Ceramic Fuel Cells (SOFC)

DOE H2/FC Manufacturing R&D Workshop

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Ceramic SMEs have wide-ranging backgrounds

- Joe Bonadies – Delphi
- Rick Kerr – Delphi
- David Carter – Argonne
- Aaron Crumm – AMI
- Randy Petri – Versa Power
- Jolyon Rawson - Acumentrics
- Marc Gietter – Army-CERDEC
- Scott Swartz – NexTech Materials
- Eric Stanfield – NIST
- Mike Ulsh – NREL / DOE
- Matt Steinbroner – Consultant (DRS)
Considerations and approach

**Things to consider for SOFC manufacturing:**
- Materials and designs vary widely
- Planar and tubular geometries considered
- Three planar technologies: 500 W to 10 kW
- Two tubular technologies: 50-500 W and 0.5-10 kW

**General approach to define and solve issues:**
- Identify cost drivers
- Outline current best manufacturing practices
- Identify manufacturing gaps
- Propose projects to address gaps
- Estimate manufacturing cost savings resulting from the projects
Cells, separator plates & seals drive costs

- Planar Cells, 40%
- Separator Plates, 23%
- Seals, 15%
- Contact Layers, 5%
- Terminal Conductor Plates, 3%
- Manifolds, 7%
- Compression Means, 7%
Key cost drivers identified for planar designs

- Cells
- Separator plates (interconnect)
- Seals
- Manifolds
- Compression hardware
- Electrical contact layers
- End Plates (terminals & gas plenums)
Key manufacturing gaps for planar designs

• Capital Intensive Equipment:
  • Automated assembly machines
  • Stack commissioning equipment

• Time/cost intensive:
  • Acceptance tests for stacks & BOP
  • Numerous manned QC/QA inspections
  • End plate machine work
  • Powder acceptance methods

• Repeat & Non-repeat Parts costs/automation needs:
  • Coating processes for metallic components.
  • Material waste in complex shaped gaskets or glass seals

• Institutional Issues:
  • Hazardous solvents in slurries, inks and pastes
Cells and current collectors drive tubular costs

Less than 500 watt systems

Greater than 500 watt systems

BOP in hot box included
Key cost drivers identified for tubular designs

- Cell
- Current Collectors
- Seals

BOP in hot box:
- Insulation (thermal)
- Recuperator
- Burner
- Tube-end seals
- Reforming
- Manifold

![Tubular SOFC](Courtesy AMI)

![Coil Winding for Current Collection](Courtesy AMI)
Key manufacturing gaps for tubular designs

• Capital Intensive Equipment:
  • Stack acceptance and commissioning tests

• Time/cost intensive/automation needs:
  • Procedures for winding current-collector wire
  • Ceramic powder characterization methods
  • QC/QA inspections

• Repeat & Non-repeat Parts costs:
  • Dimensional tolerance of tubes
  • Non-continuous batch fabrication of tubes
  • Improved-yield on thin-film electrolyte application
  • New coating process for current-collector wire
  • Insulation shaping operations
Ceramic cell & stack projects

*Planar and tubular geometries combined*

- Protective coatings (for metallic components)
- Defect free electrolyte layer (application)
- Low-cost, high-efficiency insulation (shaping, installation)
- Automated assembly
- Stack assembly, commissioning and testing
- Net shape manufacturing of manifolds and end plates
- Current collection winding for tubular SOFC
- Ceramic powder characterization
Key cost drivers for BOP

- Power Management
- Mechanicals and Packaging
- Controls/Software
- Thermal Management
- Reactant Management
  - Fuel processing
  - Fuel and oxidant delivery

SOFC hot box. Courtesy of Staxera
Key manufacturing gaps for BOP

- Power management systems
- Need specified commercial-scale pumps and blowers
- Software for system control and safety
- Thermal insulation shaping and installation
- High efficiency heat exchangers (recuperator)
- Mitigation strategies for coking in catalytic partial oxidation reformers
- Sulfur removal technology

SOFC system flow diagram
Ceramic BOP Projects

- Low-cost, high-efficiency heat exchangers (recuperators)
- Specification-analysis for fuel cell power systems
- Low-cost fuel efficient tactical fuel processor for desulfurized fuels
- High efficiency fuel processor for logistic and renewable fuels
- Manufacturing for cathode air delivery system pump-blower
## Ceramic system cost savings

<table>
<thead>
<tr>
<th>Cold Zone</th>
<th>Hot Zone</th>
<th>Average Project Cost</th>
<th>Average break-even (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanicals / Packaging</td>
<td>Protective coatings</td>
<td>$2,391,146</td>
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<tr>
<td>Controls / Software</td>
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<td>Thermal Management</td>
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<td>Desulfurizer</td>
<td>Low-cost insulation</td>
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<td>Liquid Pumps</td>
<td>Automated assembly</td>
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<tr>
<td>Cathode air blower</td>
<td>Net-shape manifold &amp; end plates</td>
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<tr>
<td>Anode gas recycle</td>
<td>Current collection winding</td>
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<tr>
<td>Power Management</td>
<td>Recuperator</td>
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<tr>
<td></td>
<td>Seals</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
<td><strong>$2,669,300</strong></td>
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