anode-supported cell
- Increased cell area by 5x...... scaling to 10x
- Increased cell power by 10x
- Improved material set for higher performance
- Improved manufacturing processes
- Reduced operating temperature by ~100°C
- Reduced cell degradation to <0.5%/1,000 hrs
Where we were ... Where we are ...

**Stack Development**

- **Reduced Cost**
  - Improved mfg processes
  - Simplified design

- **Improved Performance**
  - Improved materials sets
  - Modeling tools employed

- **Scale-Up**
  - Larger cells
  - 1st generation interconnects

- **Improved Reliability**
  - SS interconnects
  - Improved seals

**Single Cells & Small Stacks**
- < 10 cells, no interconnects
- Operating temperature >800°C, ΔT undefined
- Low power density
- Limited operation, <1,000 hrs
- High degradation

**30 kW Stack Tower**
- 96 cells, low cost interconnects
- Operating temperature <800°C, ΔT<100°C
- Increased power density
- Operation >> 1,000 hrs
- Degradation ~1% per 1,000 hrs

*Photo courtesy FuelCell Energy*
Where we were ... Where we are ...

**Performance and Reliability Testing**

**2000 – 2005**
Technology Validation
- Single cells
- 1-3 kW small stacks
- Degradation >4% per 1,000 hrs
- Limited operating hrs

**2006 – 2010**
Performance Improvement
- 10 kW-class stacks
- Degradation <2% per 1,000 hrs
- Operating hrs >1,500

**2011 – 2015**
Proof-of-Concept
- 100 kWe-class stacks
- Thermally-self sustaining
- Natural gas- fueled
- Degradation 1 – 1.5% per 1,000 hrs
A cost-effective, natural gas fueled DG system is planned for 2020 followed by a initiation of Utility-scale demonstration for 2025
Where we’re going …

• Test progressively larger stacks
• Initiate field test of a 400 kWe-class prototype power system
• Continue R&D to reduce cost, improve performance, and improve reliability
• Explore new cell and stack concepts to significantly undercut cost targets
FY15 SOFC Program Update

• Two competitive solicitations
  - FOA-0001244: 400 kWe SOFC Prototype System Testing
    • 400 kWe SOFC Field Test
    • One award, ~$6M, 30% Participant Cost Share
  - FOA-0001229: SOFC Innovative Concepts and Core Technology Research
    • Topic Area 1: Innovative Systems
      - R&D with potential to significantly undercut current DOE cost targets
      - 5 – 10 kWe-scale stack test, 1000 hrs
      - Five awards, ~$2.5M per award, 20% Participant Cost Share
    • Topic Area 2: SOFC Core Technology
      - R&D that improves performance, reliability, and/or endurance of cell or stack technology
      - Lab or bench scale testing on any cell or stack component
      - Ten awards, ~$200k per award, 20% Participant Cost Share

• Four new SBIR Projects

• Closer collaboration with ARPA-E
Natural gas fueled DG systems will establish the manufacturing and operational experience necessary to validate and advance the technology for both natural gas and gasified coal-based central power generation.
SOFC Program ... *Key Takeaways*

- Emphasis on increased reliability
- Awarded the 1st prototype system field test
- Five new projects are focusing on advanced stack/system concepts
- Ten new projects developing innovative cell/stack components
16th Annual SOFC Workshop - Overview

**Tuesday**
- **Plenary Session:** Dr. Grace Bochenek, Director NETL
- **Industry Team Presentations**
- **Core Technology Teams:** Reliability, Robustness, & Endurance
- ARPA-E REBELS Projects: IT Fuels Cells for DG

**Tuesday Evening Poster Session and Reception**

**Wednesday**
- National Laboratories
- **Core Technology Teams:** Reliability, Robustness, & Endurance
- ARPA-E REBELS Projects: IT Fuels Cells for DG
- ARPA-E REBELS Projects: Load-Following IT Fuels Cells

**Thursday**
- **Core Technology Teams:** Reliability, Robustness, & Endurance
- ARPA-E REBELS Projects: Liquid Fuel-Producing IT Fuels Cells
- ARPA-E REBELS Projects: Load-Following IT Fuels Cells
- ARPA-E REBELS Projects: SOFC Projects
SOFC FY15 Program Participants
Websites and Contact Information


NETL Website:  [www.netl.doe.gov/](http://www.netl.doe.gov/)

SOFC Program website:  [www.netl.doe.gov/research/coal/energy-systems/fuel-cells](http://www.netl.doe.gov/research/coal/energy-systems/fuel-cells)

Reference Shelf:
- SOFC Program FY15 Project Portfolio
- SOFC Technology Program Plan
- Technology Readiness Assessment
- Past SECA Workshop Proceedings
- Systems Analysis
- Fuel Cell Handbook

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[www.netl.doe.gov/research/coal/energy-systems/fuel-cells](http://www.netl.doe.gov/research/coal/energy-systems/fuel-cells)
## SOFC Program – FY15 Awards

### FOA-0001229: SOFC Innovative Concepts and Core Technology Research

#### Topic Area 1 - Innovative Systems

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<tr>
<td>FuelCell Energy</td>
<td>Innovative SOFC Technologies</td>
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<tr>
<td>General Electric</td>
<td>Development of a Thermal Spray Redox Stable, Ceramic Anode for Metal Supported SOFC</td>
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<tr>
<td>Redox Power Systems</td>
<td>High Power, Low Cost SOFC Stacks For Robust And Reliable Distributed Generation</td>
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<tr>
<td>U.C. San Diego</td>
<td>Innovative Versatile and Cost-Effective Solid Oxide Fuel Cell Stack Concept</td>
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#### Topic Area 2 - SOFC Core Technology

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<tr>
<td>Acumentrics</td>
<td>Matrix Study of Aged SOFC Performance and Materials Degradation</td>
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<tr>
<td>Boston University</td>
<td>Processing of SOFC Anodes for Enhanced Intermediate Temperature Catalytic Activity at High Fuel Utilization</td>
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<tr>
<td>Georgia Tech</td>
<td>Low-Cost, Durable, Contaminant-Tolerant Cathodes for SOFCs</td>
</tr>
<tr>
<td>Kettering University</td>
<td>LSCF-CDZ Composite Cathodes for Improved SOFC Electrical Performance</td>
</tr>
<tr>
<td>MIT</td>
<td>Self-regulating surface chemistry for more robust highly durable solid oxide fuel cell cathodes</td>
</tr>
<tr>
<td>Montana State University</td>
<td>Enhancing High Temperature Anode Performance with 2° Anchoring Phases</td>
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<tr>
<td>Tennessee Tech. University</td>
<td>Development of Low-Cost, Highly-Sinterable, Co-Free (Ni,Fe)3O4 Spinel-Based Contact Materials for SOFC Cathode-Side Contact Application</td>
</tr>
<tr>
<td>University of Maryland</td>
<td>In-Operando Evaluation of SOFC Cathodes for Enhanced ORR Activity and Durability</td>
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<tr>
<td>University of South Carolina</td>
<td>Developing Accelerated Test Protocols and Tuning Microstructures of the Common Materials to Improve Robustness, Reliability, and Endurance of SOFC Cells</td>
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<tr>
<td>West Virginia University</td>
<td>Scalable Nano-Scaffold Architecture On the Internal Surface of SOFC Anode For Direct Hydrocarbon Utilization</td>
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### FOA-0001244: 400 kWe SOFC Prototype System Testing

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