U.S. DOE Office of Fossil Energy
Solid Oxide Fuel Cell (SOFC) Program

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April 29, 2019
SOFC Program Mission

To enable the generation of efficient, low-cost electricity with intrinsic carbon capture capabilities for:

- **Near term**: Natural gas-based distributed generation

- **Long term**: Coal and natural gas utility-scale applications with Carbon Capture and Sequestration (CCS)
SOFC Program Structure

Key Technologies

TECHNOLOGY AREA

SOLID OXIDE FUEL CELLS

KEY TECHNOLOGIES

Cell Development

Core Technology

Systems Development

Figure courtesy FuelCell Energy

Figure courtesy LG Fuel Cell Systems

Figure courtesy NETL
The SOFC Program is focused on the design, scale-up, and integration of the SOFC technology into modules and systems, and the development and testing of progressively larger stacks/systems.

**R&D Approach**

- **Applied Research**
  - Cell and Core Technologies
  - TRL 2 – 5
  - Collaboration with an SOFC Developer (industry) encouraged

- **Development**
  - State-of-the-Art systems development
  - Innovative Concepts
  - TRL 5 – 6
SOFC Program Project Portfolio
FY19 Participants
<table>
<thead>
<tr>
<th>Metric</th>
<th>Current</th>
<th>2020 Target</th>
<th>2025/2030 Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Cost (100 kW- 1MW)</td>
<td>&gt;$12,000/kWe</td>
<td>$6,000/kWe</td>
<td>$900/kWe</td>
</tr>
<tr>
<td>Single Cell Degradation</td>
<td>0.2 - 0.5% per 1,000 hrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell Manufacturing Approach</td>
<td>Batch</td>
<td>Semi- Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td>System Degradation</td>
<td>1 – 1.5% per 1,000 hrs</td>
<td>0.5 - 1.0% per 1,000 hrs</td>
<td>&lt;0.2% per 1,000 hrs</td>
</tr>
<tr>
<td>Fuel Reformation</td>
<td>Primarily external natural gas conditioning/reforming</td>
<td>100% integrated natural gas reform inside cell stack</td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>&lt;2,000 hrs</td>
<td>5,000 hrs</td>
<td>5 years</td>
</tr>
<tr>
<td>Platform</td>
<td>Proof-of-Concept</td>
<td>Prototype/Pilot</td>
<td>DG: Commercial Pilot</td>
</tr>
<tr>
<td>Configuration</td>
<td>Breadboard/Integrated systems</td>
<td>Fully packaged</td>
<td>Fully packaged</td>
</tr>
<tr>
<td>Fuel</td>
<td>Natural gas</td>
<td>Natural gas Simulated syngas</td>
<td>Natural gas Coal-derived syngas</td>
</tr>
<tr>
<td>Demonstration Scale</td>
<td>50 kWe – 200 kWe</td>
<td>200 kWe – 1 MWe</td>
<td>DG: MWe-class</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Utility-scale: 10 – 50 MWe</td>
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</tbody>
</table>

*Single-cell performance and degradation meet targets; system performance, cost and durability are being evaluated*
## SOFC Program
### R&D Gaps

<table>
<thead>
<tr>
<th>Technology</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cells</td>
<td>Manufacturing/QC</td>
</tr>
<tr>
<td></td>
<td>Chemical Instability</td>
</tr>
<tr>
<td>Stacks</td>
<td>Manufacturing/QC</td>
</tr>
<tr>
<td></td>
<td>Contacts</td>
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<td></td>
<td>Seals</td>
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<tr>
<td>Systems</td>
<td>Degradation</td>
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<tr>
<td></td>
<td>Reliability</td>
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<tr>
<td></td>
<td>System integration</td>
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<tr>
<td></td>
<td>Balance-of-Plant</td>
</tr>
<tr>
<td></td>
<td>Operations</td>
</tr>
</tbody>
</table>
SOFC Program Development Timeline

**CELL AND CORE TECHNOLOGY DEVELOPMENT**
- Cell power enhancement & reliability
- Modeling & systems analysis
- Innovative stack design(s) & balance-of-plant
- Evaluation of cell/system operation on syngas
  - TRL 2-5

**INNOVATIVE CONCEPTS**
- Surpass SOA performance, cost, and reliability
- Novel cell & stack architecture
- Advanced manufacturing
  - TRL 4-6

**2015**
- **50 kWe POC**
  - Thermally self-sustaining
  - Fully integrated system
  - Natural gas
  - TRL 6
  - COMPLETED

**2015**
- **200 kWe POC**
  - Thermally self-sustaining
  - Natural gas
  - Fully integrated system
  - TRL 6
  - COMPLETED

**2020**
- **200 kWe Prototype Tests**
  - Natural gas
  - Fully integrated system
  - TRL 6

**2020**
- **1 MWe Prototype Tests**
  - Natural gas
  - TRL 6

**2025**
- **10 MWe Pilot(s)**
  - IGFC/NGFC slipstream
  - CCS
  - TRL 6

**2025**
- **Commercial DG Systems**
  - Natural gas
  - CCS capable
  - TRL 7-9
  - Privately funded

**2030**
- **50 MWe Utility-Scale Pilot(s)**
  - First-of-a-kind
  - CCS
  - TRL 7-9

**COMPLETED**
- Thermally self-sustaining
- Fully integrated system
- Natural gas
- TRL 6
- Two awarded

**SOFC Program Development Timeline**
- Natural gas
- TRL 6
- COMPLETED
- Natural gas
- CCS capable
- Privately funded
- First-of-a-kind
- CCS
- TRL 7-9

**SOFC Program Development Timeline**
- Natural gas
- TRL 6
- CCS capable
- Privately funded
- First-of-a-kind
- CCS
- TRL 7-9
### SOFC R&D at NETL

**Cell and Stack Degradation Modeling**
- Development of comprehensive predictive modeling tool
- Atoms to system scale bridging
- Validated through experiment

**Electrode Engineering**
- Mitigation of prominent degradation modes
- Successful transfer of technology to industry

**Systems Engineering and Analysis**
- Public dissemination of SOFC market potential, performance, and cost advantages
- Hybrid configuration assessment
- Tie to R&D goals and objectives

**High Temp Optical Sensors**
- Multi-application technology under development for high temperature sensing
- Demonstrated in SOFC
- In-situ sensing of temperature distribution and gas composition
### Materials
- Quantitative understanding of Cr poisoning
- Validation of Cr capture materials
- Enhanced reliability of cathode/contact material interfaces
- Cobalt-free protective coatings for metallic interconnects

### Modeling
- Advanced Reduced Order Models (ROM) for accurate simulation of stack performance in system models
- Modeling to mitigate stack degradation and increase reliability

### Small-Scale SOFC Test Platform
- Designed and fabricated SOFC test platform (1-10 kW)
- Used for evaluation of performance and reliability of emerging stack technologies
- First technology to be tested: Ceres Power stack module (~4 kW)
1. FuelCell Energy 200 kW Prototype Field-Test

- 200 kWe integrated SOFC Power System
- Test site: NRG Energy Center
  Pittsburgh, PA
- Natural gas fuel, Grid Connected
- Target operating time: 5,000 hrs

Photo courtesy FuelCell Energy
SOFC Power Systems

2. LG 250 kW Prototype Field-Test

- 250 kW integrated SOFC Power System
- Test site: Stark State College
  North Canton, OH
- Natural gas fuel, grid connected
- 1,300 hrs on load
- Efficiency: 55% AC
- Power degradation: 0.3% per 1000 hrs

Photo courtesy LG Fuel Cell Systems
SOFC Program
DOE Funding History

Annual Appropriation, $M

Emphasizing the resolution of design, operation, and performance considerations at the system level

Acquiring fabricating and operational experience on integrated, prototype field tests

Cell Development and Core Technology research continues and is well aligned with industry need
For Additional Information

NETL Website: www.netl.doe.gov/
SOFC Program website: www.netl.doe.gov/coal/research/energy-systems/fuel-cells

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

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