Portable Power Fuel Cell Manufacturing Cost Analyses

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Due diligence objective was to assess cost implications of portable power fuel cell systems being rated at 2W, 25W, 250W, and 5kW.

System Configurations

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Fuel Cell Cost Assessments

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Results:

- *Cost of fuel cell systems*
- *Identification of factors with significant impact on fuel cell system costs*
- *Identification of areas where more research could lead to significant reductions in fuel cell cost*

We employed a parametric approach in which Austin Power Engineering's fuel cell cost model was applied many times with different sets of input parameters.

INPUTS

- System power
- Cell voltage
- Power density
- System voltage
- Pt loading
- Pt price
- Membrane type
- Membrane thickness
- Bipolar plate material
- Bipolar plate thickness
- Production volume
- . . .

APPLICATION

Cost Model

ANALYSES*

- Economies of scale
- Single variable sensitivity analysis
- Monte Carlo simulation
- Scenario analysis
- System cost comparison
- Life cycle cost analysis

OUTPUTS

- System cost
- Stack cost
- Component cost
- Factors with significant influence on fuel cell cost

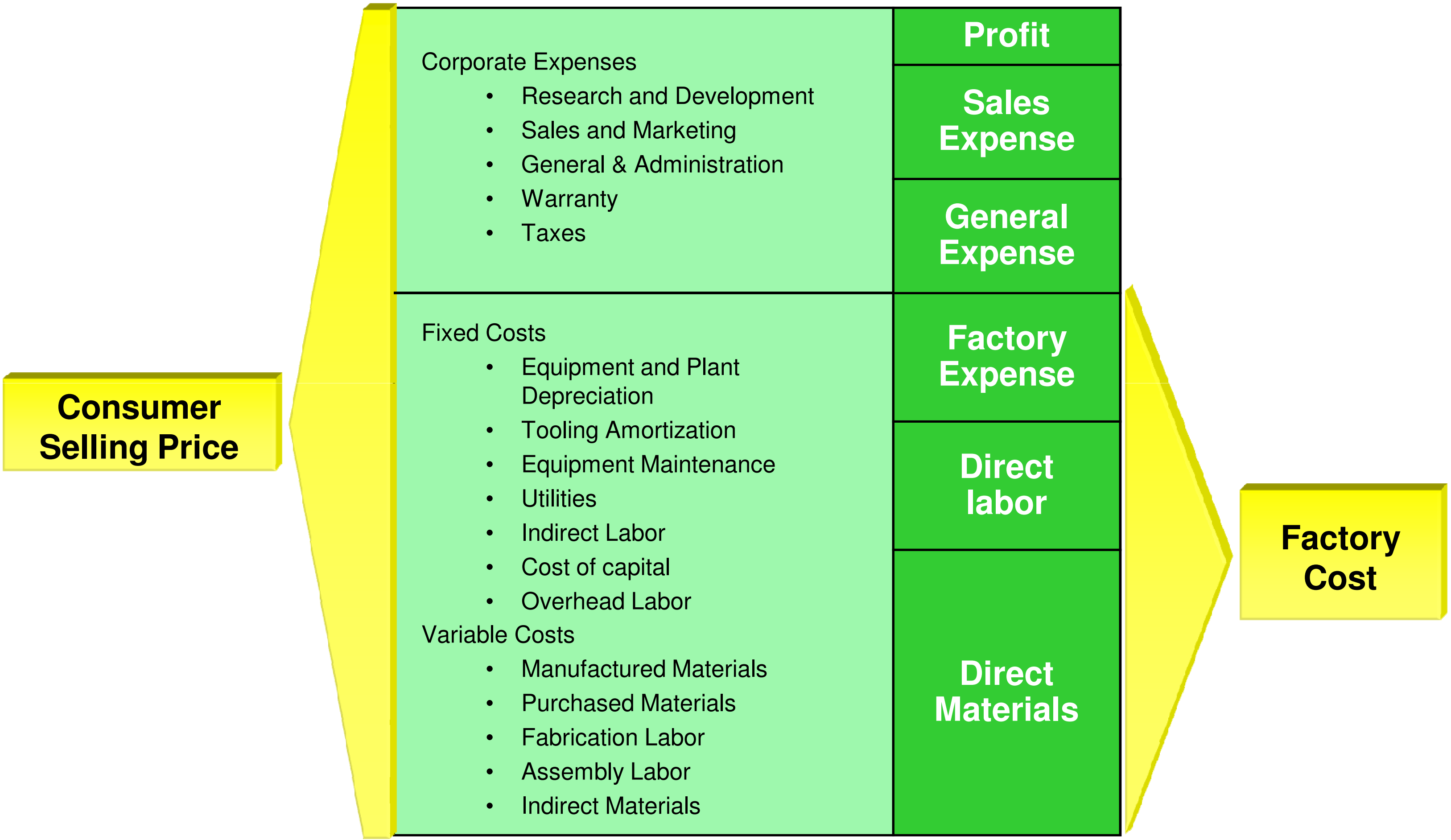
* Not shown in this presentation

The information used in this presentation was public available, which was mainly from DOE reports, patents, Journal papers, etc.

This approach has successfully used for estimating the cost of fuel cell technologies for commercial clients and the DOE.

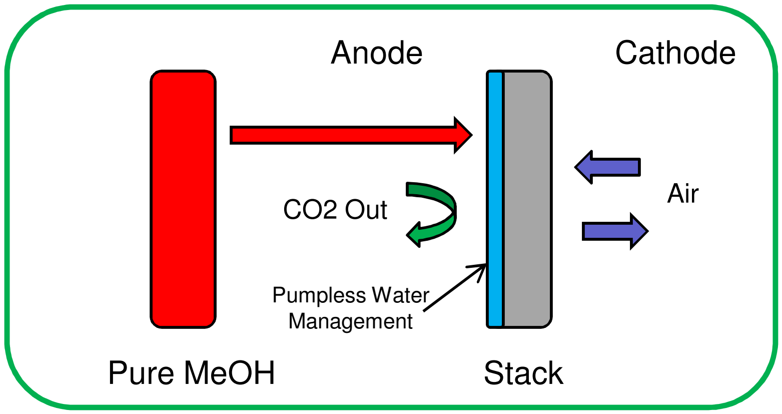
Technology Assessment	Manufacturing Cost Model	Scenario Analysis
• Definition of system and component diagrams • Definition of technology options • Kinetic analysis to size the components • Develop component designs and integrate into system with piping, controls, and sensors • Develop bill-of-materials for cost model	• Define value chain with split between purchased and internally fabricated materials and components • Develop processes for internally produced items • Specify production volumes and other manufacturing parameters • Assemble bottom-up activities based cost model (fixed and variable costs, yields, scrap, recycle, …) • Develop baseline cost	• Pareto of cost contributors •Sensitivity analysis to individual cost contributors •Monte Carlo analysis of impact of uncertainty on cost estimate •Technology scenarios (system configuration, technology options, performance assumptions) •Production volume scenarios

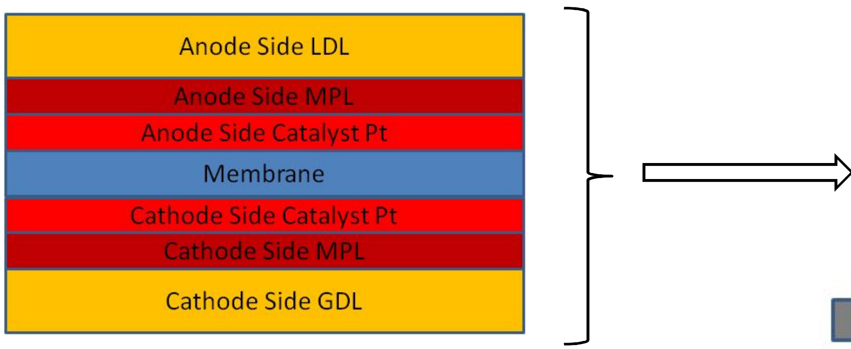
Austin Power Engineering manufacturing cost models can be used to determine fully loaded selling price to the consumer, at high or low volumes.



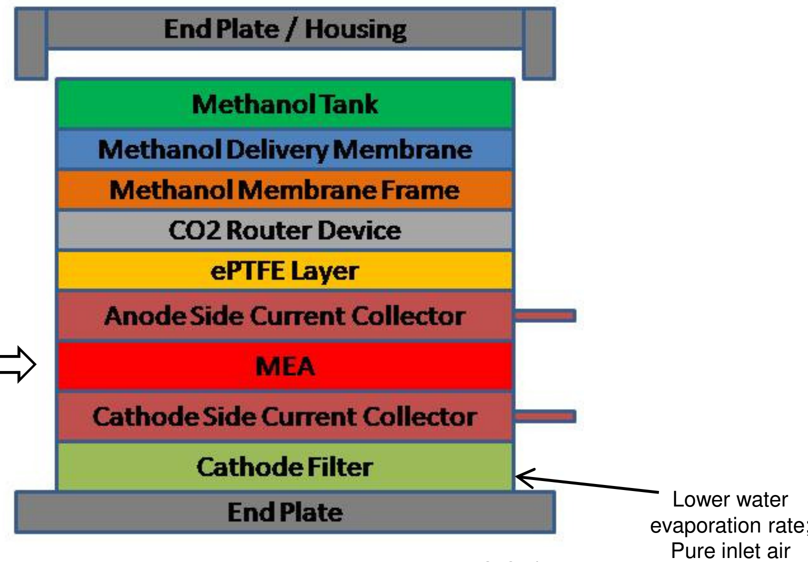
Factory cost will only be considered in the cost analyses.

The system configuration of the portable fuel cell application under 2W was referenced from MTI Mobion® type passive DMFC structure.





2W DMFC MEA Structure[2, 3, 4]



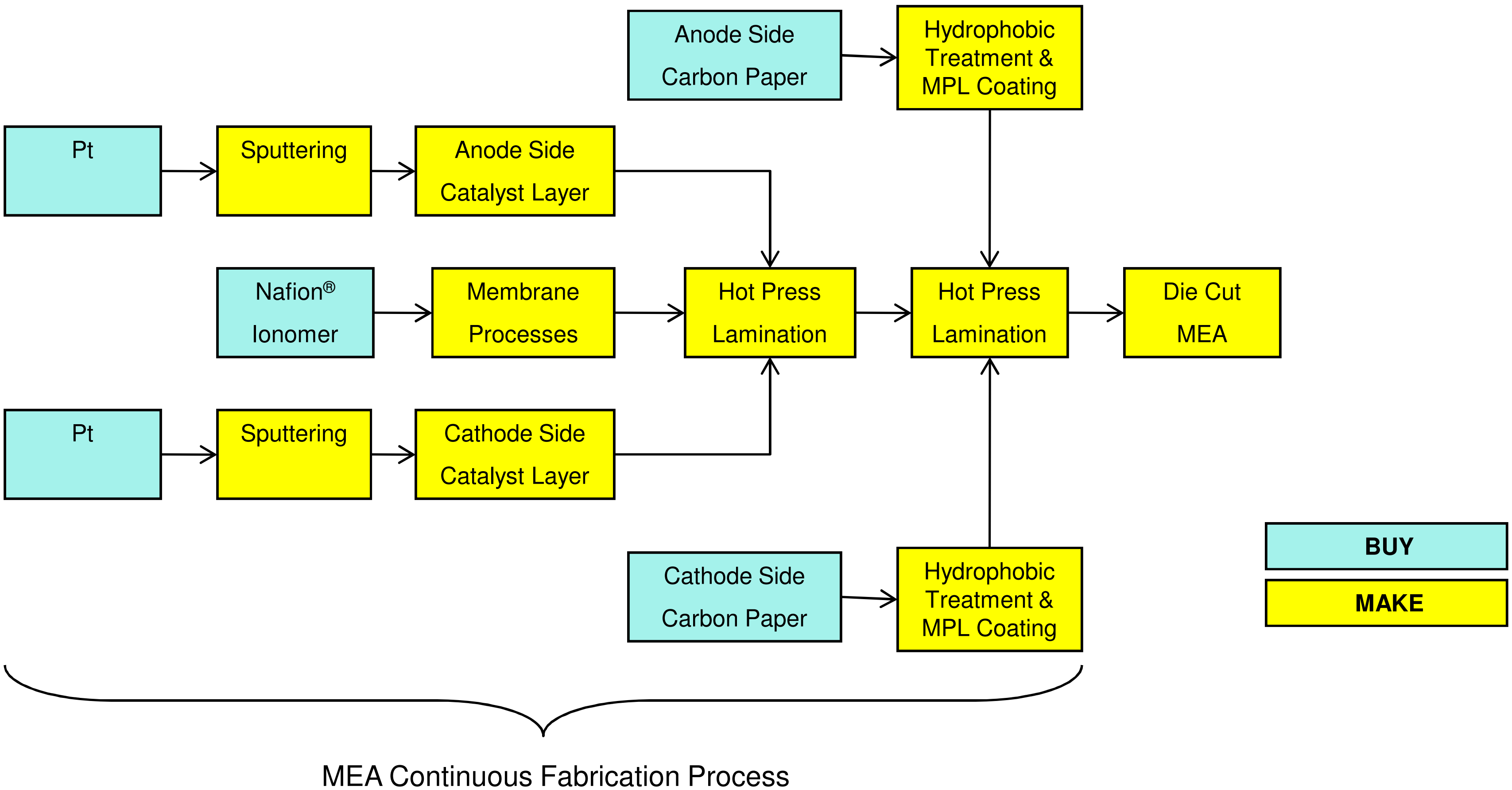
2W DMFC Stack Structure[2, 3, 4]

1. P. Lim, “MTI Micro’s latest development of fuel cells system for mobile use”, 6th Int’l Hydrogen & Fuel Cell Expo, 2010
2. Referenced from US patent: 7,407,721; 7,282,293; 7,297,430; 7,179,501
3. U.A. Icardi, “Compact direct methanol fuel cells for portable application”, Journal of Power Sources 176 (2008) 460–467
4. K. Song, “MEA design for low water crossover in air-breathing DMFC”, Electrochimica Acta 53 (2007) 637–643
5. T. Shimizu, “Design and fabrication of pumpless small direct methanol fuel cells for portable applications”, Journal of Power Sources , 137 (2004) 277–283

As a passive system, the designed fuel cell did not have fuel pump and air blower.

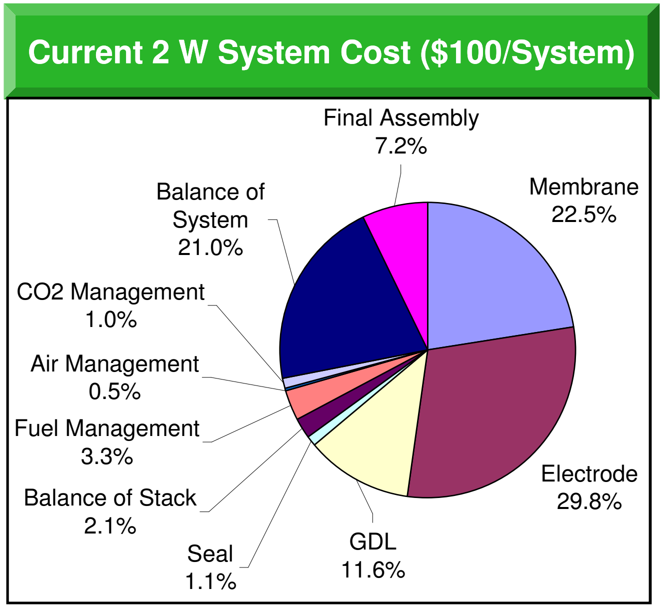
Stack Components	Unit	Current System	Comments
Production volume	systems/year	25,000	DOE input
Stacks' new power	W	2	
Stacks' gross power	W	2.2	Electronics efficiency loss
Stacks' gross power density	mW/cm^2	50	
Max. Stack Temp.	Degree C	40	
Cell Voltage	V	0.6	
Stack Voltage	V	0.6	
Active Area Size	cm^2	49	Calculated
Platinum price	\$/tr.oz. (\$/g)	\$1,100 (\$35.4)	Same as DOE automotive PEMFC
Pt Loading	Mg/cm^2	6	
Membrane Type		Nafion®	
Membrane Thickness	micro meter	50	
GDL Layer		None-woven Carbon Paper	
GDL Thickness	micro meter	185	@50 kPa pressure
MPL Layer Thickness	micro meter	40	

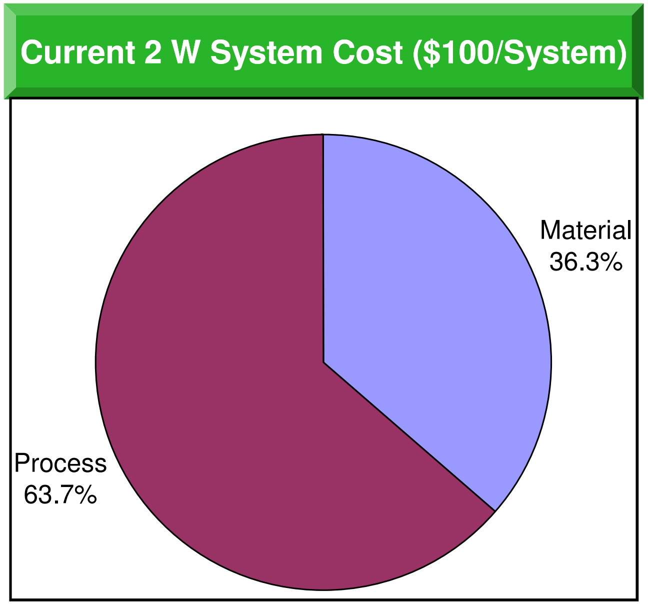
A vertically integrated manufacturing process was assumed for the 2 W stack production.



Assumed a roll-to-roll continuous process for MEA fabrication. Nafion® membrane was used in the model for costing purpose only.

The manufacturing cost analysis was based on an annual production of 25,000 units. Electrode, membrane, and balance of system (Electronics, etc.) were the top three cost drivers.



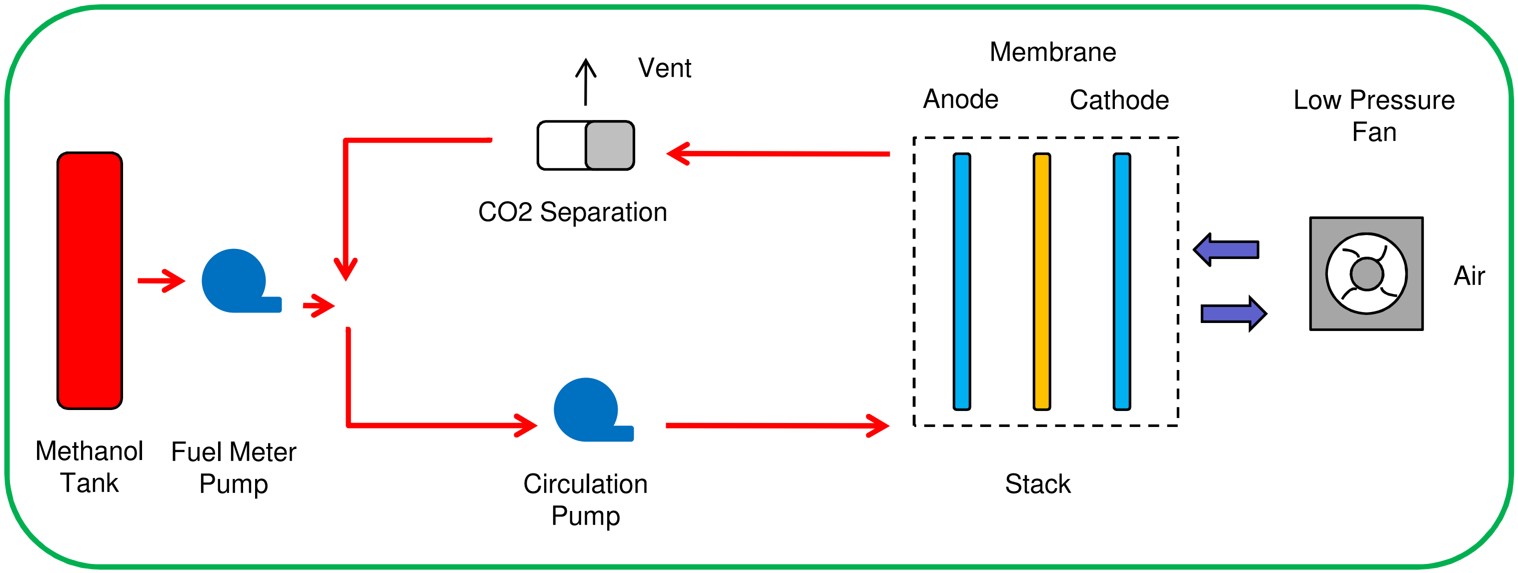


	Unit	Current System
Specific Power	W/kg	6
Power Density[1]	W/L	15
Energy Density[2]	Wh/L	160

[1] Based on total fuel cell system excluding fuel tank, fuel, and any hybridization batteries. Based on total fuel cell
[2] system including sufficient fuel for 5 hours of operation at system rated power.

The low annual production volume leaded to the high process cost.

The 25W system configuration was referenced from Polyfuel type structure, which had passive water recovery MEA.



25 W DMFC system configuration[1, 2]

1. DMFC power supply for all-day true-wireless mobile computing, PolyFuel, 2008; US patent 7,316,855 ;US patent 7,005,206
2. K. Song, "MEA design for low water crossover in air-breathing DMFC", Electrochimica Acta 53 (2007) 637–643

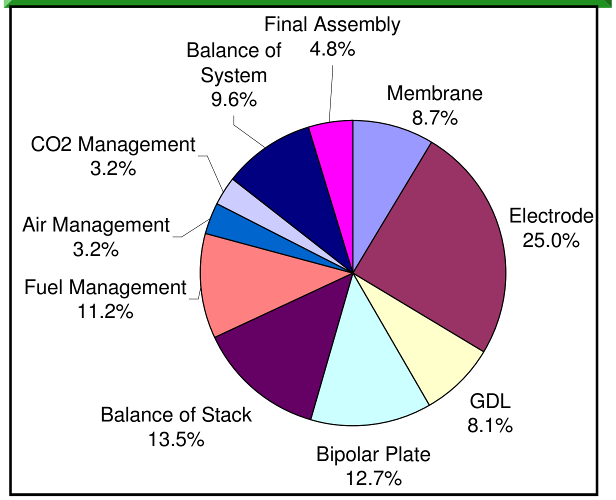
The passive water recovery MEA eliminated water separation and simplified the system structure.

With limited information on Polyfuel type membrane and GDL, the typical Nafion® membrane and carbon paper GDL with MPL were used in the model for costing purpose only.

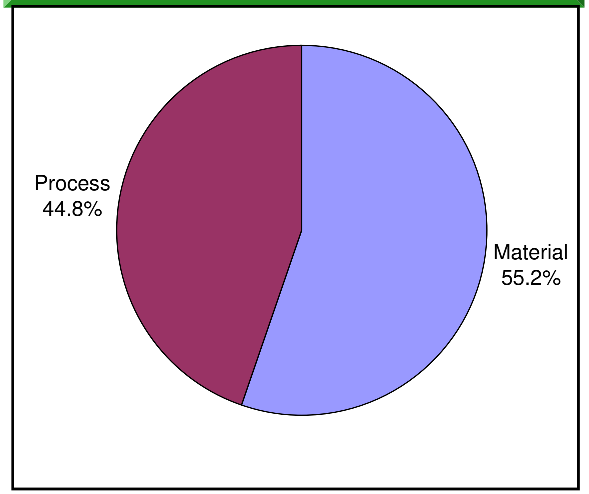
Stack Components	Unit	Current System	Comments
Production volume	systems/year	25,000	DOE input
Stacks' new power	W	25	
Stacks' gross power	W	30	Parasitic loss
Stacks' gross power density	mW/cm^2	60	
Max. Stack Temp.	Degree C	50	
Cell Voltage	V	0.6	
Stack Voltage	V	12	
Active Area Size	cm^2	25	Calculated
# of Cell per Stack	#	20	
Platinum price	$/tr.oz. ($/g)	$1,100 ($35.4)	Same as DOE automotive PEMFC
Pt Loading	Mg/cm^2	3	
Membrane Type		Nafion®	
Membrane Thickness	micro meter	50	
GDL Layer		None-woven Carbon Paper	
GDL Thickness	micro meter	185	@50 kPa pressure
MPL Layer Thickness	micro meter	40	
Bipolar Plate Type		Nitride SS316	100 Um Thick base Mtl.
Bipolar Plate Thickness	mm	1	

The manufacturing cost analysis was based on an annual production of 25,000 units. Electrode, balance of stack(seals, etc.), and metal bipolar plate were the top three cost drivers

Current 25 W System Cost ($12/W)



Current 25 W System Cost ($12/W)

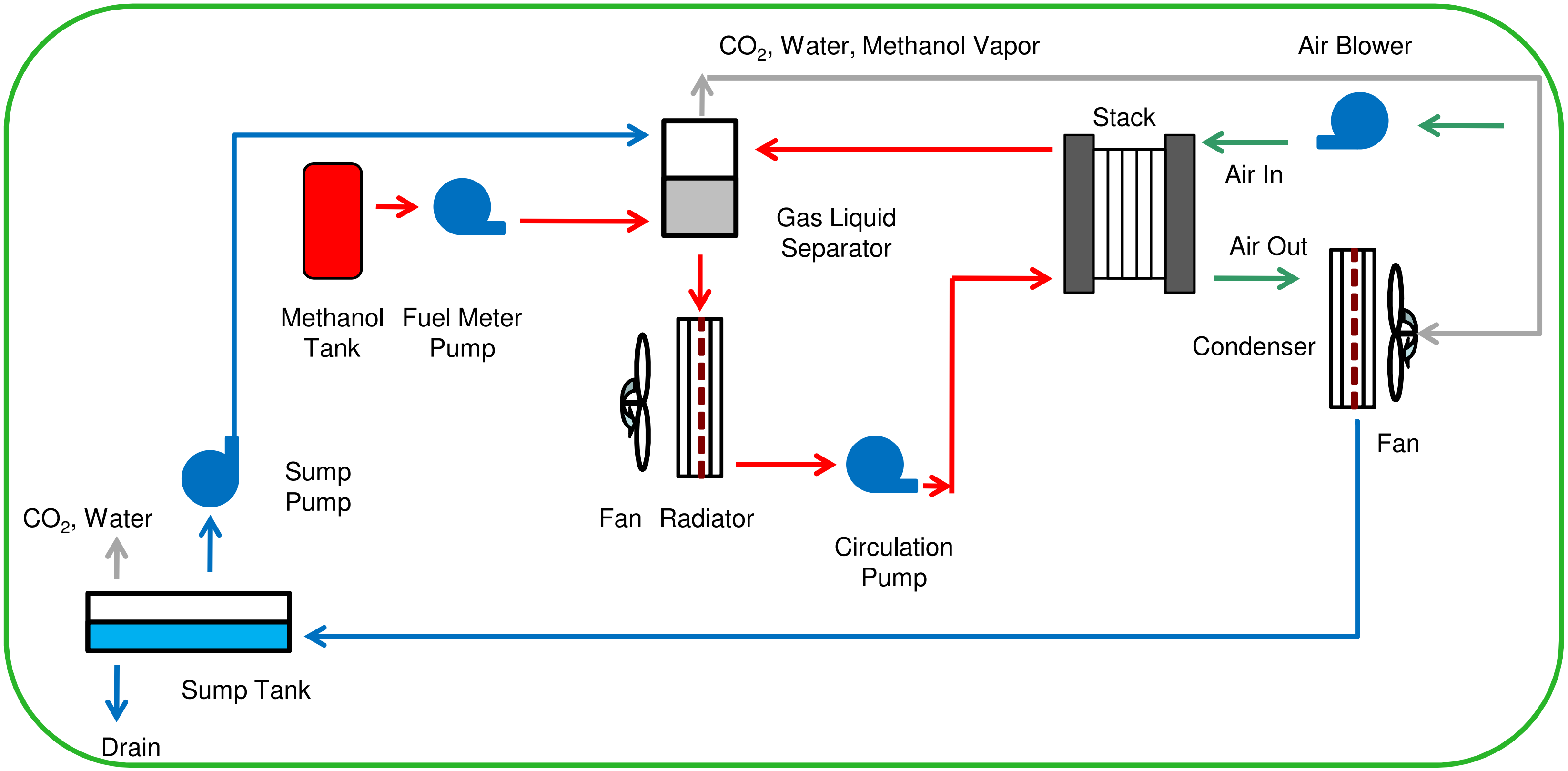


	Unit	Current System
Specific Power	W/kg	23
Power Density[1]	W/L	48
Energy Density[2]	Wh/L	362

[1] Based on total fuel cell system excluding fuel tank, fuel, and any hybridization batteries. Based on total fuel cell
[2] system including sufficient fuel for 5 hours of operation at system rated power.

The low annual production volume leaded to the high process cost. The process cost would drop down once the annual production volume climbing up.

The 250W system configuration was referenced from JPL type active DMFC structure.



250 W DMFC system configuration[1]

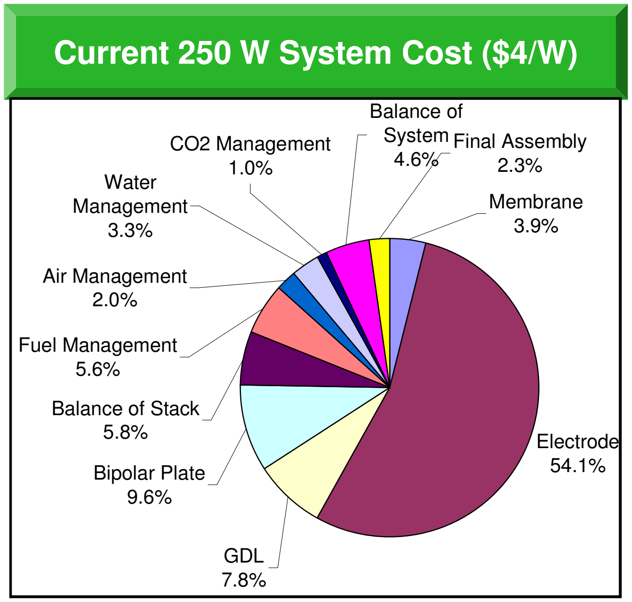
1. High-energy portable fuel cell power sources, S. R. Narayan, The Electrochemical Society Interface. Winter 2008

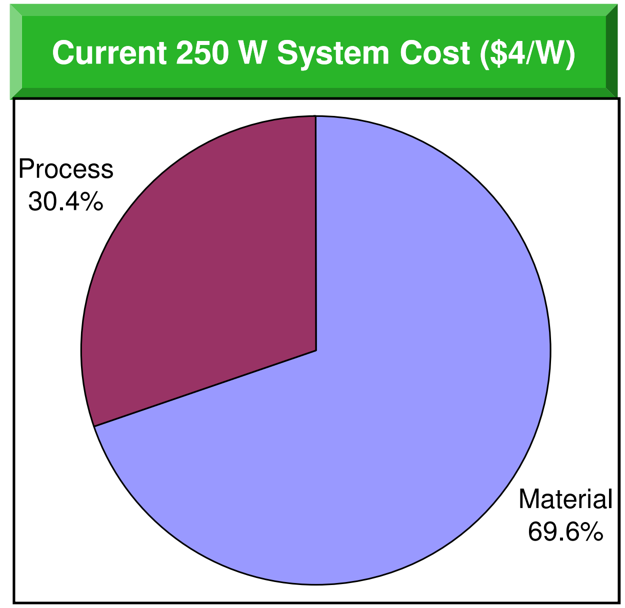
Unlike Polyfuel design, a high pressure air blower and a water separation sub-system was included in the model.

The BOP system included fuel management, air management, water management, CO2 management, electronics, packaging, etc.

Stack Components	Unit	Current System	Comments
Production volume	systems/year	25,000	DOE input
Stacks' new power	W	250	
Stacks' gross power	W	275	Parasitic loss
Stacks' gross power density	mW/cm^2	60	
Max. Stack Temp.	Degree C	50	
Cell Voltage	V	0.6	
Stack Voltage	V	24	
Active Area Size	cm^2	115	Calculated
# of Cell per Stack	#	40	
Platinum price	\$/tr.oz. (\$/g)	\$1,100 (\$35.4)	Same as DOE automotive PEMFC
Pt Loading	Mg/cm^2	3	
Membrane Type		Nafion®	
Membrane Thickness	micro meter	50	
GDL Layer		None-woven Carbon Paper	
GDL Thickness	micro meter	185	@50 kPa pressure
MPL Layer Thickness	micro meter	40	
Bipolar Plate Type		Nitride SS316	100 Um Thick base Mtl.
Bipolar Plate Thickness	mm	1	

The manufacturing cost analysis was based on an annual production of 25,000 units. Electrode, metal bipolar plate, and GDL were the top three cost drivers



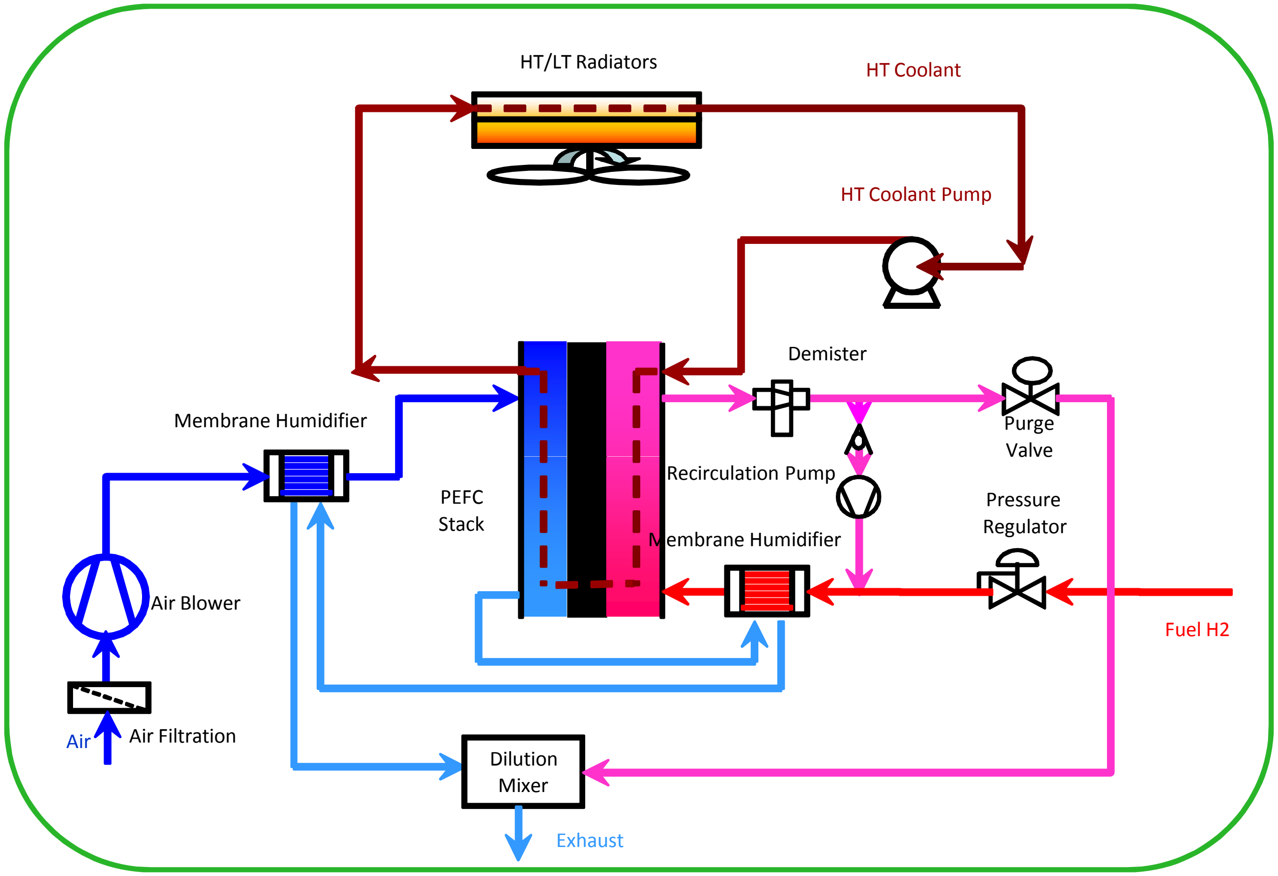


	Unit	Current System
Specific Power	W/kg	53
Power Density[1]	W/L	130
Energy Density[2]	Wh/L	529

[1] Based on total fuel cell system excluding fuel tank, fuel, and any hybridization batteries. Based on total fuel cell
[2] system including sufficient fuel for 5 hours of operation at system rated power.

High Pt loading and large active area size led electrode cost approximately 50% of the system cost.

A 5kW PEM fuel cell system schematic was shown as follow.

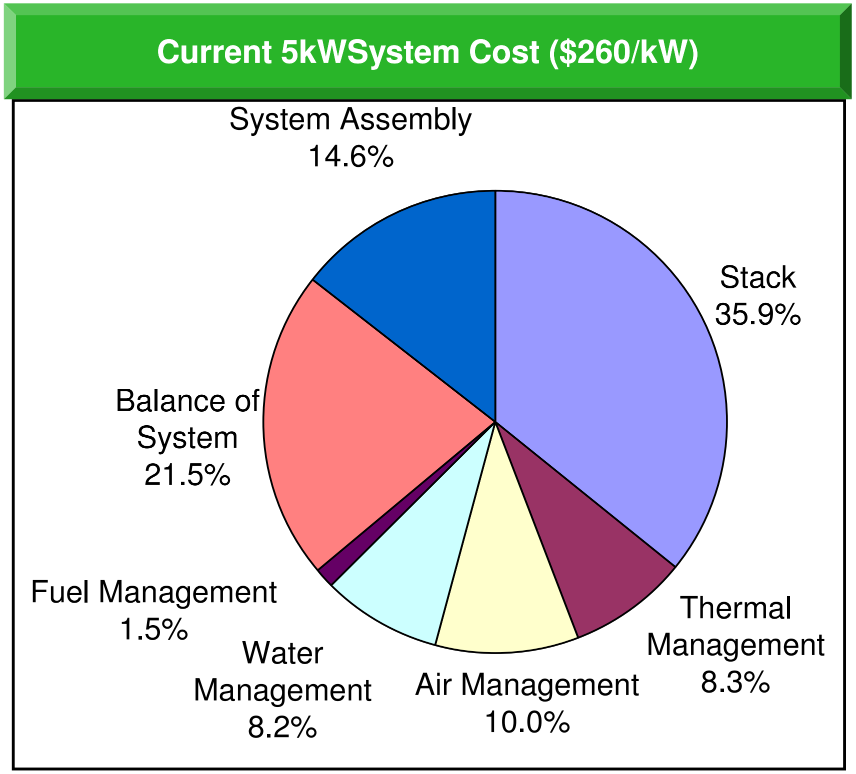


The system included stack, water management (membrane humidifiers, etc.), air management (air blower, etc.), fuel management (H2 pump, etc.), thermal management (radiator, coolant pump, etc.), electronics, packaging, etc.

We developed material cost assumptions and stack specifications consistent with performance assumptions.

Stack Components	5 kW Baseline (Current)	Current System	Comments
Production volume	systems/year	50,000	
Stacks' new power	kW	5	
Stacks' gross power	kW	5.5	Electronics efficiency loss
Stacks' gross power density	mW/cm^2	500	
Max. Stack Temp.	Degree C	80	
Cell Voltage	V	0.7	
Stack Voltage	V	48	
Active Area Size	cm^2	160	Calculated
Platinum price	\$/tr.oz. (\$/g)	\$1,100 (\$35.4)	Same as DOE automotive PEMFC
Pt Loading	Mg/cm^2	0.3	
Membrane Type		3M PSFA	
Membrane Thickness	micro meter	30	
GDL Layer		woven Carbon Cloth	
GDL Thickness	micro meter	225	@50 kPa pressure
MPL Layer Thickness	micro meter	40	
Bipolar Plate Type	-	Molded Graphite	To be updated to metal plate
Bipolar Plate Thickness	mm	2	

The manufacturing cost analysis was based on an annual production of 50,000 units. Stack had about 40% of the system costs. The total fuel cell system cost was approximately $1,300 per system.



- Balance of system included control, power electronic, etc.
- System assembly included the BOP sub-systems, control and electronic elements & wire harness, etc.

The system cost reduction will be focused on BOP since it represented approximately 60% of the system cost.

The due diligence was preliminary and the following actions are needed to improve the current work.

- More analysis work to be done, such as system modeling, sensitivity, scenario, life cycle analysis, etc.
- Feedbacks from system integrators.
- Communication with component suppliers and equipment suppliers.
- Possible funding opportunities for the extended work.

Thank You!