Economic Analysis of Stationary PEM Fuel Cell Systems

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

Battelle

June 8, 2010

Project Id: FC050

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

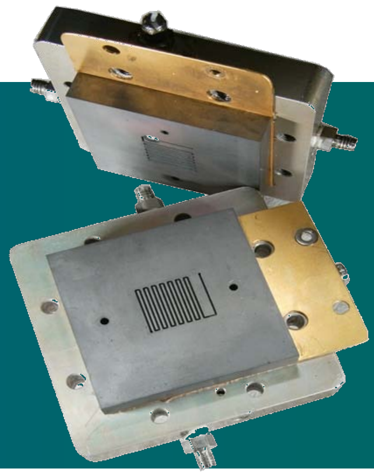
- Total Project Funding: DOE Share $3,163,843 and No Contractor Cost Share
- Funding received in FY04: $526,548
- Funding received in FY05: $650,659
- Funding received in FY06: $599,013
- Funding received in FY07: $703,283
- Funding received in FY08: $684,340
- Funding received in FY 09: $300,000

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.*

Battelle
The Business *of* Innovation

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

Battelle
The Business *of* Innovation

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

Manufacturing Cost Analysis Task Approach

We are here → Future Case Cost Modeling

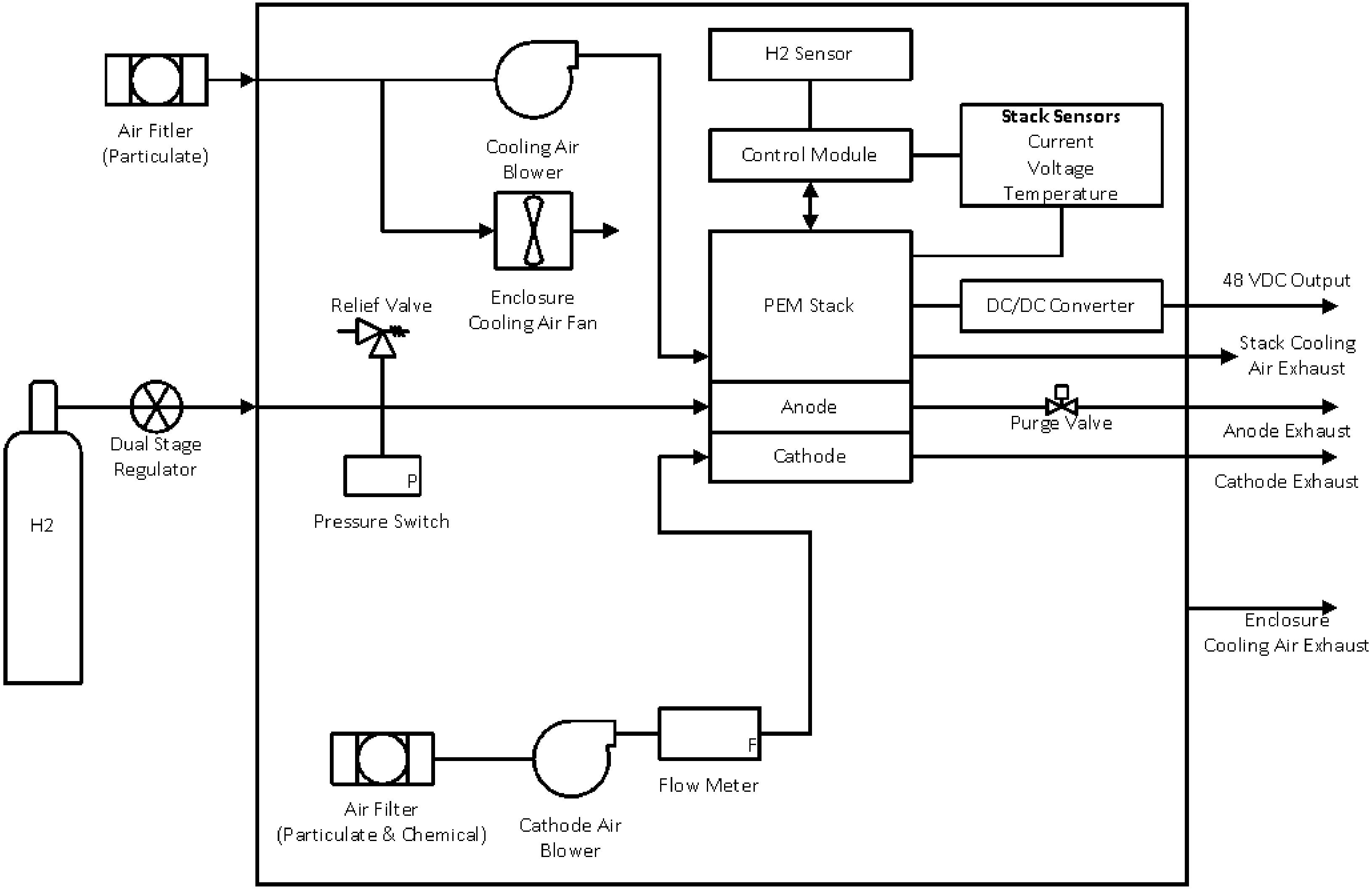
System Design
- Literature search
- Patent review
- Industry input
- System design
- Develop BOM

Base Case Cost Modeling
- Process models
- Develop material costs
- Define processes and manufacturing costs
- Develop base cost estimate
- Sensitivity analysis for base case

Future Case Cost Modeling
- Define design modifications for higher volumes (100K)
- Further develop material costs & manufacturing processes
- Develop high manufacturing volume costs

Analysis Refinement Technical Targets
- Industry input and feedback
- Revise model assumptions and inputs
- Establish technical targets for product manufacture

Technical Accomplishments
System Design



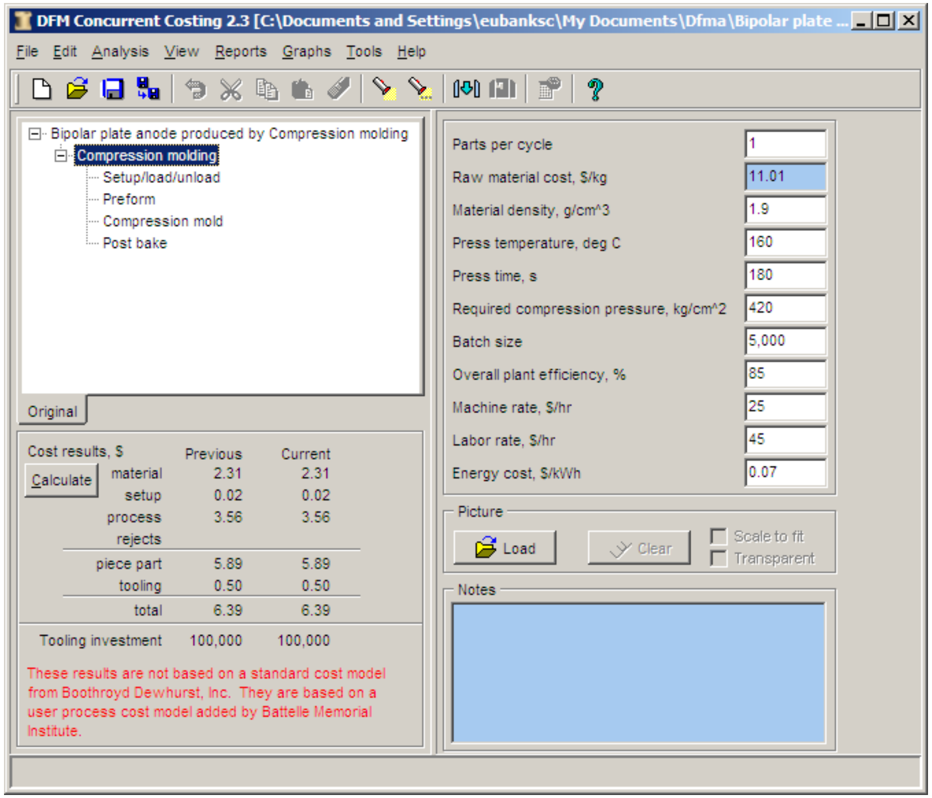
Technical Accomplishments
System Design and Stack Assumptions

Design Assumptions
Air-cooled system
Bipolar plate material is composite polymer with graphite
Membrane is reinforced with ePTFE base
77 cells in stack producing total of 5 kW net output
Membrane size is 230x135 mm (9.1x5.3 in) with 175x80 mm (6.9x3.1in) active area
GDL and catalyst are applied to entire membrane and not just the active area
No separate humidification is required
0.4 mg/cm^2 total Platinum loading

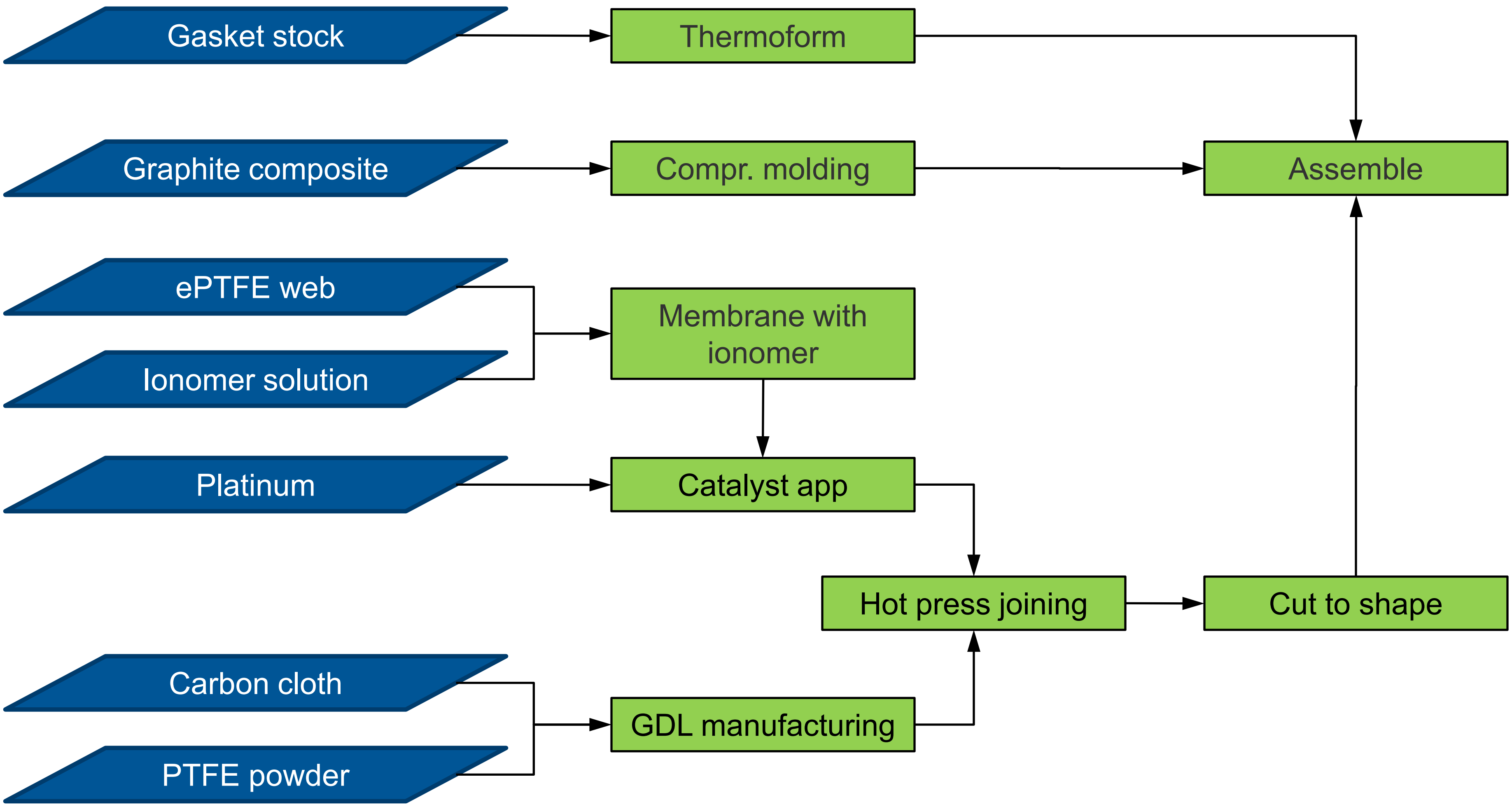
Stack Specification	Value
Net Power Output	5 kW
Gross Power Output	7 kW
Cell Voltage	0.65 V
Current Density	1 A/cm^2
Stack Voltage	50 V
Number of Cells	77
Active Area per Cell	140 cm^2
Power Density	650 mW/cm^2

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



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/cm^2
  - Cathode: 0.3 mg/cm^2

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)

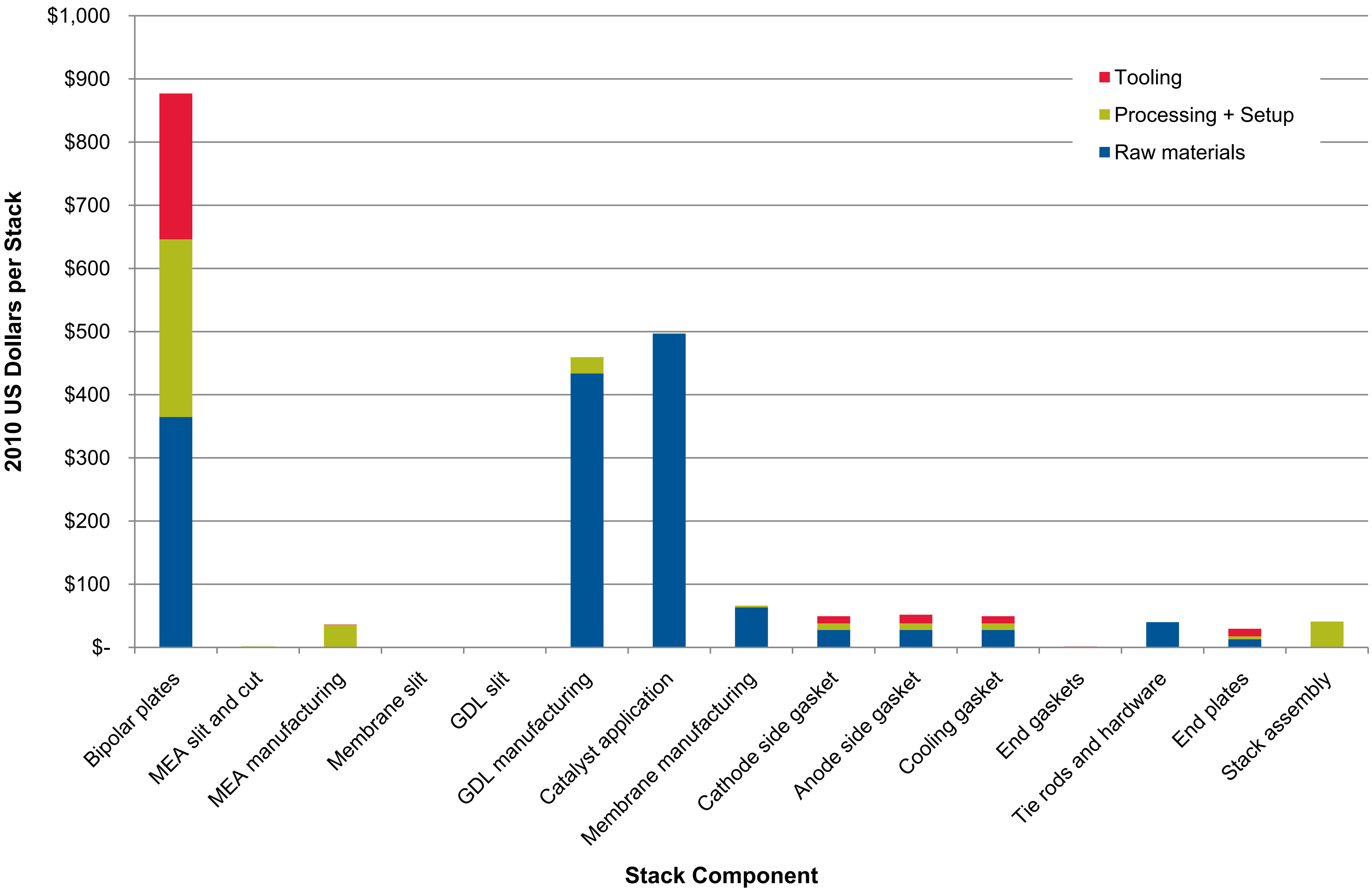
Technical Accomplishments

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)



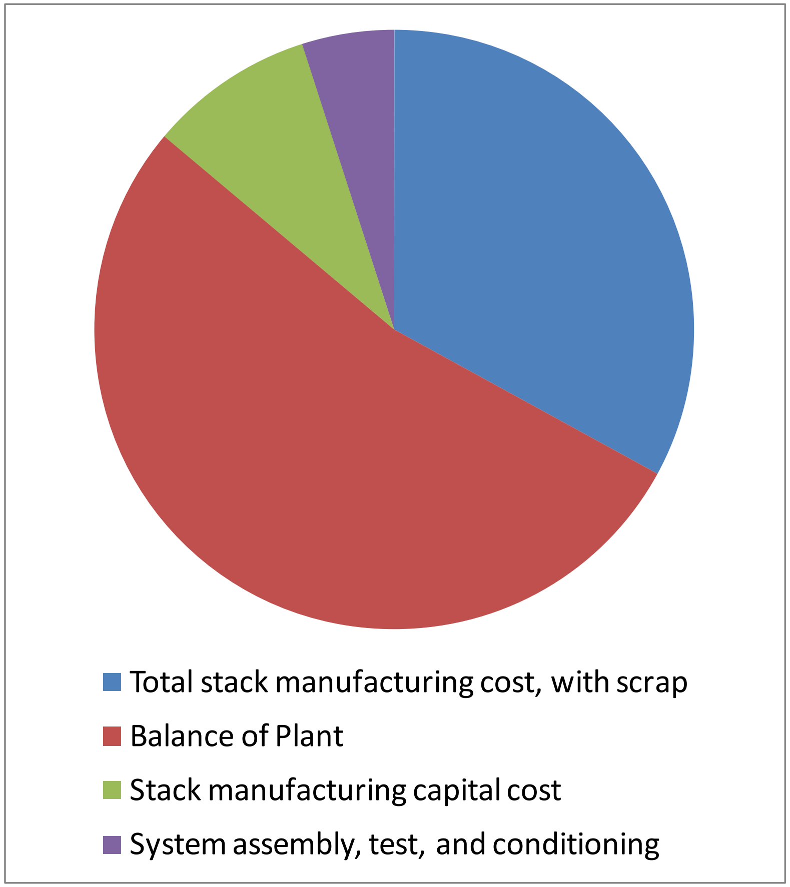
Technical Accomplishments
Balance of Plant (BoP) Cost Summary

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}						
			Change					
	Current Value		**Value**		**$/m²**	**$/stack**	**$/kW$_{gross}$**	
Carbon cloth	50	$/m²	-10	$/m²	-14.29	-65.67	-9.38	
Nafion®	250	$/kg	-50	$/kg	-3.75	-8.62	-1.23	
Pt Loading	0.4	mg/cm²	-0.1	mg/cm²	-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	$/m²	+5	$/m²	+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

System Design
- Literature search
- Patent review
- Industry input
- System design
- Develop BOM

Base Case Cost Modeling
- Process models
- Develop material costs
- Define processes and manufacturing costs
- Develop base cost estimate
- Sensitivity analysis for

Future Case Cost Modeling
- Define design modifications for higher volumes (100K)
- Further develop material costs & manufacturing processes
- Develop high manufacturing volume costs

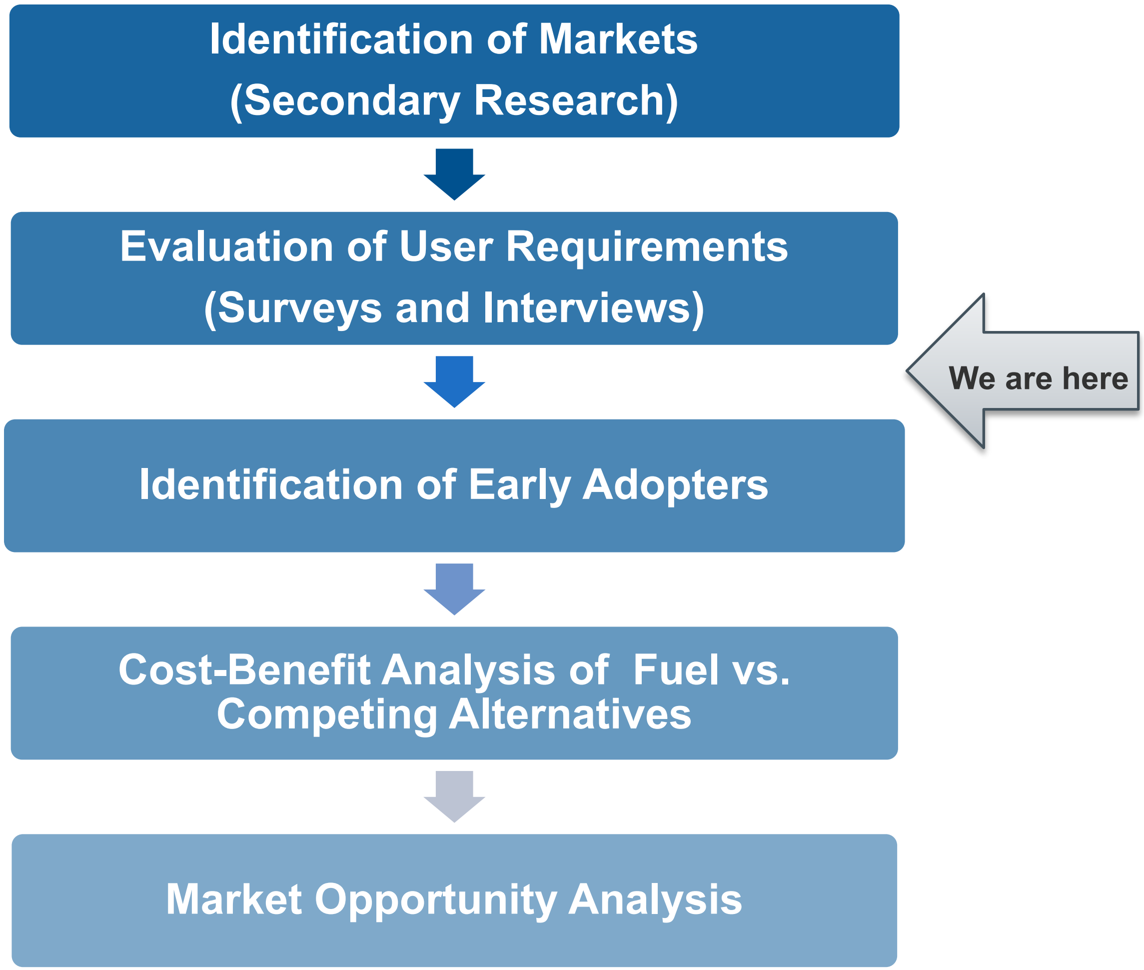
Analysis Refinement Technical Targets
- Industry input and feedback
- Revise model assumptions and inputs
- Establish technical targets for product manufacture

- 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	• Combined heat and power for residential – single and multi-family dwellings and small commercial applications
Current Market	• 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.	• 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	• Photovoltaics, Solar Thermal, Boilers, Heat pumps
Size of Systems	• 3-5 kW
Cost of PEM Fuel Cells Vs. Competing Alternatives	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
Market Drivers	• Cost • Reliability and durability • Ease of use • Familiarity and confidence in product
Market Requirements	• 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

Identification of Markets (Secondary Research)

↓

Evaluation of User Requirements (Surveys and Interviews)

↓

Identification of Early Adopters

↓

Cost-Benefit Analysis of Fuel vs. Competing Alternatives

↓

Market Opportunity Analysis

Complete market opportunity assessment and identification of early markets