Manufacturing Fuel Cell Manhattan Project:

Ceramic Fuel Cells (SOFC)

DOE H2/FC Manufacturing R&D Workshop

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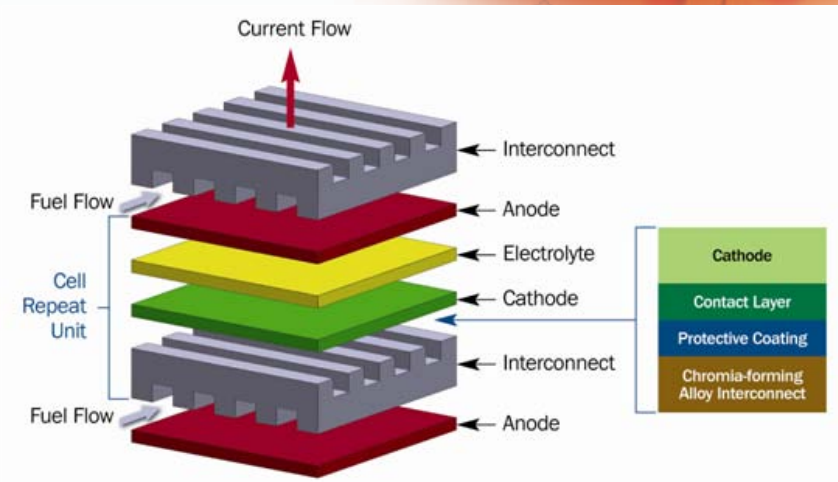
Ceramic SMEs have wide-ranging backgrounds

- 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

Courtesy of AMI

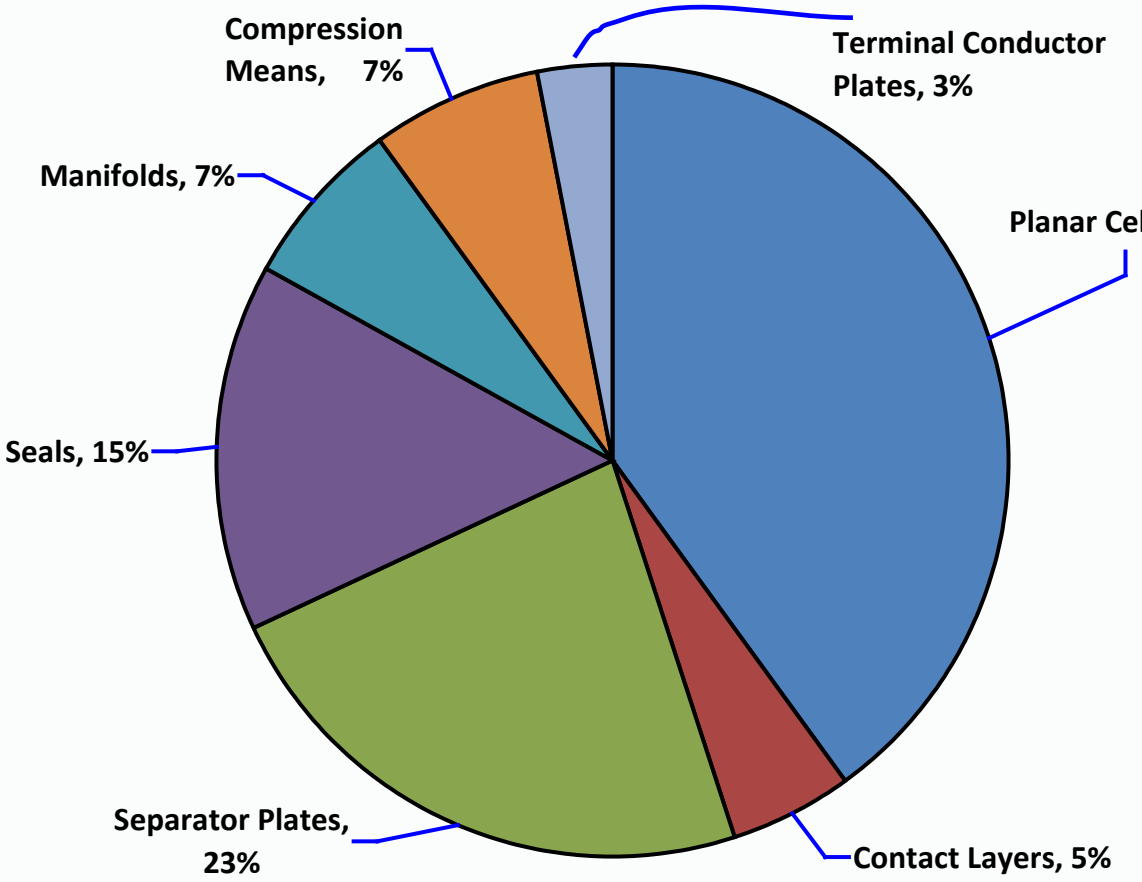
Courtesy of NexTech

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

Courtesy of Acumentrics

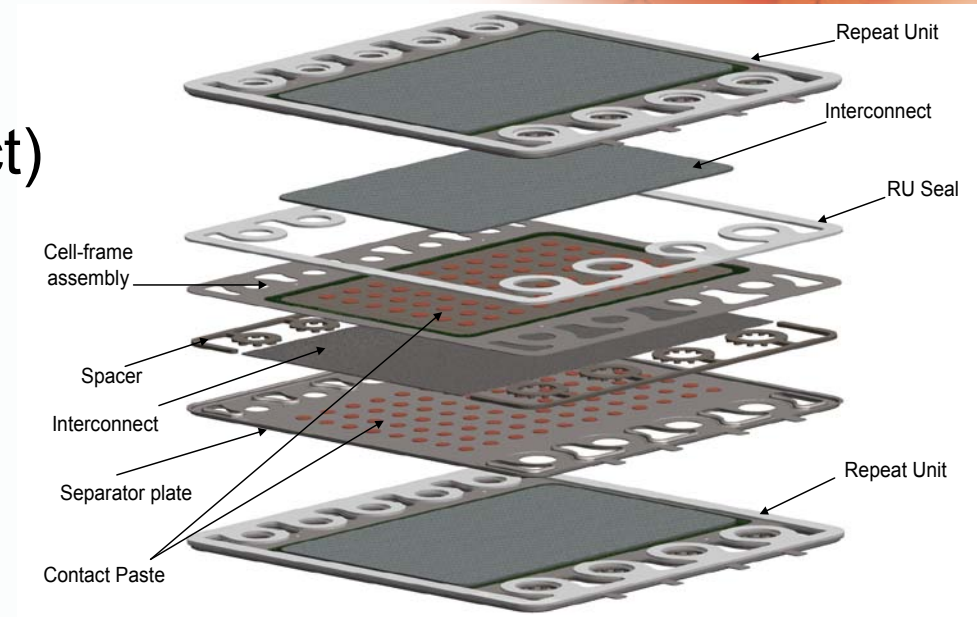
Cells, separator plates & seals drive costs



Planar SOFC (Courtesy of NexTech)

Key cost drivers identified for planar designs

- Cells
- Separator plates (interconnect)
- Seals
- Manifolds
- Compression hardware
- Electrical contact layers
- End Plates (terminals & gas plenums)

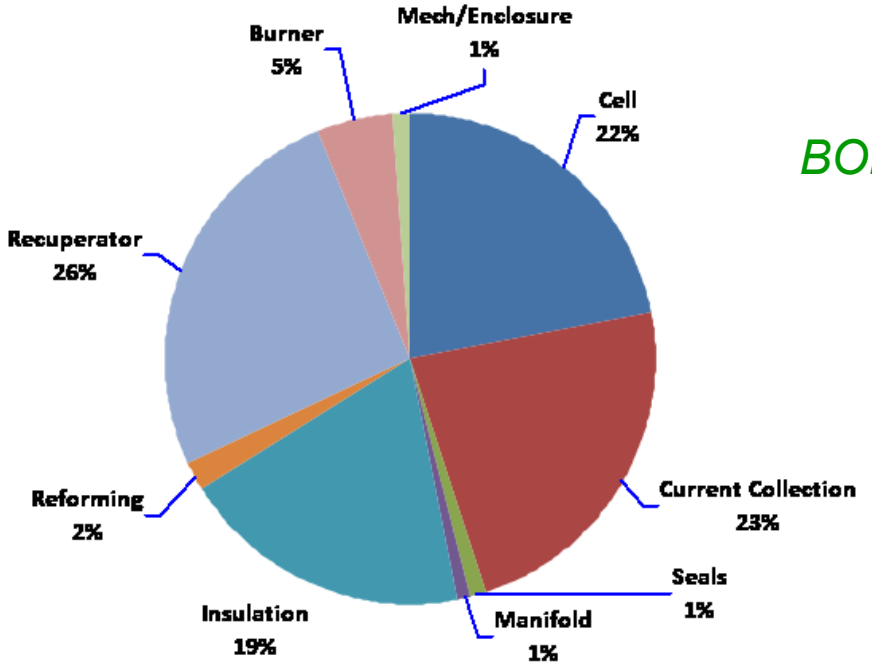


Planar SOFC (Courtesy of Delphi)

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

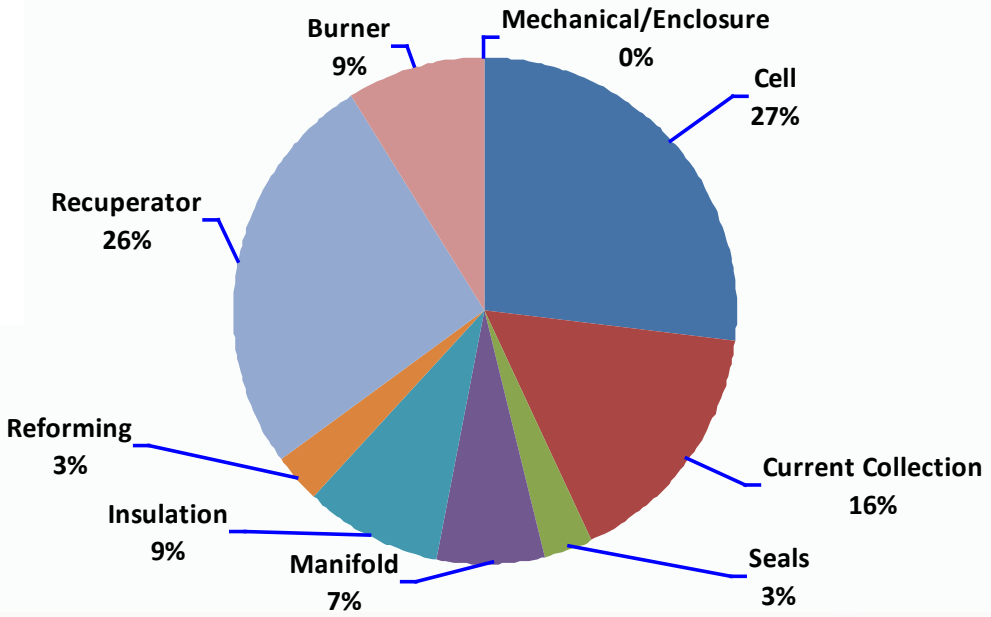
Cells and current collectors drive tubular costs



BOP in hot box included

Courtesy of Acumentrics

Greater than 500 watt systems



Less than 500 watt systems

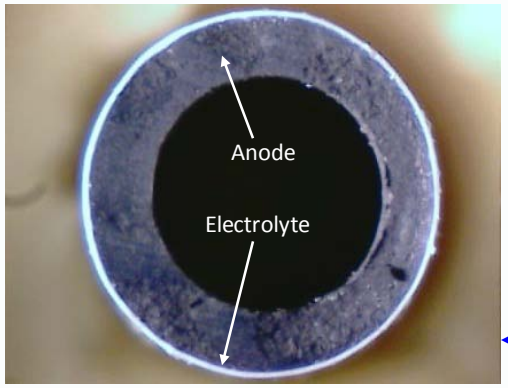
Courtesy of AMI

Key cost drivers identified for tubular designs

- Cell
- Current Collectors
- Seals

BOP in hot box:

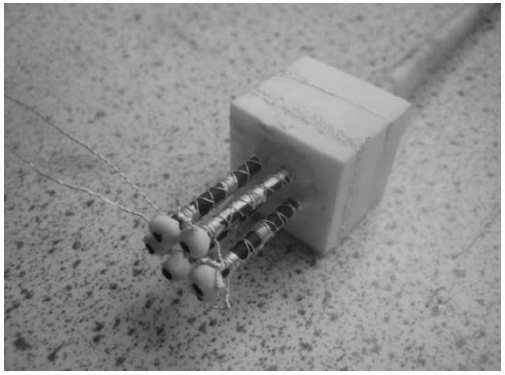
- Insulation (thermal)
- Recuperator
- Burner
- Tube-end seals
- Reforming
- Manifold



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

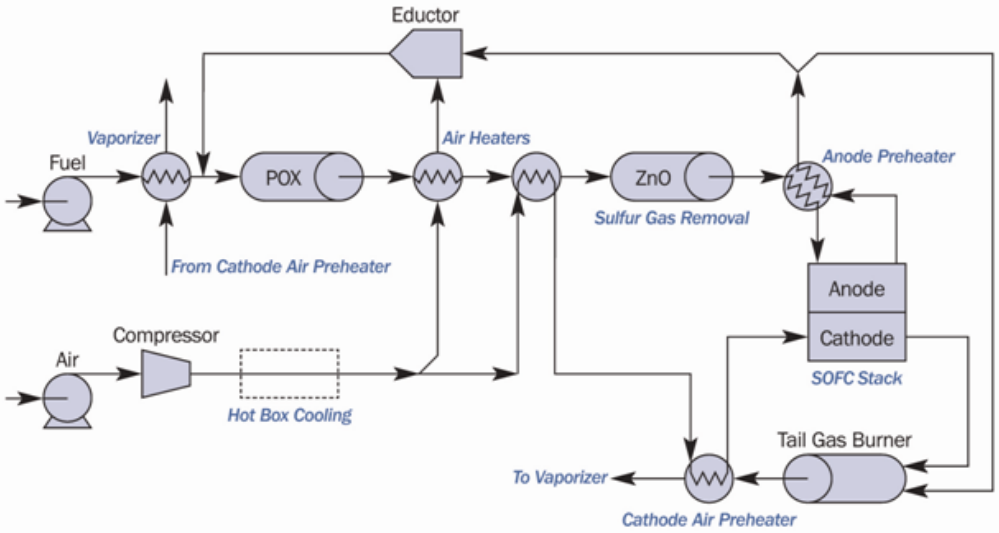
Key cost drivers for BOP

- 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

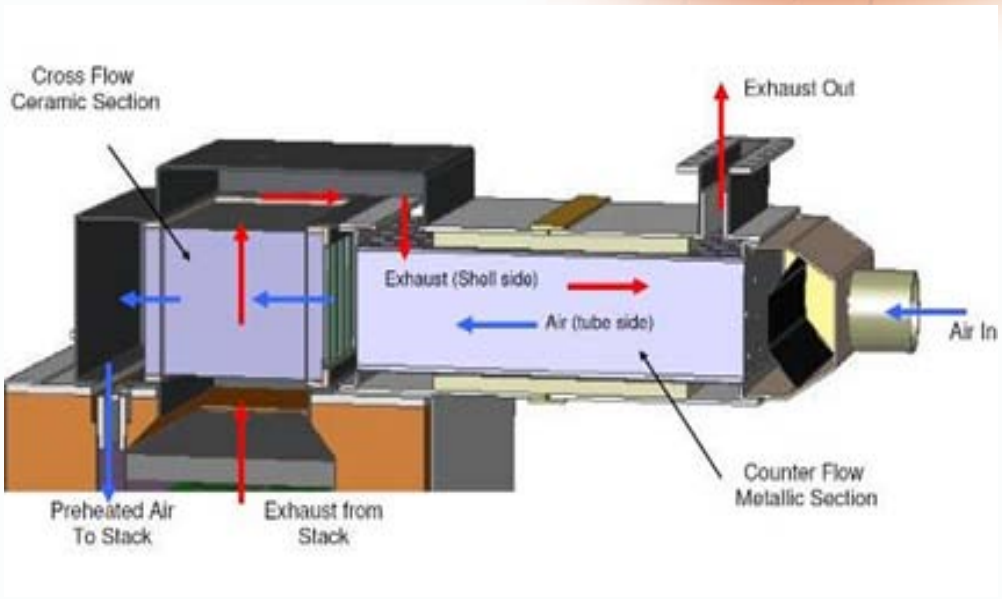
- Power management systems
- Need specified commercial-scale pumps and blowers
- Software for system control and safety
- Thermal insulation shaping and installation
- High efficiency heat exchangers (recuperator)
- Mitigation strategies for coking in catalytic partial oxidation reformers
- Sulfur removal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

Ceramic system cost savings

Cold Zone	Hot Zone
Mechanicals / Packaging	Protective coatings
Controls / Software	Defect free electrolyte
Thermal Management	Stack commissioning
Desulfurizer	Low-cost insulation
Liquid Pumps	Automated assembly
Cathode air blower	Net-shape manifold & end plates
Anode gas recycle	Current collection winding
Power Management	Recuperator
	Seals

	Average Project Cost	Average break-even (MW)
0.5-10kW Planar	$ 2,391,146	5.2
0.5-10kW Tubular	$ 2,307,207	5.4
< 500 W Tubular	$ 2,391,146	4.8
Cold Zone	$ 1,148,974	3.0
Hot Zone	$ 2,669,300	6.4