SECA Core Technology

Fossil Energy Fuel Cell Program

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National Energy Technology Laboratory
Office of Fossil Energy
SECA CORE TECHNOLOGY PROGRAM

W. Nernst
“Electrical Glow-Light”
U.S. Patent 623,811
April 25, 1899

Solid Oxide Fuel Cell

Fuel
CO + H₂O → H₂ + CO₂

Heat

H₂O + CO₂

H₂ + CO

Permeable Anode

H₂ + 2H₂ + 2O²⁻ → 4e⁻ + 2H₂O

O₂ + 4e⁻ → 2O²⁻

Permeable Cathode

O₂

Impermeable Electrolyte

Air

Depleted O₂

Heat

Oxidant
SECA Program Structure

- Industry Input
- Program Management
- Needs
- Research Topics
- Project Management
- Technology Transfer
- Industry Integration Teams
- Core Technology Program

- University
- National Lab
- Industry
- Small Business

- Fuel Cell
- Core Technology
Core Technology Program Powering All Ships

- Materials
- Modeling and simulation
- Fuel processing

- Power electronics
- Controls and diagnostics
- Manufacturing
Intellectual Property
Cornerstone of the Alliance

- Non-Exclusive License
  - Open for 1 year after issue of a U.S. patent
  - Ready market of potential licensees
  - Best designs vs. highest bidder
  - Dispute Resolution Mechanism

- Promotes Collaboration - Limits Duplication
- Pilot program; reevaluate after 2 years
Solid Oxide Fuel Cell

Current Flow

End Plate

Anode

Electrolyte Matrix

Cathode

Bipolar Plate

Fuel Flow

Oxidant Flow

Fuel Flow

Oxidant Flow

Interconnection

Electrolyte

Cathode

Air flow

Fuel Flow

Anode
The Vision: *Fuel Cells in 2010*

**Low Cost/High Volume**

$400/kW > 50,000$ units/yr
## Different Approaches!

<table>
<thead>
<tr>
<th>Team</th>
<th>Design</th>
<th>Manufacturing</th>
</tr>
</thead>
</table>
| Cummins-SOFCo               | • Electrolyte supported  
                            • 850 C  
                            • Thermally matched materials  
                            • Seal-less stack | • Tape casting  
                            • Screen printing  
                            • Co-sintering |
| Delphi-Battelle             | • Anode supported  
                            • 750 C  
                            • Ultra compact  
                            • Rapid transient capability | • Tape casting  
                            • Screen printing  
                            • 2–stage sintering |
| General Electric Company    | • Anode supported  
                            • 750 C  
                            • Hybrid compatible  
                            • Internal reforming | • Tape calendering  
                            • 2–stage sintering |
| Siemens Westinghouse        | • Cathode supported  
                            • 800 C  
                            • Redesigned tubular  
                            • Seal-less stack | • Stack extrusion  
                            • Plasma spray  
                            • Tape extrusion  
                            • Seal-less stack  
                            • Redesigned tubular  
                            • Internal reforming  
                            • Hybrid compatible  
                            • 750 C  
                            • Ultra compact  
                            • Rapid transient capability  
                            • Anode supported  
                            • 750 C  
                            • Tape casting  
                            • Screen printing  
                            • Co-sintering  
                            • Tape casting  
                            • Screen printing  
                            • 2–stage sintering  
                            • Tape casting  
                            • Screen printing  
                            • 2–stage sintering  
                            • Tape calendering  
                            • 2–stage sintering  
                            • Tape extrusion  
                            • Plasma spray  
                            • Stack extrusion  
                            • Plasma spray |

**NETL**

IAPG, GPPD-DWC 4/30/03
Two New Different Approaches!

<table>
<thead>
<tr>
<th>Team</th>
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<th>Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acumentrics Corporation</td>
<td>• Anode supported microtube</td>
<td>• Extrusion</td>
</tr>
<tr>
<td></td>
<td>• 750 C</td>
<td>• Dip processing</td>
</tr>
<tr>
<td></td>
<td>• Thermally matched materials</td>
<td>• Spray deposition</td>
</tr>
<tr>
<td></td>
<td>• Robust &amp; rapid start-up</td>
<td></td>
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<tr>
<td>FuelCell Energy, Inc.</td>
<td>• Anode supported</td>
<td>• Tape casting</td>
</tr>
<tr>
<td></td>
<td>• &lt; 700 C</td>
<td>• Screen printing</td>
</tr>
<tr>
<td></td>
<td>• Low cost metals</td>
<td>• Co-sintering</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Electrostatic deposition</td>
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</tbody>
</table>
## SOFC Materials Costs

<table>
<thead>
<tr>
<th>SOFC Component</th>
<th>Material Cost ($/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common Materials (excluding interconnects)</strong></td>
<td></td>
</tr>
<tr>
<td>Ni/ZrO₂ anode (500 microns)</td>
<td>11.67</td>
</tr>
<tr>
<td>ZrO₂/Y₂O₃ electrolyte (10 microns)</td>
<td>0.40</td>
</tr>
<tr>
<td>LaMnO₃ cathode (50 microns)</td>
<td>2.30</td>
</tr>
<tr>
<td>ss End Plates (1.25 centimeters)</td>
<td>0.70</td>
</tr>
<tr>
<td><strong>Subtotal Common Materials</strong></td>
<td><strong>15.07</strong></td>
</tr>
<tr>
<td><strong>Ceramic Interconnect (2.5 millimeters)</strong></td>
<td>137.50</td>
</tr>
<tr>
<td><strong>Subtotal Ceramic Interconnect &amp; Common Materials</strong></td>
<td><strong>152.57</strong></td>
</tr>
<tr>
<td><strong>50% Contingency</strong></td>
<td>76.28</td>
</tr>
<tr>
<td><strong>Total Material Costs Using Ceramic Interconnects</strong></td>
<td><strong>228.85</strong></td>
</tr>
<tr>
<td><strong>Metallic Interconnect (2.5 millimeters)</strong></td>
<td>6.67</td>
</tr>
<tr>
<td><strong>Subtotal Metallic Interconnect &amp; Common Materials</strong></td>
<td><strong>21.74</strong></td>
</tr>
<tr>
<td><strong>50% Contingency</strong></td>
<td>10.87</td>
</tr>
<tr>
<td><strong>Total Material Costs Using Metallic Interconnects</strong></td>
<td><strong>32.61</strong></td>
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</tbody>
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## Current Priorities: Core Technology Program

<table>
<thead>
<tr>
<th></th>
<th>Gas seals</th>
<th>Interconnect</th>
<th>Modeling</th>
<th>Cathode performance</th>
<th>Anode/ fuel processing</th>
<th>Power electronics</th>
<th>Material cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Glass and compressive seals</td>
<td>Modifying components in alloys, Coatings</td>
<td>Models with electrochemistry, Structural characterization</td>
<td>Micro structure optimization, Mixed conduction, Interface modification</td>
<td>Metal oxides with interface modification, Catalyst surface modification, Characterize thermodynamics/kinetics</td>
<td>Direct DC to AC conversion, DC to DC design for fuel cells</td>
<td>Lower cost precursor processing, Cost model methodology</td>
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</table>

**Interconnect**:
- Glass and compressive seals
- Modifying components in alloys, Coatings

**Modeling**:
- Models with electrochemistry, Structural characterization

**Cathode performance**:
- Micro structure optimization, Mixed conduction, Interface modification

**Anode/ fuel processing**:
- Metal oxides with interface modification, Catalyst surface modification, Characterize thermodynamics/kinetics

**Power electronics**:
- Direct DC to AC conversion, DC to DC design for fuel cells

**Material cost**:
- Lower cost precursor processing, Cost model methodology
SECA Budget ($M)

- Industry Teams
- Core Technology Program
Core Technology Program FY 2003

- Materials: $4,648,150
- Fuel Processing: $2,467,900
- Manufacturing: $1,999,963
- Sensors and Diagnostics: $533,987
- Modeling and Simulation: $150,000
- Power Electronics: $500,000

Total: $9,848,150
Stack Technology – Seals & Cross Cutting

PNNL – Seals, Modeling and Analysis, Cathodes, Anodes, Interconnects, Fuel Processing

LBNL – Metallic supported cell structure, Cathode interface modification

ANL – Metallic supported cell structure, Interconnects, Fuel Processing
Materials - Interconnects

Develop low temperature interconnect suitable for SOFC

- U. of Pittsburgh
- Ceramatec
- Southwest Research Institute
- PNNL
- ANL

Images courtesy of Delphi
Modeling and Simulation

Structural, performance, and optimization design tools

- PNNL
- NETL
- ORNL
- U. of Florida
- Georgia Tech
- TIAAX
Materials - Cathodes

Cathode performance – 2x improvement

- U. of Washington
- U. of Missouri Rolla
- U. of Utah
- Functional Coating, LLC
- Georgia Tech
- PNNL

Images courtesy of NexTech
Fuel Processing and Anode Tolerance

Carbon and sulfur resistant anodes

- Northwestern
- GTI

Carbon and sulfur resistant reforming catalysts

- LANL
- ANL
- NETL
Power Electronics / Controls & Diagnostics

Interaction between fuel cell, power conditioning system and application loads
  - U. of Illinois

DC-DC / DC-AC converters
  - Texas A&M
  - Virginia Polytechnic Institute

High Temperature Sensors
  - NexTech Materials
Manufacturing

Low cost and consistent precursor materials

- NexTech Materials
- U. of Utah

![Diagram of manufacturing process]

Image courtesy of Honeywell