

Economic Analysis of Stationary PEM Fuel Cell Systems

Kathya Mahadevan, Vince Contini, Matt Goshe, Joseph Price, Fritz Eubanks and Fred Griesemer

Battelle

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Project Id: FC050

Overview

Status of the Economic Analysis Project

Timeline

- Project start date: November 2003
- Project end date: October 2010
- Percent complete (2009): 65% (Apr 2009)

Barriers

- All distributed generation systems barriers
- All fuel-flexible fuel processor barriers
- All fuel cell component barriers
- Manufacturing costs
- Material costs

Budget

- Total Project Funding: DOE Share \$3,163,843 and No Contractor Cost Share
- Funding received in FY04: \$526,548
- Funding received in FY05: \$650,659
- Funding received in FY06: \$599,013
- Funding received in FY07: \$703,283
- Funding received in FY08: \$684,340
- Funding received in FY 09: \$300,000

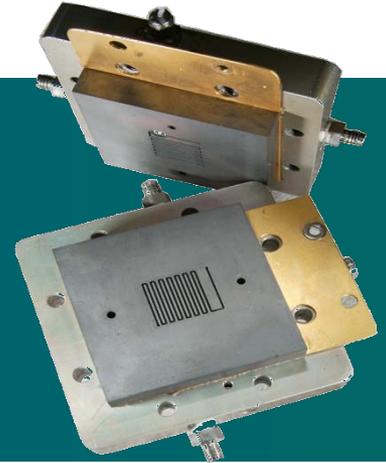
Partners

- Extensive solicitation with fuel cell industry stakeholders for design, data, and review
 - Fuel cell industry and associated stakeholders. More than 60 companies and agencies have participated in facilitated discussions
 - Since the start of the project, more than 400 current or candidate users have participated in surveys, interviews, and focus groups

Relevance

Project Objectives and Impact

To assist DOE in developing fuel cell systems by analyzing the technical, economic, and market drivers of polymer electrolyte membrane (PEM) fuel cell adoption*. Support in 2009 included two tasks:



- Developing technical targets for a 5 kW direct hydrogen PEM fuel cells for backup power by developing a manufacturing cost analysis at varying levels of production
 - 2000 units per year [Base case presented here]
 - 10,000 units per year
 - 100,000 units per year
- Developing an economic and market opportunity analysis for micro-CHP PEM fuel cells to identify key target markets and value proposition for PEM fuel cells

**Note: Scope of the project is limited to PEM fuel cells for stationary applications.*

Relevance

Project Progress to Date

Manufacturing Cost Analysis

- Established baseline system design
- Received input from major fuel cell manufacturers and component suppliers
- Developed base cost estimates for a 2010 design of a 5 kW PEM fuel cell system for 2000 units
- Initiated sensitivity analysis

MicroCHP Analysis

- Identified markets for microCHP PEM fuel cells
- Analyzed the status of current PEM fuel cell products and competing alternatives
- Performed comprehensive marketing research through primary and secondary methods to understand user requirements

Collaborations

Manufacturing Cost Analysis

Industry input through detailed discussions for system design, manufacturing process review, material cost inputs, and peer review

- 3M
- Gore
- GrafTech
- Bulk Molding Company
- Metro Mold & Design
- DuPont
- Ballard
- Plug Power
- IdaTech
- Hydrogenics
- ReliOn
- Nuvera

MicroCHP Analysis

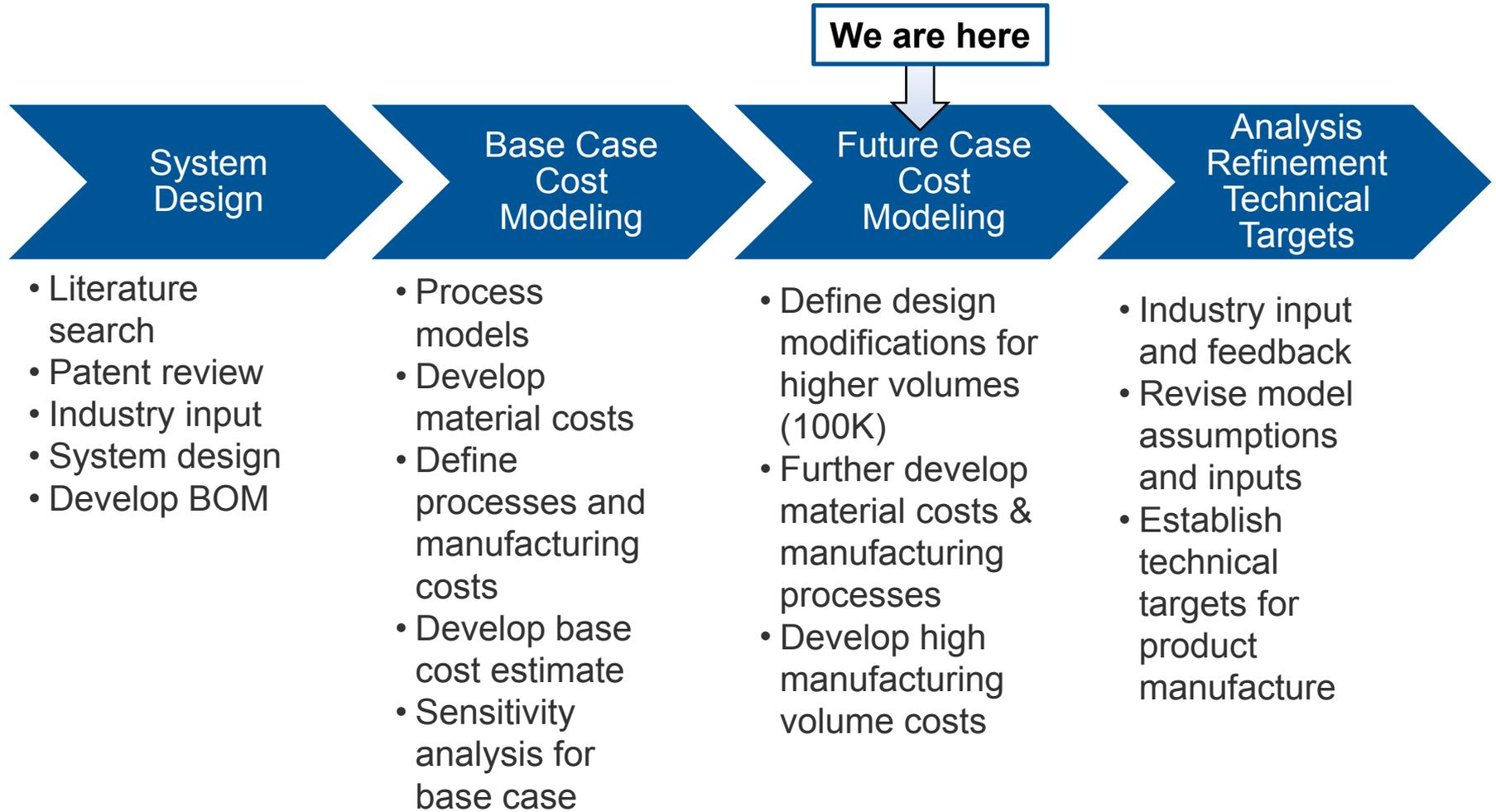
Fuel cell industry, Utility, government, and competing technology input is used for understanding markets, user requirements, technology performance received through surveys and interviews. Examples of interviewees include -

- Plug Power
- Ballard
- Accumetrics
- Ceramic Fuel Cells
- ClearEdge
- Baxi Group
- Enerfuel
- National Grid
- Delta Energy
- Japanese microCHP industry

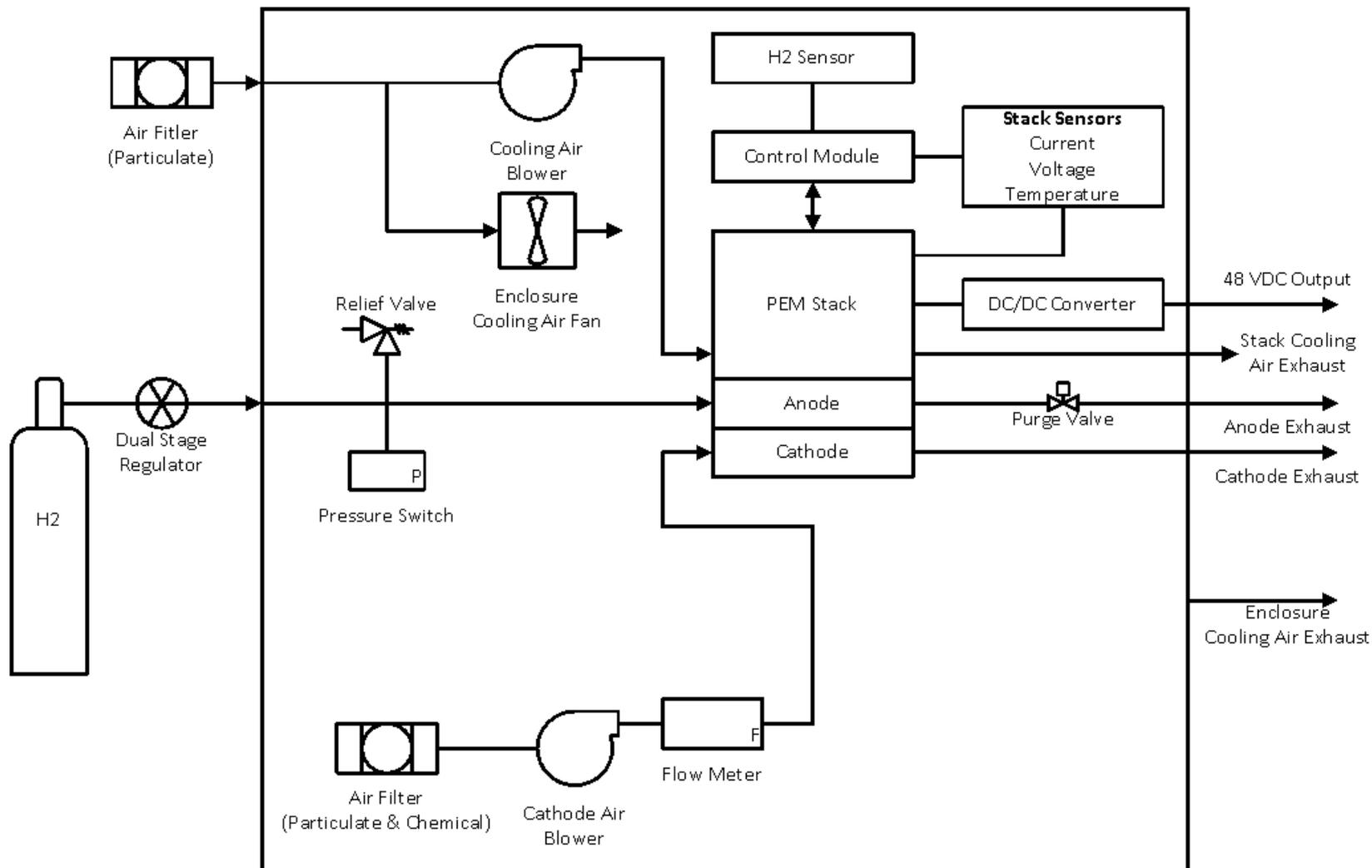
Manufacturing Cost Analysis Technical Accomplishments

Approach

Manufacturing Cost Analysis Task Approach



Technical Accomplishments System Design



Technical Accomplishments System Design and Stack Assumptions

Design Assumptions	Stack Specification	Value
Air-cooled system	Net Power Output	5 kW
Bipolar plate material is composite polymer with graphite	Gross Power Output	7 kW
Membrane is reinforced with ePTFE base	Cell Voltage	0.65 V
77 cells in stack producing total of 5 kW net output	Current Density	1 A/cm ²
Membrane size is 230x135 mm (9.1x5.3 in) with 175x80 mm (6.9x3.1in) active area	Stack Voltage	50 V
GDL and catalyst are applied to entire membrane and not just the active area	Number of Cells	77
No separate humidification is required	Active Area per Cell	140 cm ²
0.4 mg/cm ² total Platinum loading	Power Density	650 mW/cm ²

Technical Accomplishments Methodology for Calculating Manufacturing Costs

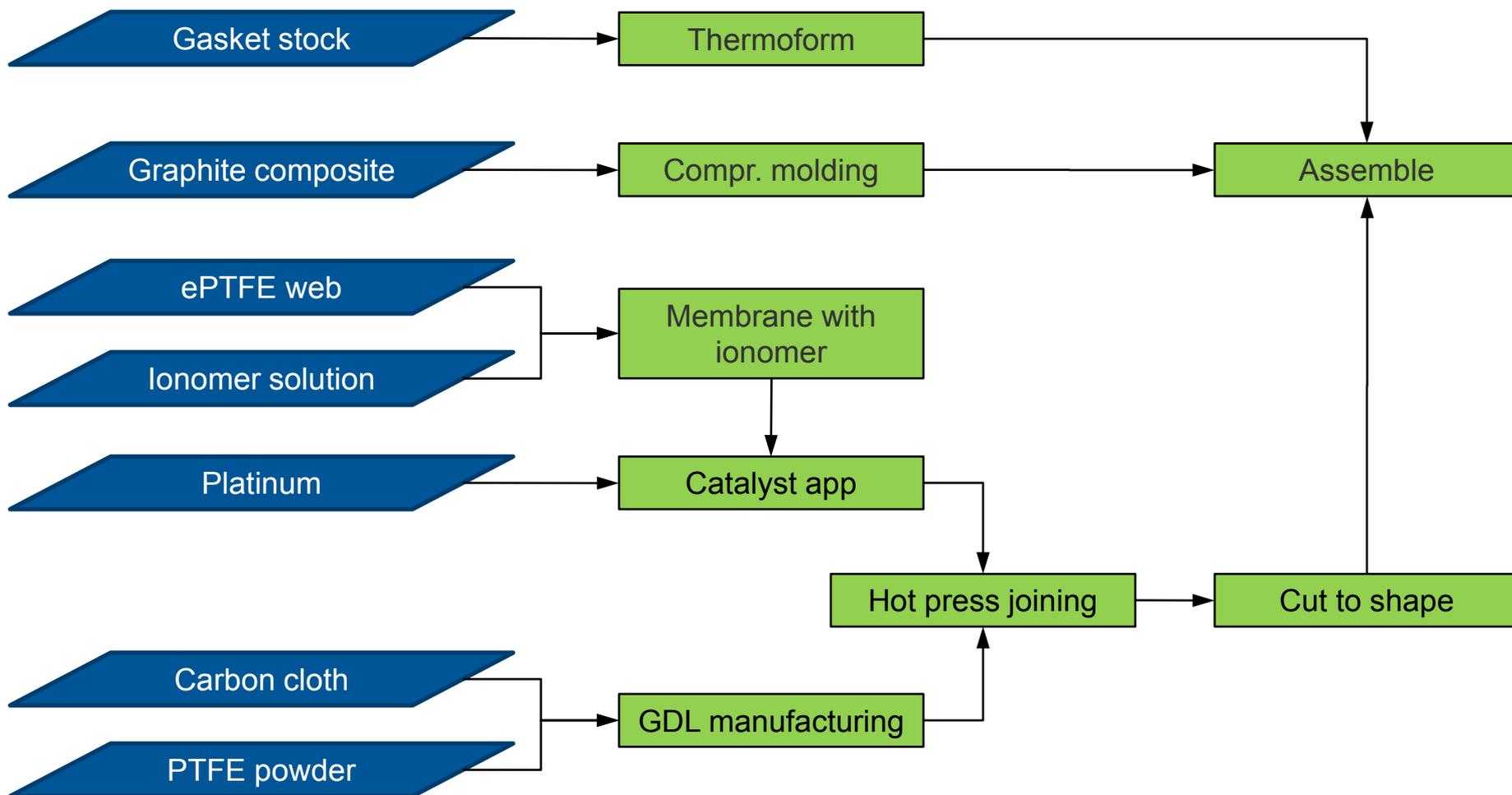
- Use the Boothroyd-Dewhurst estimating software
- Employed standard process models whenever they exist
 - Gaskets, end plates
- Developed custom models as needed
 - Parametric equations running behind BDI DFMA[®] user interface
 - Models based on both fundamental and empirical formulations

The screenshot displays the 'DFM Concurrent Costing 2.3' software interface. The main window title is 'Bipolar plate anode produced by Compression molding'. The interface is divided into several sections:

- Process Tree:** A tree view on the left shows the process steps: 'Compression molding' (selected), 'Setup/load/unload', 'Preform', 'Compression mold', and 'Post bake'.
- Parameters:** A list of input parameters on the right, including:
 - Parts per cycle: 1
 - Raw material cost, \$/kg: 11.01
 - Material density, g/cm³: 1.9
 - Press temperature, deg C: 160
 - Press time, s: 180
 - Required compression pressure, kg/cm²: 420
 - Batch size: 5,000
 - Overall plant efficiency, %: 85
 - Machine rate, \$/hr: 25
 - Labor rate, \$/hr: 45
 - Energy cost, \$/kWh: 0.07
- Cost Results Table:** A table comparing 'Previous' and 'Current' costs for various categories.

Cost results, \$	Previous	Current
material	2.31	2.31
setup	0.02	0.02
process	3.56	3.56
rejects		
piece part	5.89	5.89
tooling	0.50	0.50
total	6.39	6.39
- Tooling Investment:** A section showing 'Tooling investment' of 100,000 for both previous and current states.
- Notes:** A red text note at the bottom states: 'These results are not based on a standard cost model from Boothroyd Dewhurst, Inc. They are based on a user process cost model added by Battelle Memorial Institute.'

Technical Accomplishments Manufacturing Process Overview Diagram



Preliminary analysis - do not cite or quote

Technical Accomplishments

Material and Process Assumptions

Material	Cost (\$)	Measure
Platinum	1100	troy oz
ePTFE web	5	m ²
Nafion® NR50	250	kg
Carbon cloth	50	m ²
Carbon powder	18	kg
PTFE polymer	18	kg
BMC 940 for Bipolar Plate	11	kg

- Catalyst ink composition:
 - 32% platinum
 - 48% carbon powder
 - 20% Nafion®
- Catalyst loading:
 - Anode: 0.1 mg/cm²
 - Cathode: 0.3 mg/cm²

Process Assumptions	Parameter
Membrane manufacturing process	Roll-to-roll
Process line speed	10 m/min
Roll length	1000 ft
ePTFE roll width	1 m
Carbon cloth	1 m
Overall plant efficiency	85%

Process Assumptions	Value
Scrap rate	Varies
Inspection steps included in processing	None
Labor cost	\$45/hr
Machine cost*	\$25/hr
Energy cost	\$0.07/kW-h
Setup operations per roll	1
Operators on membrane line	3
Operators on all other lines	1

*note that energy cost of high power machines is included in processing cost

Technical Accomplishments

Scrap/Reject Rate Assumptions

Scrap/Reject Rates	
Membrane fabrication	30%
Catalyst application	30%
GDL fabrication	30%
MEA Hot Pressing	5%
Slit to width	0.5%
Slit and cut	0.5%
Compression molding	
Pre-form	0.5%
Mold	1%
Post bake	1%
Die cast end plate	
Die casting	0.5%
Thread tapping	0.5%
Testing and conditioning	5%

Technical Accomplishments

Capital Cost Assumptions

Capital Cost	Unit Cost	Units	Total Cost (2010\$)	Assumption/Reference
Factory Total Construction Cost	250	\$/sq.ft.	4,034,780	Includes Electrical Costs (\$50/sq.ft.). Total plant area based on line footprint plus 1.5x line space for working space, offices, shipping, etc
Production Line Equipment Cost (2,000 units/year, constant production)	varies by component		9,665,000	Year 1 (2,000 units) – 1 Membrane mfg. line, 1 Catalyst Application line, 1 GDL Manufacturing line, 1 Membrane slit line, 1 GDL slit line, 1 MEA press, 1 MES slit and cut line, 1 Bipolar plate press, 1 Assembly station, 2 Testing stations. (\$9.6M)
Additional Line Equipment Cost (Increased Production Levels Years 2-6)	varies by component		28,865,000	Year 2 (4,500 units/year) - 1 Bipolar plate press, 2 Testing stations. (\$800K) Year 3 (10,000 units/year) - 2 Bipolar plate presses, 1 Assembly station, 5 Testing stations. (\$1.65M) Year 4 (21,000 units/year) - 3 Bipolar plate presses, 3 Assembly Stations, 9 Testing Stations. (\$2.55M) Year 5 (46,000 units/year) - 1 MEA Press, 1 MEA slit and cut, 9 Bipolar plate presses, 5 Assembly Stations, 21 Testing Stations. (\$8.2M) Year 6 (100,000 units/year) - 1 MEA press, 1 MEA slit and cut, 18 Bipolar plate presses, 10 Assembly Stations, 45 Testing Stations. (\$15.7M)
Forklifts	25,000	\$/lift	50,000	Assumes 2 forklifts with extra battery and charger.
Cranes	66,000	\$/crane	198,000	5 ton crane, 20' wide per line
Real Estate	125,000	\$/acre	125,000	Assumes 1 acre of vacant land, zoned industrial Columbus, OH
Contingency	10% CC		1,407,280	Construction Estimation Assumption
Total			15,780,060 – 44,645,060	Baseline CC (2,000 units/year) – Max CC (100K units/year)

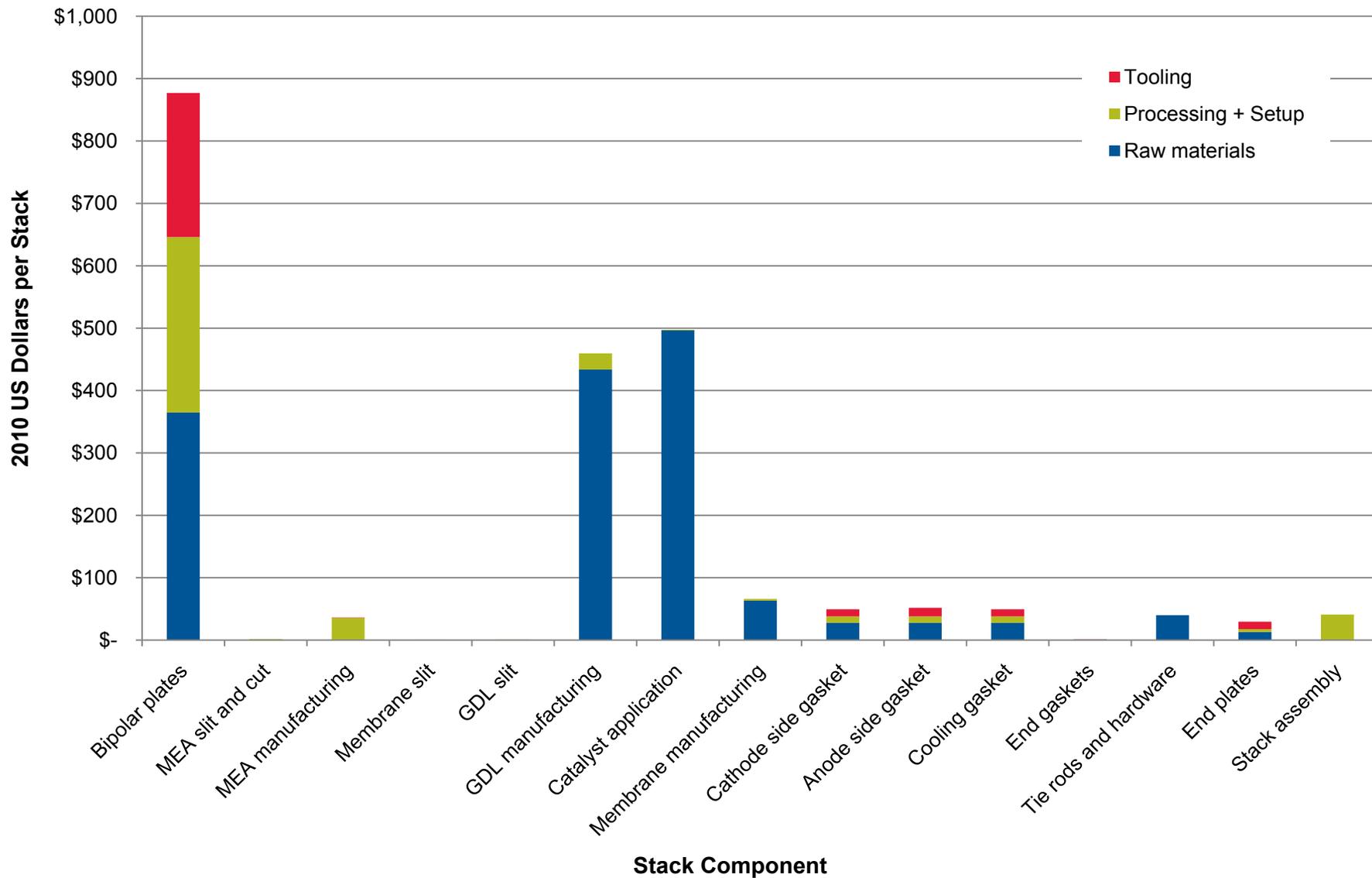
Technical Accomplishments

Stack Manufacturing Cost Summary

Stack Component	2010 cost per stack	Qty per stack	Qty per cell	2010 cost each
Bipolar plates	\$ 876	154	2	\$ 5.69
MEA	\$ 1,053	77	1	\$ 13.98
Cathode side gasket	\$ 49	77	1	\$ 0.64
Anode side gasket	\$ 52	77	1	\$ 0.68
Cooling gasket	\$ 49	77	1	\$ 0.64
End gaskets	\$ 1	2		\$ 0.64
Tie rods and hardware	\$ 40	8		\$ 5.00
End plates	\$ 30	2		\$ 14.88
Stack assembly	\$ 41	1		\$ 40.89
Stack total	\$ 2,215			

All costs include manufacturing scrap

Stack Component Manufacturing Cost Breakdown (includes scrap cost)



Technical Accomplishments

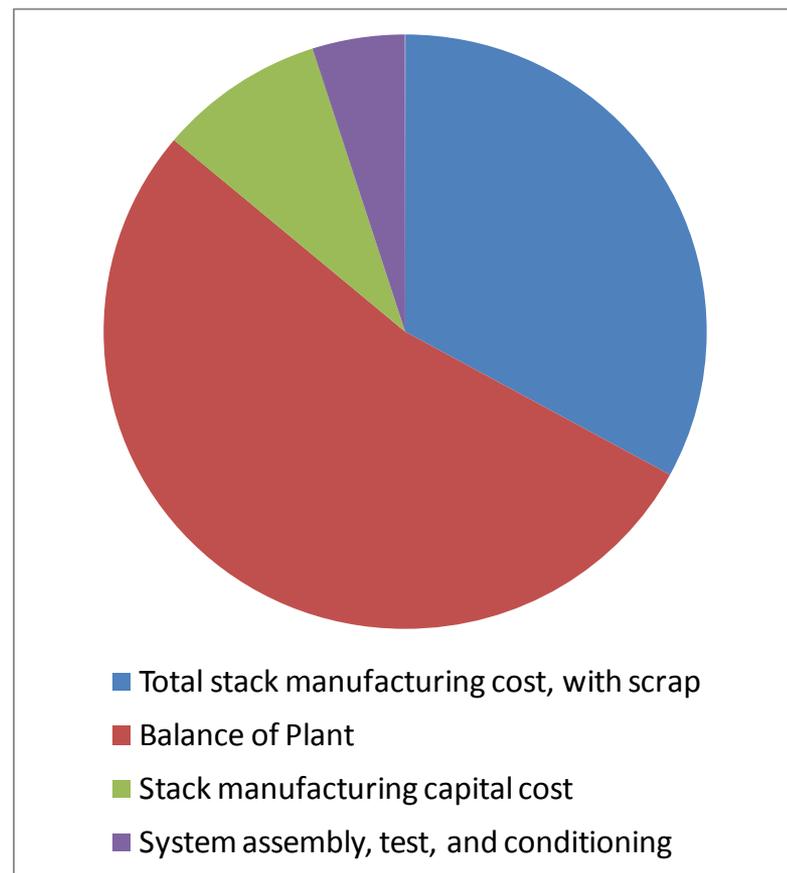
Balance of Plant (BoP) Cost Summary

Component	Unit Cost*
Air Filter (Cooling Air)	\$28
Fan (Cooling Air)	\$155
Blower (Cooling Air)	\$150
Air Filter (Cathode Air)	\$83
Blower (Cathode Air)	\$320
Flow Meter (Cathode Air)	\$99
Relief Valve	\$130
Anode Purge Valve	\$40
Stack Temperature Sensor(s)	\$18
Stack Current Sensor	\$15
Stack Voltage Sensor	\$60
DC/DC Converter	\$1,250
Fuel Cell ECU	\$380
H2 Shutoff Valve	\$55
Enclosure Heater	\$30
Enclosure Heater Relay	\$3
Assorted Plumbing/Fittings	\$160
Buss Bar	\$16
H2 Sensor	\$124
Wiring and Connectors	\$50
Assembly Hardware	\$30
Frame	\$207
Total	\$3,403
\$/kW (net)	\$681

*Based on quantity of 2,000 units

System Manufacturing Cost Summary

Description	Value
Total stack manufacturing cost, with scrap	\$ 2,215
Stack manufacturing capital cost	\$ 570
BOP	\$ 3,403
System assembly, test, and conditioning	\$ 318
Total system cost	\$ 6,506
System cost per KW_{net}	\$ 1,301



* Stack cost based on high quantity manufacturing process in place. BoP cost based on purchase price for 2,000 units.

Sensitivity Analysis

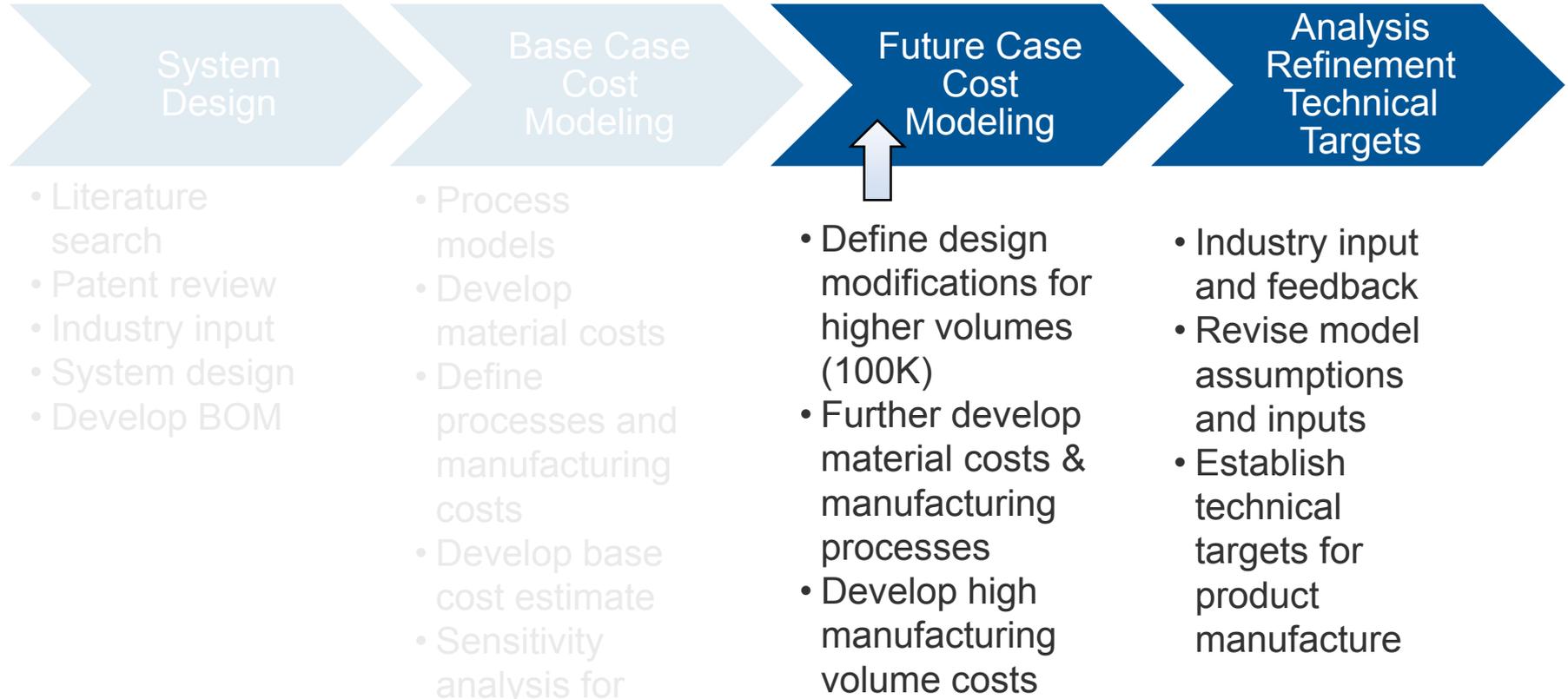
Selected Material Cost Sensitivities						
Stack area	2.30 m ²					
Stack output	7 kW _{gross}					
	Current Value		Change			
	Current Value		Value	\$/m ²	\$/stack	\$/kW _{gross}
Carbon cloth	50 \$/m ²		-10 \$/m ²	-14.29	-65.67	-9.38
Nafion®	250 \$/kg		-50 \$/kg	-3.75	-8.62	-1.23
Pt Loading	0.4 mg/cm ²		-0.1 mg/cm ²	-50.82	-116.77	-16.68
Pt Cost	1100 \$/tr.oz.		+100 \$/tr.oz.	+18.37	+42.21	+6.03
PTFE	18 \$/kg		-5 \$/kg	-4.5	-10.34	-1.48
ePTFE web	5 \$/m ²		+5 \$/m ²	+7.14	+16.41	+2.34

Summary

Opportunities for Cost Reduction

- Primary opportunities for cost reduction
 - Bipolar Plates
 - Material and process
 - Potential alternatives needing technology advancements
 - Stamping of metal plates
 - Injection molding
 - MEA material costs
 - Carbon cloth
 - Platinum loading
 - DC/DC converter
- Continuing to gather data, refine costs and update model
- Considering various design changes for 2015 design. Top candidates under consideration include:
 - metal bipolar plates
 - reduced catalyst loading

Future Work Next Steps

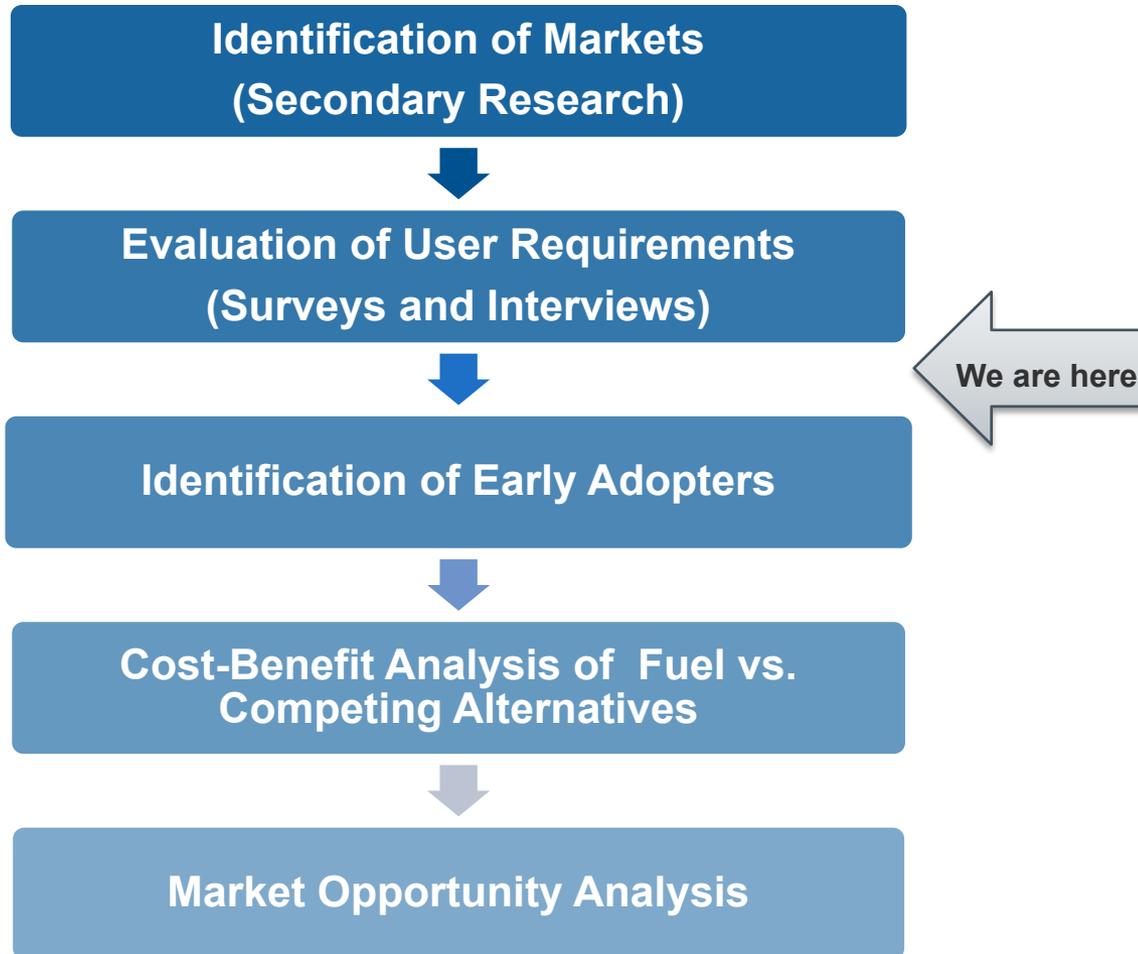


- Considering various design changes for 2015 design. Considering:
 - Metal bipolar plates
 - Reduced catalyst loading
- Seeking industrial input for other considerations

MicroCHP Technical Accomplishments

Approach

Economic and Market Opportunity Assessment for MicroCHP



Summary

MicroCHP Market Analysis

Parameter	Description
Technology Application	<ul style="list-style-type: none"> • Combined heat and power for residential – single and multi-family dwellings and small commercial applications
Current Market	<ul style="list-style-type: none"> • In 2008, global micro-CHP markets reached 100,000 units • Annual commercial sales comprised of 33.5 MW of micro-CHP and a market size of \$245 million
Target Markets for PEM Fuel Cells in the U.S.	<ul style="list-style-type: none"> • Areas with high electricity rates and high heat requirements • Regions with high spark spread • Areas where the grid is not reliable, remote locations with no power distribution • Consumers interested in 'being green' – reducing their carbon footprint, consumers interested in 'high-tech' products
Competing Alternatives	<ul style="list-style-type: none"> • Photovoltaics, Solar Thermal, Boilers, Heat pumps
Size of Systems	<ul style="list-style-type: none"> • 3-5 kW
Cost of PEM Fuel Cells Vs. Competing Alternatives	<p>PEM Fuel Cell - \$35-50,000 ICE - \$6-22,000 Boilers, heat pumps, and gas fired furnaces - \$5000 to 8,000 PV - \$7,000 - \$9,000</p>
Market Drivers	<ul style="list-style-type: none"> • Cost • Reliability and durability • Ease of use • Familiarity and confidence in product
Market Requirements	<ul style="list-style-type: none"> • Grid parallel operation • Overall unit efficiency • High power to heat ratio • Well designed system - optimal sizing (power-to-heat ratio) to ensure optimal performance (engineering) • Intuitive control interface for end user • Commissioning and integration with rest of the heating system • Lifetime of 15 years (total operating time – 60,000-80,000 hours)

Future Work

Next Steps

