Direct Hydrogen PEMFC Manufacturing Cost Estimation for Automotive Applications

Project ID # FCP36

Poster Session at: **DOE Hydrogen Program Annual Merit Review**

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This presentation does not contain any proprietary or confidential information

Timeline

- Start date: Feb 2006
- Base period: Feb 2008
- Option period: Feb 2011

Barriers

- Barriers addressed
  - A. Cost

	Cost Targets* ($/kW)		
	2005	2010	2015
Fuel Cell System	125	45	30
Fuel Cell Stack	65	30	20

* *Manufactured at volume of 500,000 per year.*

Budget

- Total project funding
  - Base Period = $343K
  - With Options = $1,484K
  - No cost share
- FY06 = $100K obligated

Partners

- Collaborate with ANL on system configuration and modeling
- Feedback from: Fuel Cell Tech Team, Developers

Objectives and Timeline

Objectives

Overall

- The project objective is to provide technical support services to the DOE for cost estimation/analysis for Direct Hydrogen PEMFC systems for automotive applications

2005–2006

- The focus over the next 12 months will be on developing system costs as a function of production volume, i.e., to understand the economies of scale for fuel cell materials, stacks, and balance-of-plant components
- Cost of systems meeting 2010 and 2015 technical targets

2006–2011

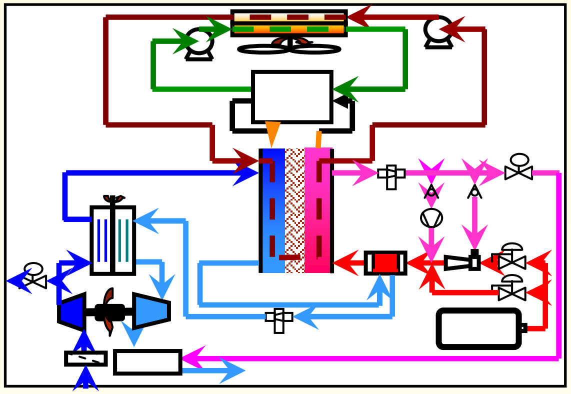
- Annual up-dates of high volume cost projection
- Specific Analysis topics including cost implications of
  - Ambient versus pressurized operation
  - High temperature, low humidity operation
  - Lower temperature, low RH hydrocarbon membrane
  - Alternative PEMFC approaches including cell/stack constructions and air compressors
  - Fuel cell vehicle hybridization
- Other topics as the need arises

Approach Manufacturing Cost Estimation

Our manufacturing cost estimation involves technology assessment, cost modeling, and industry inputs to calibrate our assumptions and findings.

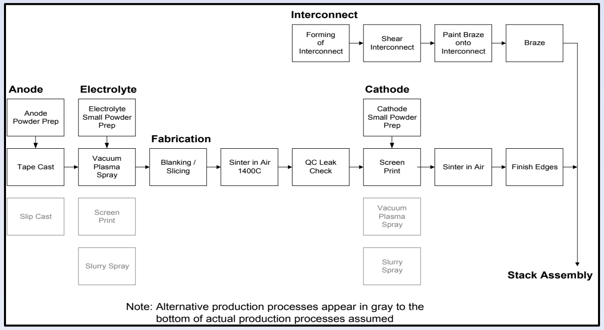
Performance/ Tech Assessment

- ◆ Literature Search
- ◆ Outline Assumptions
- ◆ System Design and Configurations
- ◆ Process Models
- ◆ Developer Input



Cost Modeling

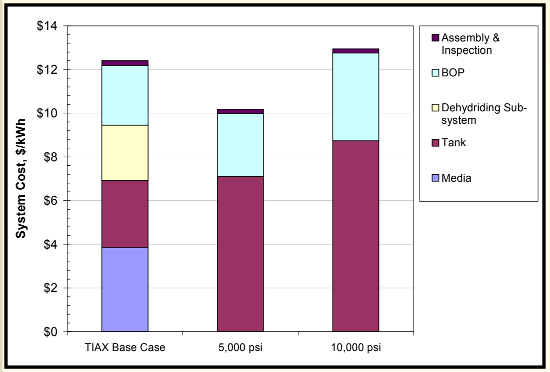
- ◆ Document Bill of Materials (BOM)
- ◆ Determine Material Costs
- ◆ Identify Processes and Mnf. Equipment
- ◆ Sensitivity Analyses



Note: Alternative production processes appear in gray to the bottom of actual production processes assumed

Overall Model Refinement

- ◆ Developer and Industry Feedback
- ◆ Revise Assumptions and Model Inputs



BOM = Bill of Materials

We will primarily use a bottom-up approach to determine the impact of production volume on manufacturing cost.

Two General Approaches:

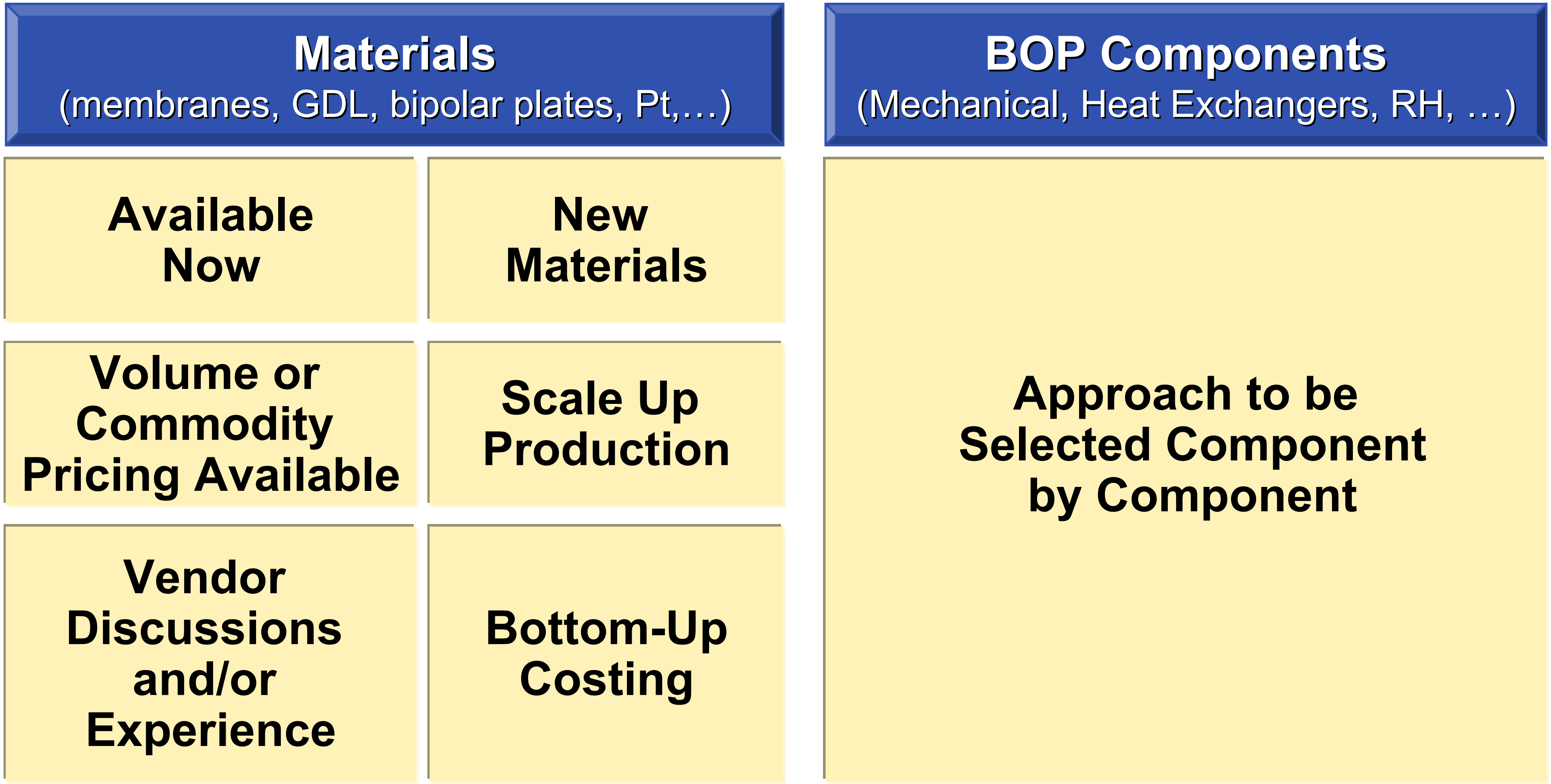
- ***Bottom-Up Manufacturing Process Methodology***
  - Based on impact of volume on material costs
  - Based on impact of volume on process type, equipment, and level of automation
  - Use for major stack cost contributors and critical processes
  - Use Boothroyd Dewhurst Design for Manufacturing (DFM®) software for BOP components cost estimation, such as the compressor expander, RH control devices, heater exchangers, etc.

- ***Experience Based Methodology***
  - Based on “learning curves” and/or comparison with similar products
  - Use for lesser cost contributors, e.g., sensors, controllers, ….

The DOE has requested costs for production volumes of 100 units/ year for 4 years, 30K/yr, 80K/yr, 130K/yr, and then 500K/yr.

Approach Economies of Scale Analysis

We will consider materials and BOP components on a case by case basis for their manufacturing maturity and our approach to scaling their cost.



Materials
(membranes, GDL, bipolar plates, Pt,…)

Available Now

Volume or Commodity Pricing Available

Vendor Discussions and/or Experience

New Materials

Scale Up Production

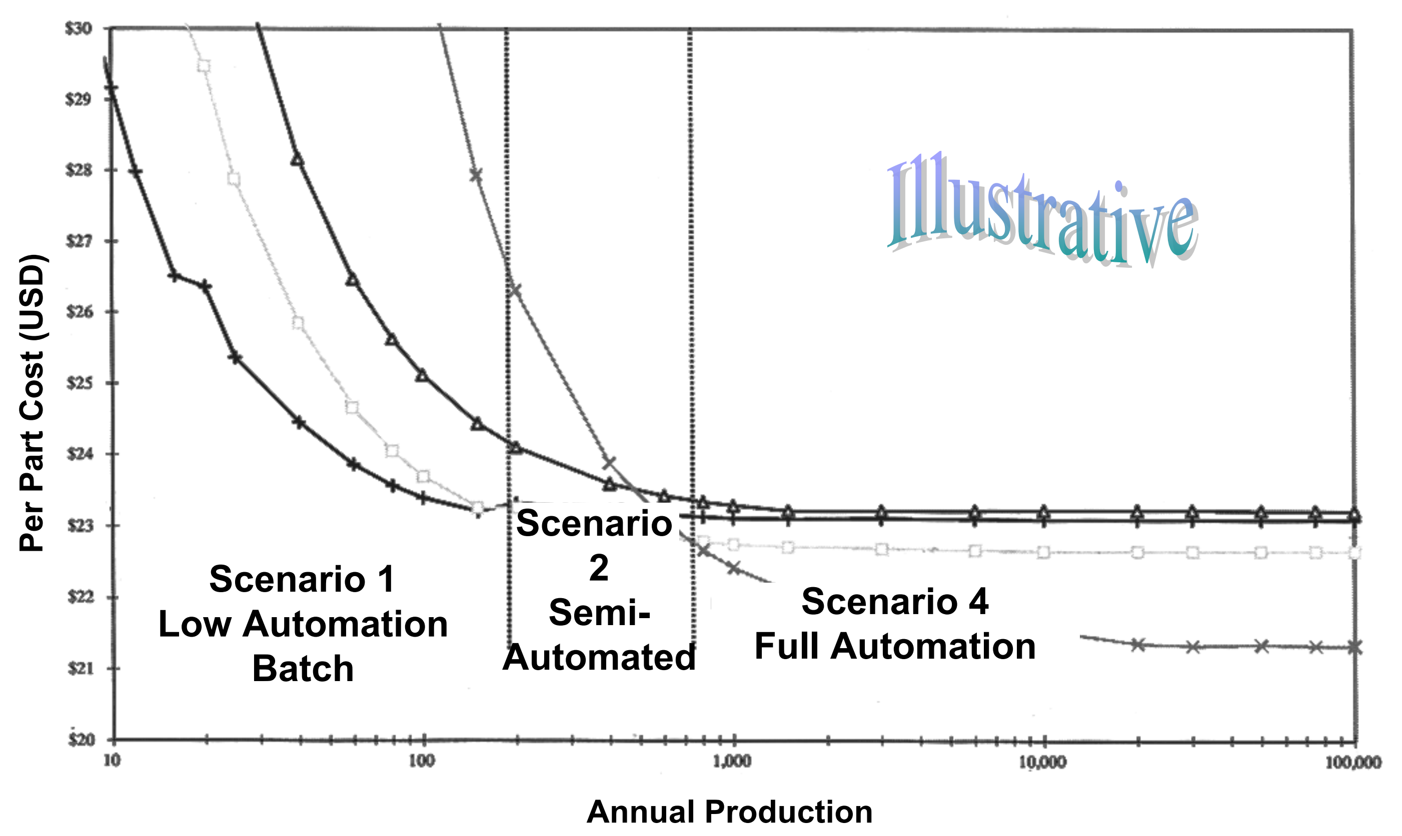
Bottom-Up Costing

BOP Components
(Mechanical, Heat Exchangers, RH, …)

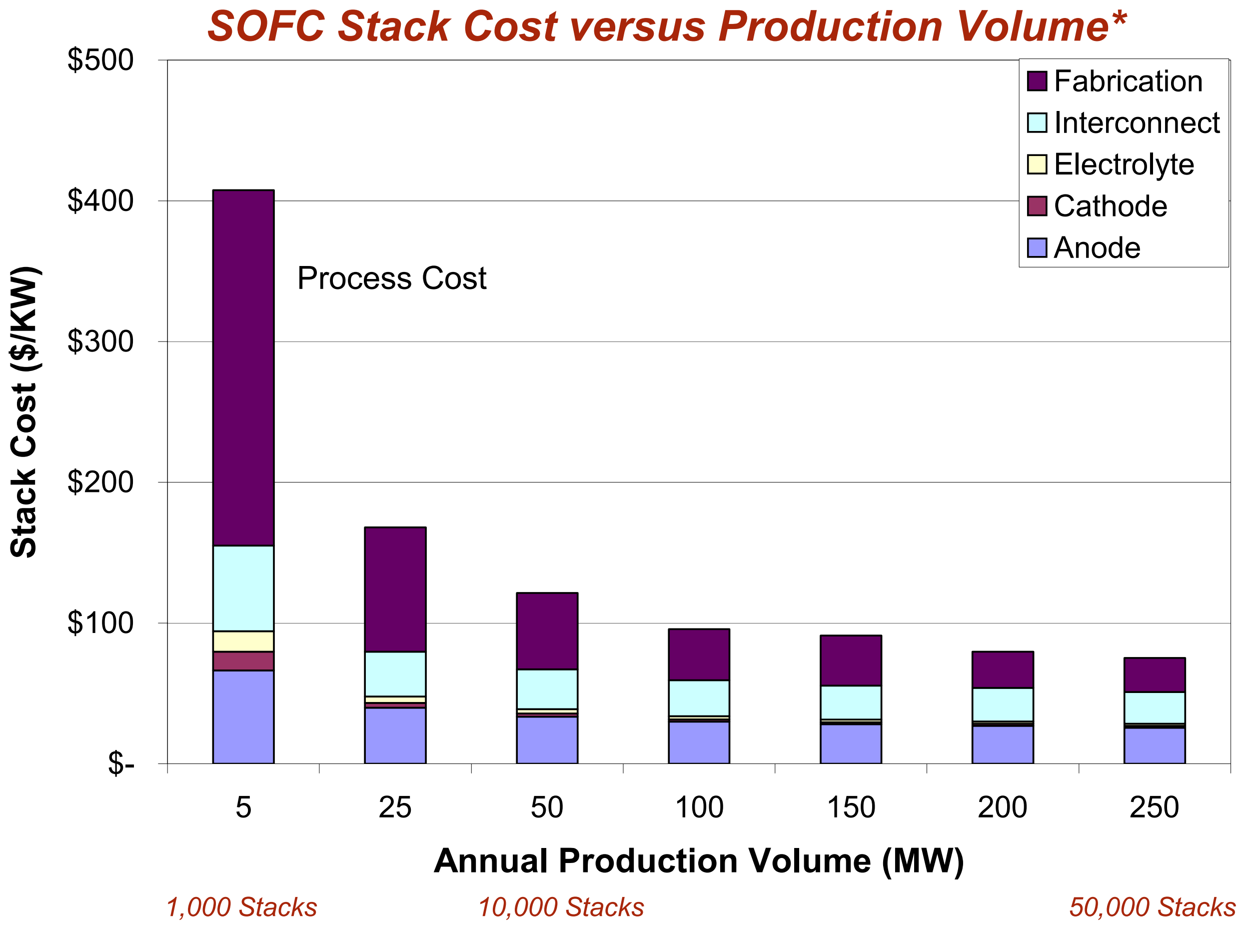
Approach to be Selected Component by Component

We will use cost versus volume curves from three production volume scenarios to define an integrated scenario.

Cost vs. Production Volume (*Example*)



The reduction in process costs was the primary driver for the economies of scale. Higher equipment utilization led to lower capital costs.

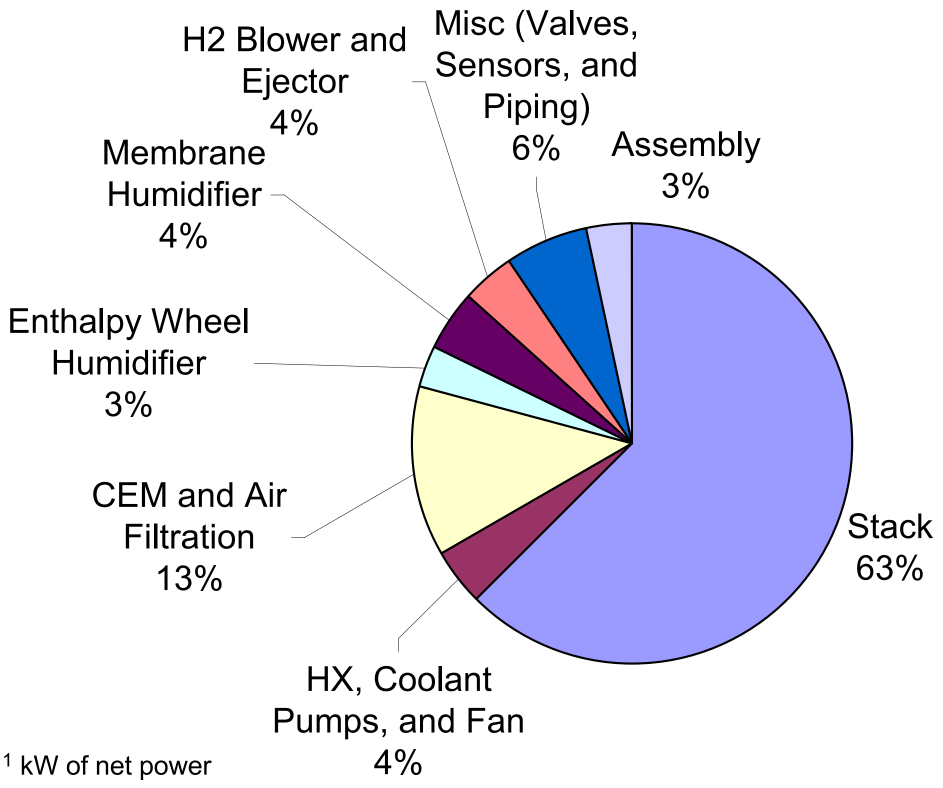


	5 MW	250 MW	Delta
Material	$73	$56	1.3x
Process	$385	$36	10.7x

* **E Carlson, et.al., "Solid Oxide Fuel Cell Manufacturing Cost Model: Simulating Relationships between Performance, Manufacturing, and Cost of Production",** National Energy Technology Laboratory (DOE), April 20, 2004, DOE Contract # DE-FC26-02NT41568

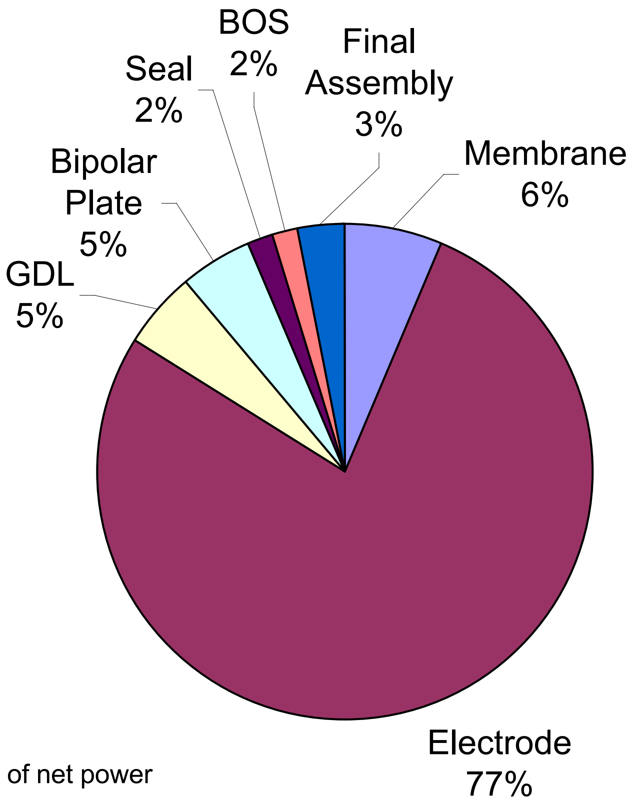
The 2005 update* of the cost projection for PEMFC technology will be used as a baseline for the economies of scale analysis.

System Cost (108 \$/kW[1], \$8,640)



[1] kW of net power

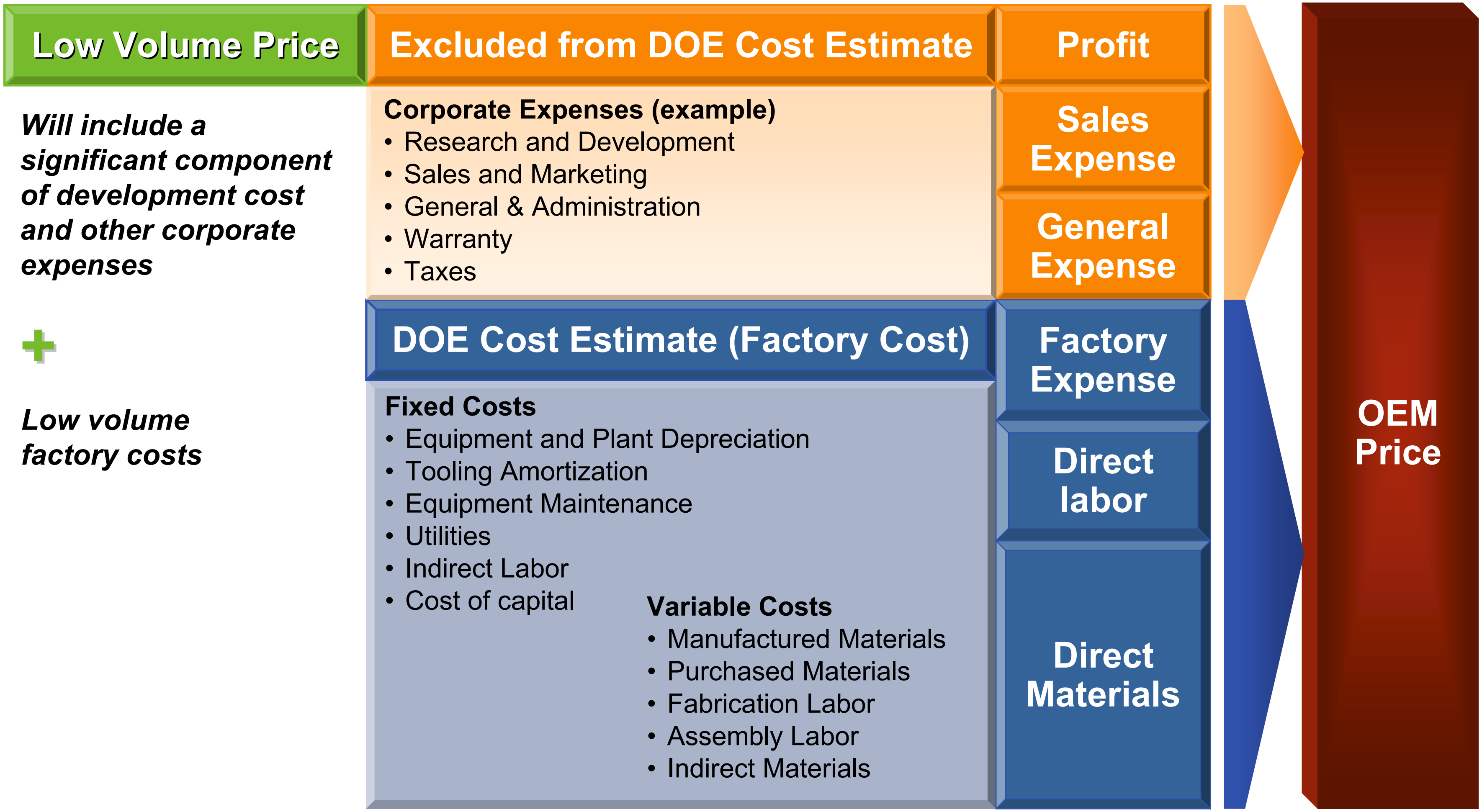
Stack Cost (67 \$/kW[1], \$5,360)



[1] kW of net power

* **E Carlson, et.al., "Cost Analysis of PEM Fuel Cell Systems for Transportation",** National Renewal Energy Laboratory (DOE), September 30, 2005, Subcontract Report NREL/SR-560-39104 (December 2005)

Our economies of scale analysis will only consider factory cost, consequently, the results will not be comparable with fuel cell prices.



Low Volume Price

Will include a significant component of development cost and other corporate expenses

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Low volume factory costs

Excluded from DOE Cost Estimate

Corporate Expenses (example)

- Research and Development
- Sales and Marketing
- General & Administration
- Warranty
- Taxes

DOE Cost Estimate (Factory Cost)

Fixed Costs

- Equipment and Plant Depreciation
- Tooling Amortization
- Equipment Maintenance
- Utilities
- Indirect Labor
- Cost of capital

Variable Costs

- Manufactured Materials
- Purchased Materials
- Fabrication Labor
- Assembly Labor
- Indirect Materials

Profit

Sales Expense

General Expense

Factory Expense

Direct labor

Direct Materials

OEM Price

Stack components, because of their large number and compatibility with continuous processes, will realize economies of scale sooner than BOP components.

High Part Count Components

- Stack unit cells (e.g., 450 per stack)
  - Individual layers (membrane, GDL, electrodes) amenable to continuous processes
  - Bipolar plates automated molding methods

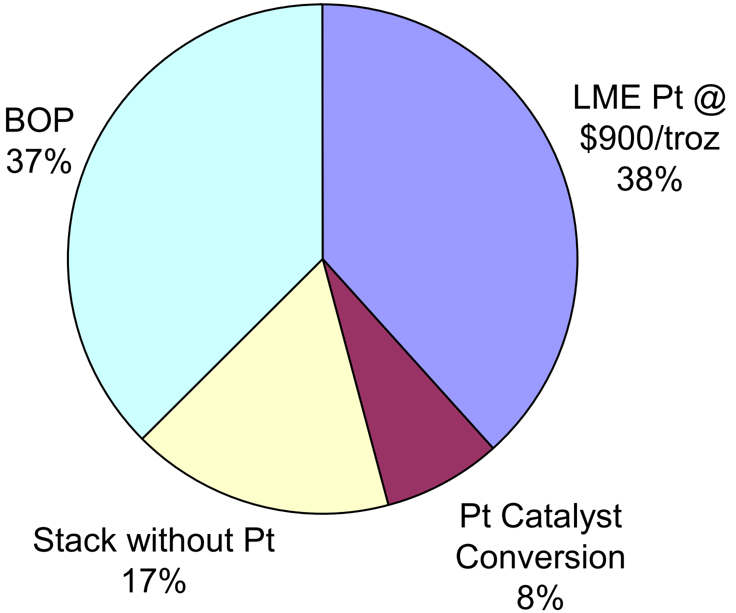
Low Part Count Components

- Stack hardware
  - End-plates (2/stack – 4/system), bolts (8/system), manifold (1/system), enclosure (1/system)
- Balance-of-Plant (Individual Components)
  - Heat exchangers (<5 pieces per system)
  - Air management (1 per system)
  - RH management (several technologies but only 1 component)
  - H_2 recirculation loop (e.g., blower, ejectors)
  - Controls, sensors, ….

Approximately 46% of the 2005 high volume cost comes from Pt commodity cost and will not be subject to economies of scale.

2005 Key Assumptions		
Power density	mW/cm^2	600
Cell voltage	V	0.65
Net power	kW$_e$	80
Gross power	kW$_e$	90
Production volume	units/yr	500,000
Pt cost	\$/g (\$/troz)	29 (900)
Pt loading	mg/cm^2	0.75
Stack Quality Control (QC) and conditioning **not included**		

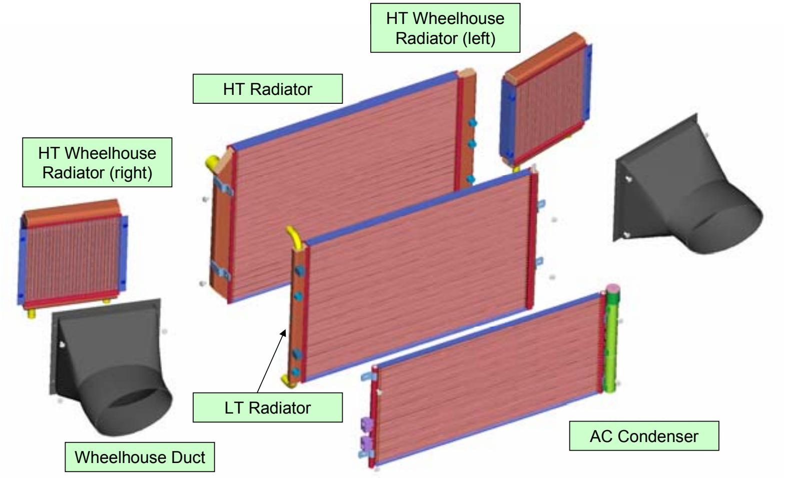
Fuel Cell System Cost—80 kW Direct H_2 (108 \$/kW[1], \$8,640)

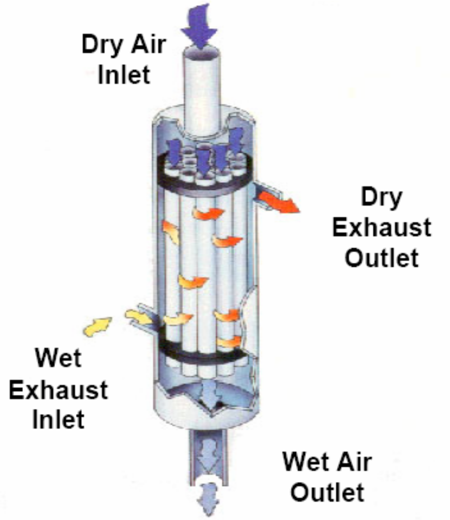


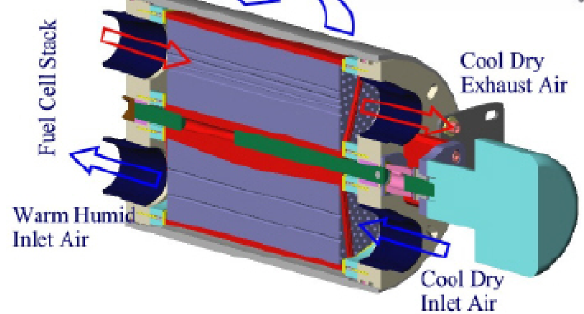
[1] kW of net power

However, with time performance improvements will lower the grams Pt/kW$_{net}$ over time.

With the exception of heat exchangers, the BOP components have not been made at high volumes.







Technology advances such as high temperature membranes could simplify the RH components and reduce the size of the heat exchangers.

Stack conditioning and final quality checks could be significant cost contributors at low volumes.

- **Example: Assumptions**
  - **Capital cost for a test station is $200,000**
  - **Labor is 0.2 per station**
  - **Yield is 100%**
  - **Up-time is 80%**
  - **Does not include consumables such as H_2 or credit for the power**
  - **Production volume: 500,000 units/year**
- **For reference, stack cost is 361 $/m^2**

	2 Hours Stack Conditioning	24 Hours Stack Conditioning
# of test stations	521	6,250
# of stacks per day	4168	4168
Total equipment cost	$104 Million	$1,250 Million
Cost ($/m^2)	9.01	108.10

Testing of the complete system with BOP would represent an additional cost.