Challenges for Transportation Fuel Cells: Fuel Processing and Cost

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Outline

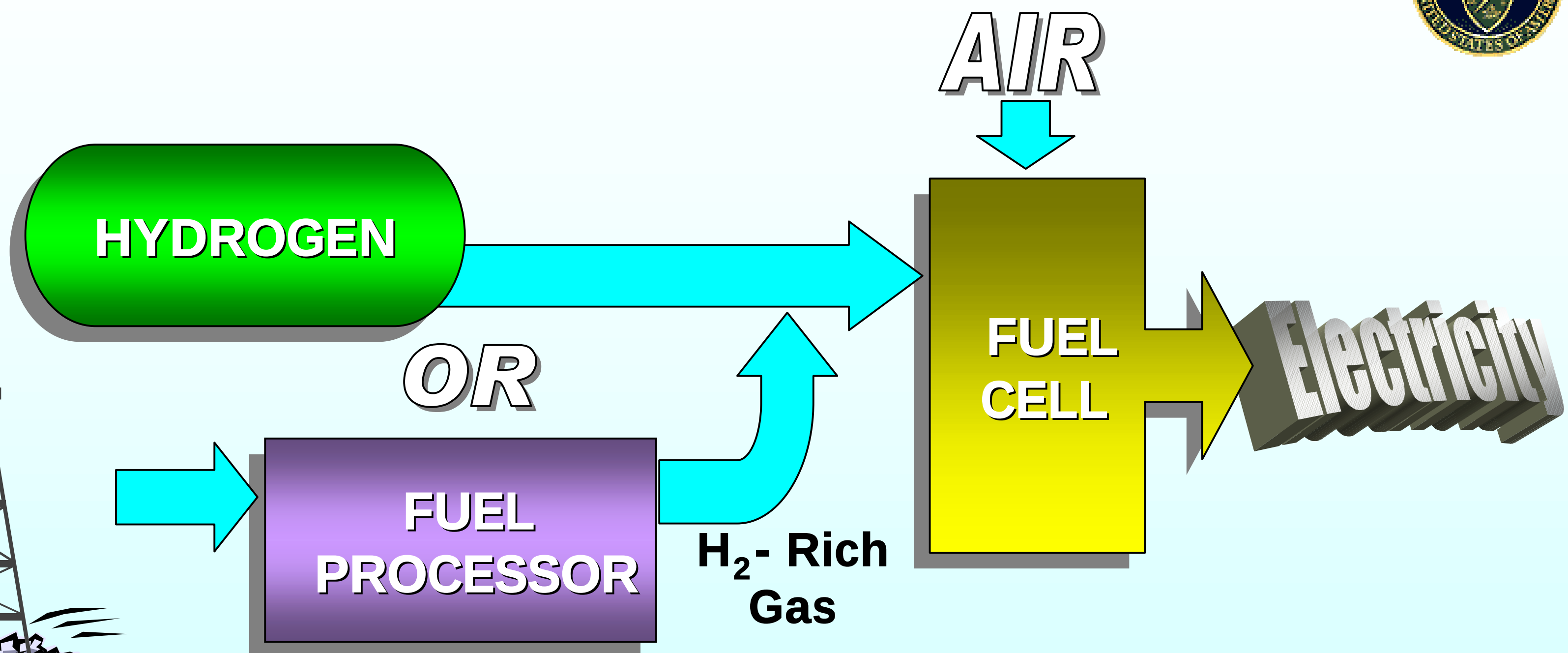
Major Challenges for Transportation Fuel Cells

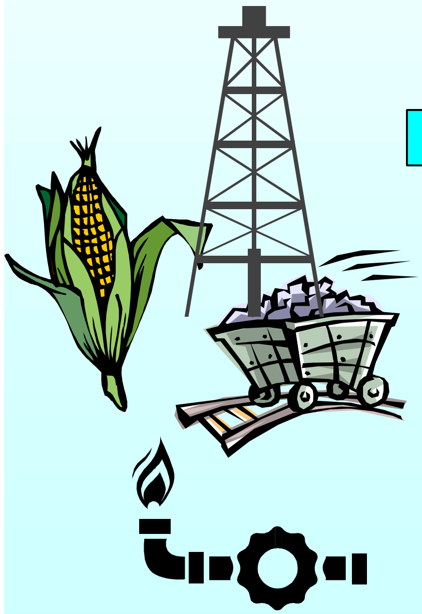
- Fuel Processing
  - Fueling Options
  - Autothermal Fuel Processing & Challenges

- Cost of Fuel Cell Systems
  - Fuel Cell Subsystem
  - Fuel Processing Subsystem
  - Materials/Purchased Components

- Summary

Fuel Options for PEM Transportation Systems





- ❑ Hydrogen can be stored and supplied directly to the fuel cell: *Storage and Infrastructure Issues*

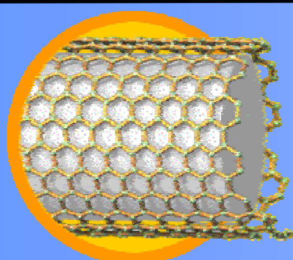
- ❑ Hydrogen can be derived from fuels such as ethanol, methanol, natural gas, gasoline or FT fuels: *Complexity, Cost, and Start-up Issues*

Hydrogen Storage and Infrastructure

Collaborating with the DOE Hydrogen Program to Address Key Issues

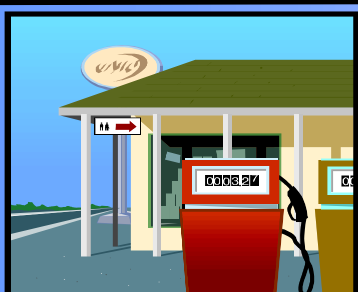
Pressurized Tanks

- Carbon Composites



Storage Materials

- Hydrides
- Carbon Nanotubes



Off-Board Reforming

- Purification
- Compression
- Dispensing

Renewables

- Wind
- Biomass

Autothermal Fuel Processing

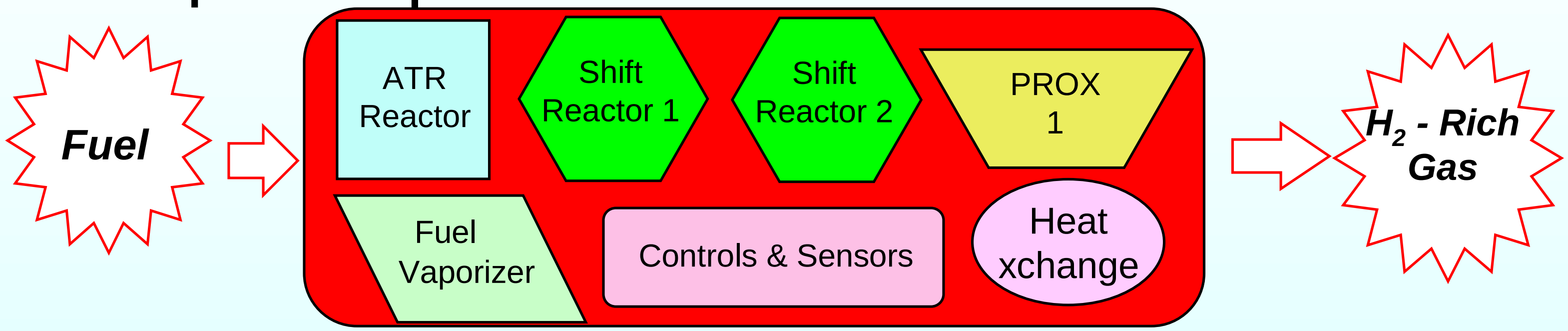
Fuel Flexible & Thermally Favorable

$$C_nH_mO_p + x(O_2+3.76N_2) + (2n\text{-}2x\text{-}p)H_2O =$$
$$nCO_2 + (2n\text{-}2x\text{-}p+m/2)H_2 + 3.76xN_2$$

- Process control thermodynamics is a function of the oxygen-to-fuel ratio (x). $\Delta H = 0$ at $x = 5.86$
  - Lower heat exchange requirements, reducing the size and weight of the fuel processor
  - improved cold starting – initially using high oxygen to fuel ratio
  - Improved transient response – only requires adjustment to feed rate while maintaining constant feed proportions (oxygen-fuel and water-to-fuel)

Challenges to On-Board Fuel Processing

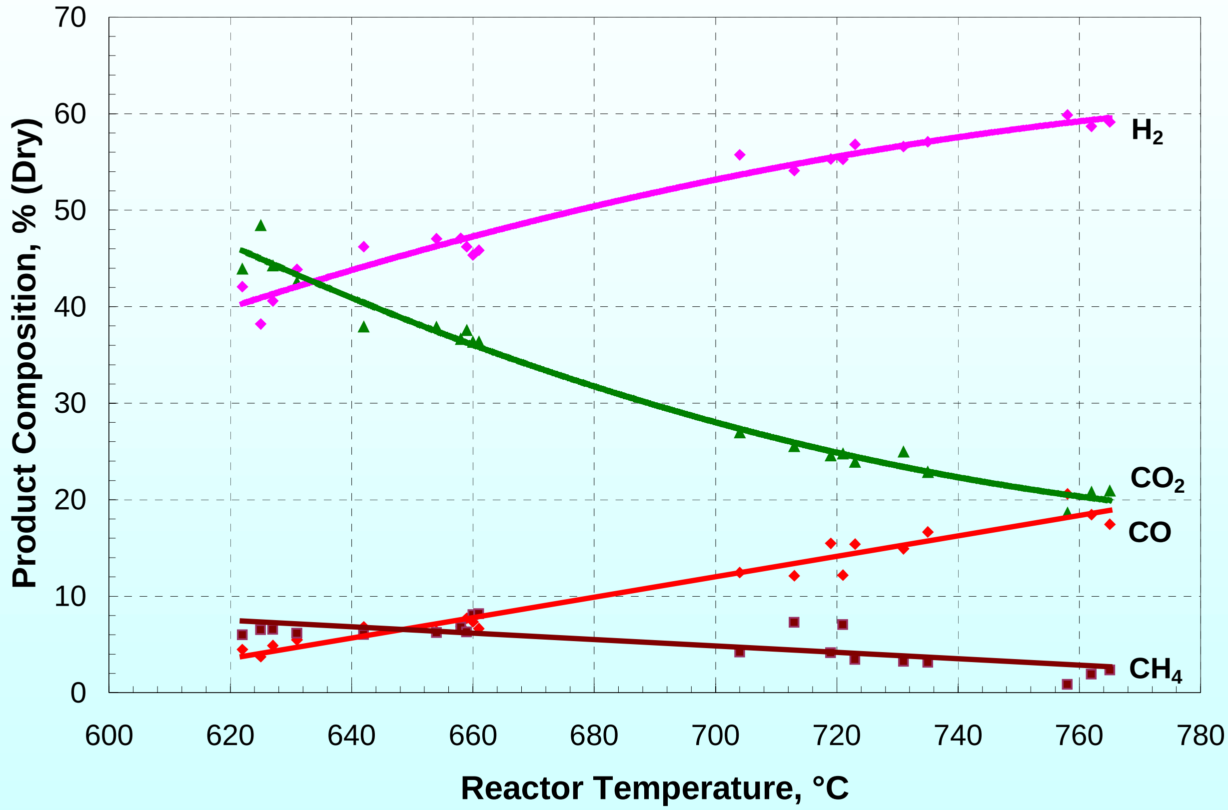
- Complexity – Complete reformer includes multiple steps.



- Cost – complexity, sophisticated catalysts, control technology and high temperature operation combine to make the cost goal of $10/kW difficult.

- Fuel – "Gasoline" may have to be tailored for the fuel cell application - a moderate infrastructure challenge.

Autothermal Reforming of Gasoline Using an ANL Catalyst



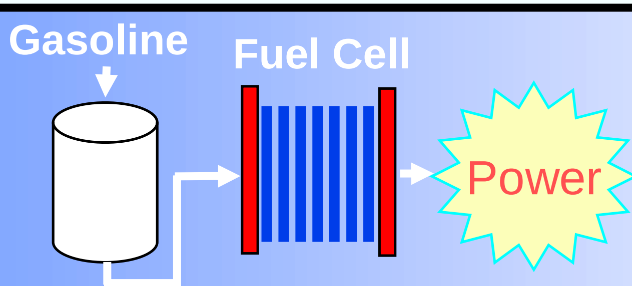
- ❑ Theoretical maximum hydrogen percentage = 66%
- ❑ No performance degradation: 40+ hrs. on gasoline containing 0.01 wt% sulfur

[1]on a nitrogen-free basis

Progress in Fuel-Flexible Fuel Processing

Full Scale Fuel Processing Being Demonstrated

1997:

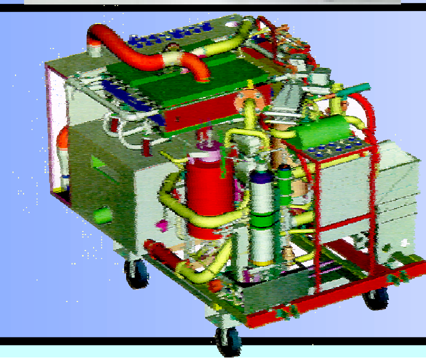


World's First Demonstration of PEM Fuel Cell Power from Gasoline - <1kW

1999:

Plug Power & Epyx (NUVERA) Demonstrate 10kW System on Multiple Fuels Including Gasoline, Methanol, and Ethanol

2000:



IFC Demonstrates 50 kW, Automated System on Gasoline

Fuel Cell Challenge: Cost

Cost Study Performed by A.D. Little with modeling support from Argonne National Lab
A multi-year study that includes a baseline case, variants, and yearly updates of the baseline

Fuel Tank

Not Included

Included in Analysis

Packaging (piping, electrical….)
Start-up power (battery); Anode Tailgas Burner

Fuel Processor | Fuel Cell

Management Systems
Air-Thermal-Water-Safety
(Incl. Sensors/Controls)

Power Conditioning
Elec. Motor
Elec. Drive Train
Regen Braking
Battery

Not Included

Other:
- AC/Heating
- Driver Interface

Not Included

Arthur D Little

Study and presentation available at:
www.ott.doe.gov/oaat/library.html

A.D. Little Cost Study Baseline System

Study available at: www.ott.doe.gov/oaat/library.html

System Requirements

- Fuel-flexible (incl. gasoline)
- System efficiency 35-40%
- Water self-sufficiency to 95^{o}F ambient condition
- 3 atmosphere operation
- Turbo-compressor/ expander

Fuel Cell Module

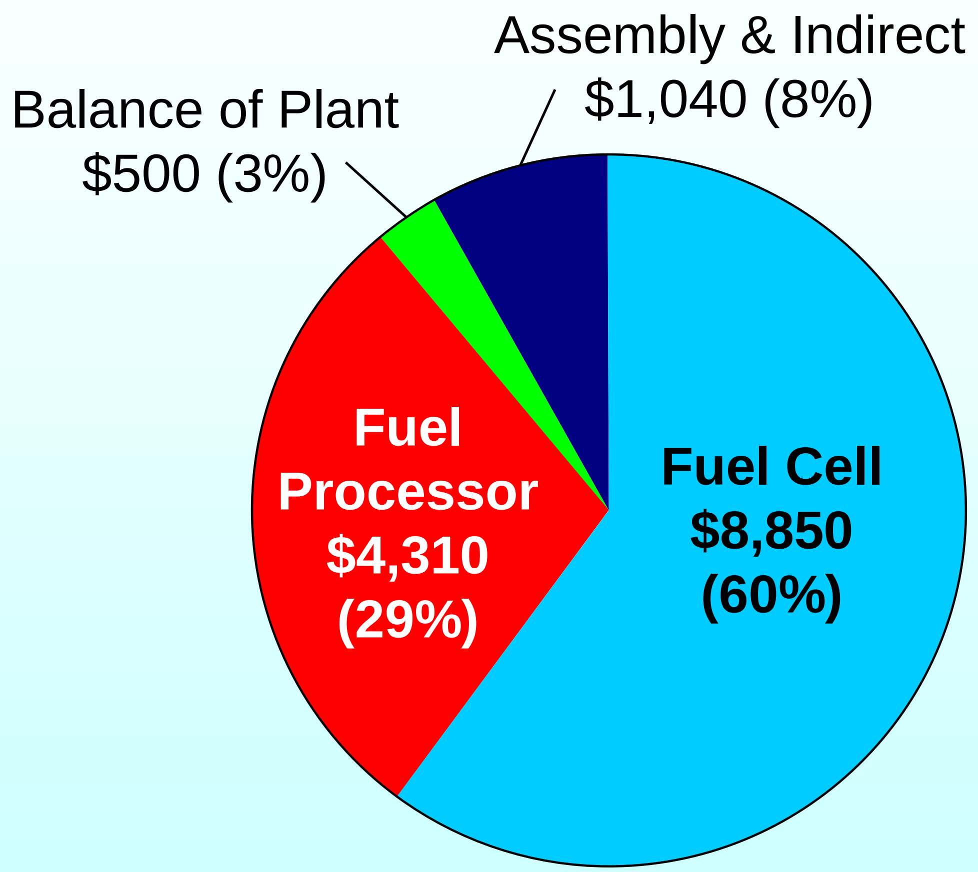
- 50kW$_e$ net
- 300 volts @ full power
- 80°C
- Reformate fuel

Fuel Cell Stack

- 0.8 volts per cell
- 310 mA/cm^2 current density
- One cooling plate per cell
- Total power 56kW$_e$
- 85% H_2 utilization

Costs include: Factory expense, labor, materials
Costs exclude: Profit, Sales Expense, Administration, Warranty

Estimated Costs for Baseline Year 2000 Fuel Cell Power System (A.D. Little Study)



Total = $14,700 or $294/kW

PNGV Goals: $130/kW (2000)
$50/kW (2004)

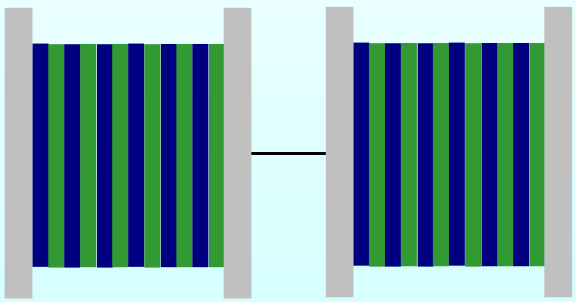
- 50 kWe
- 500,000 units per year
- Estimated accuracy ±20%
- System components scaled by year 2000 performance estimates
- Analysis driven by efficiency target

Source: A.D.Little

Fuel Cell Subsystem

- ❑ Fuel Cell Stack (Unit Cells)
- ❑ Stack Hardware
- ❑ Fuel Cell Heat Exchanger
- ❑ Compressor/ Expander
- ❑ Anode Tailgas Burner
- ❑ Sensors and Control Valves

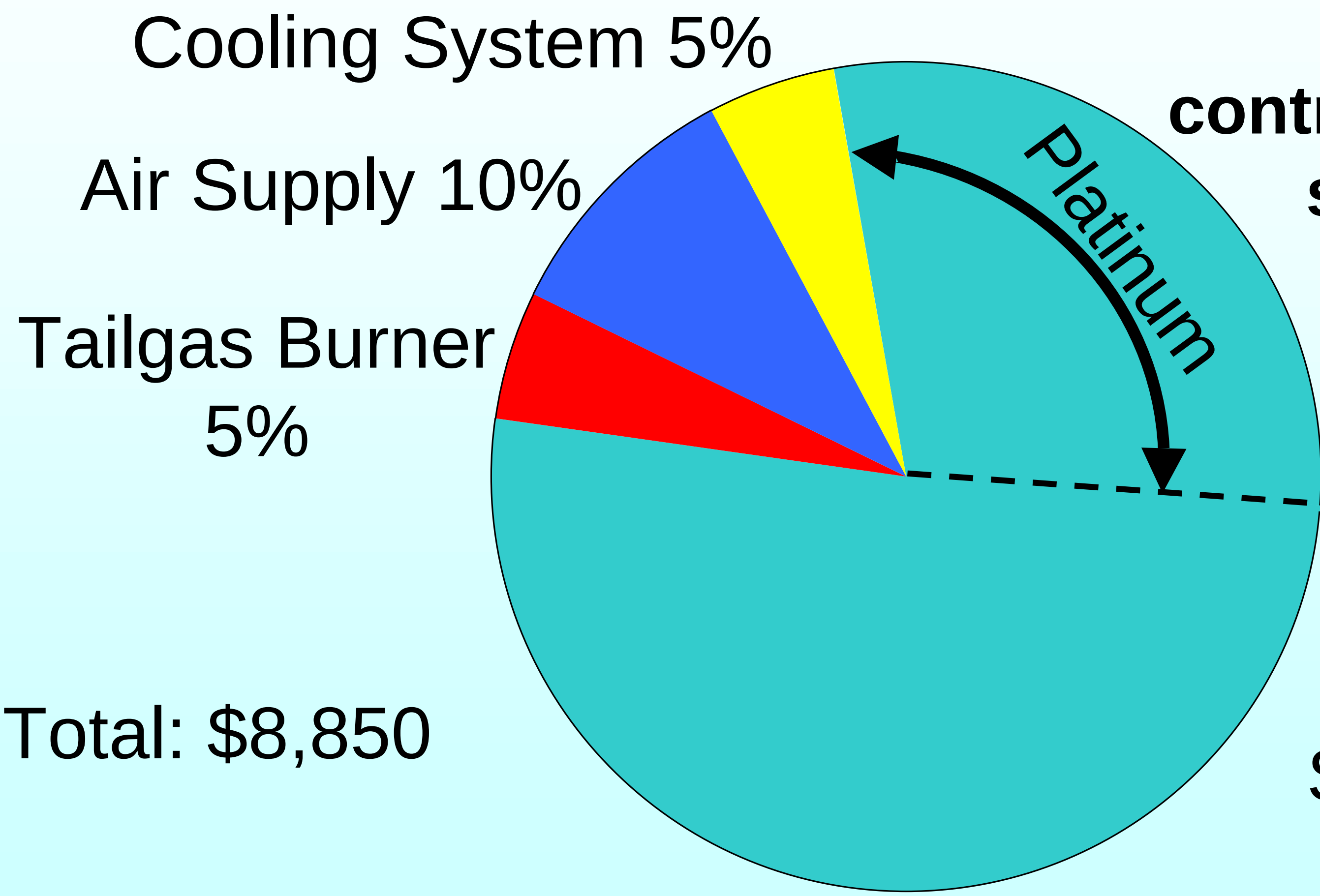
Fuel cell stack module: two stacks in series with 600 cm^2 active area per cell
375 total cells



Study and presentation available at: www.ott.doe.gov/oaat/library.html

Source: A.D.Little

Fuel Cell Stack Subsystem Dominates Fuel Cell Power System Cost



Platinum contributes 36% to stack cost

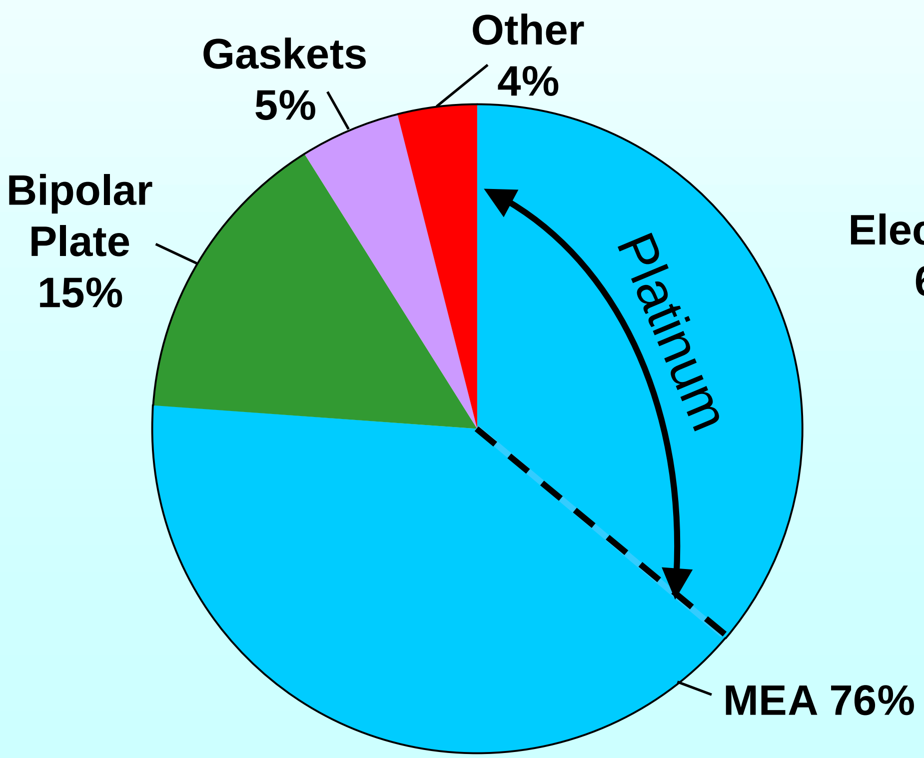
Total: $8,850

Notes: Combined Pt loading: .8 mg/cm^2, optimizing stack for power would lower stack cost by as much as 50%

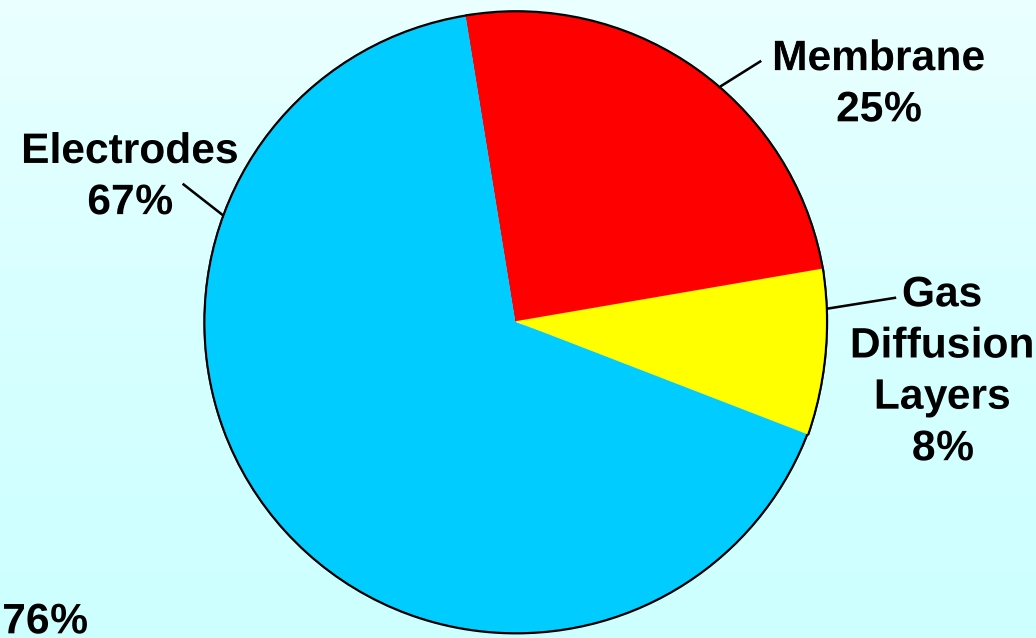
Source: A.D.Little

Fuel Cell Stack Cost Is Dominated by MEA Platinum Loading

Fuel Cell Stack Component Costs ($7,050)



Membrane Electrode Assemblies (MEA) Costs (Materials and Process: $236/m^2)



Total: Pt-180g, Ru-45g (47% of MEA cost)

Source: A.D.Little

Fuel Processing Subsystem

- **Reformate Generator**
- Catalyzed ATR
- HTS
- ZnO Sulfur Removal
- LTS
- Steam Generator
- Air Preheater
- Steam Superheater
- Reformate Humidifier

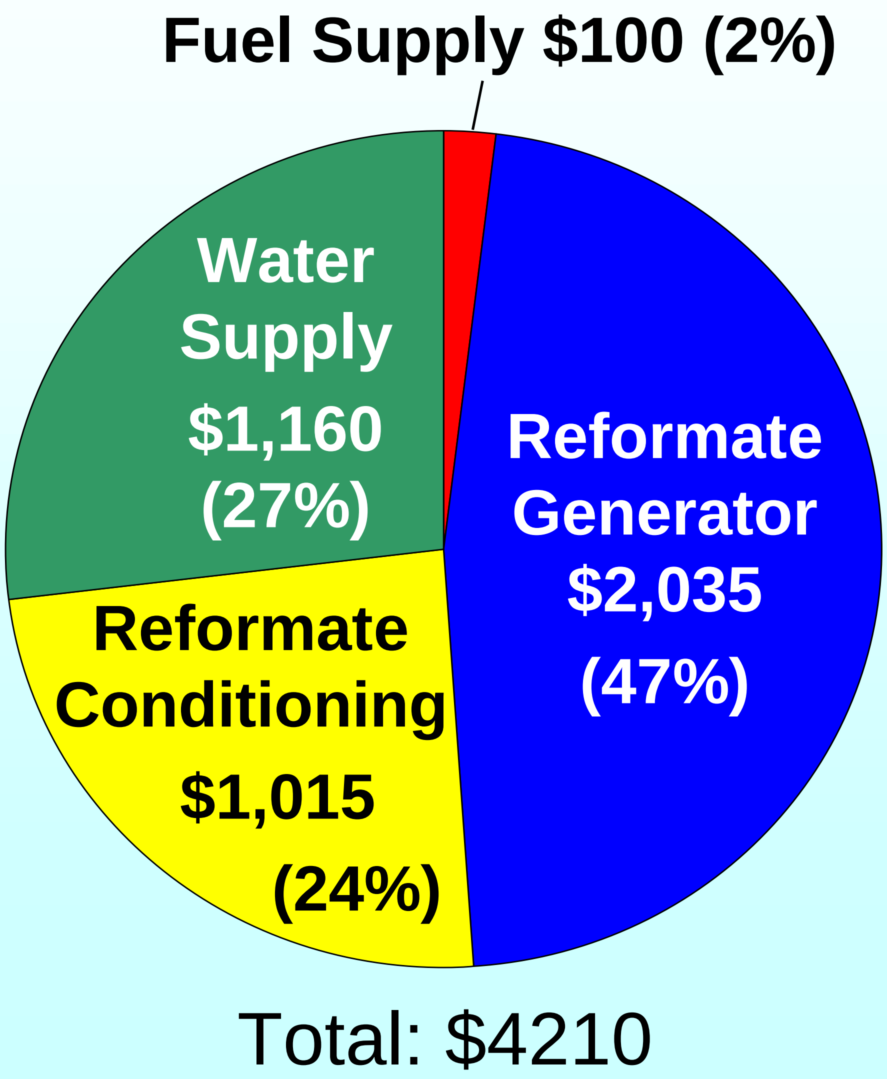
- **Fuel Supply**
- Fuel Pump
- Fuel Vaporizer

- Sensors and Control Valves

- **Reformate Conditioner**
- Carbon bed NH_3 Removal
- Multizone PROx
- Anode Gas Cooler
- Economizers (2)
- Anode Inlet Knockout Drum

- **Water Supply**
- Water Separators (2)
- Heat Exchanger
- Steam Drum
- Process Water Reservoir

The Cost Breakdown for the Fuel Processing Subsystem



- ❑ Thermal, water, and steam management; controls; and packaging are 70% of cost.
- ❑ Improved catalyst technology is necessary to reduce bed size and extend life.
- ❑ Improved system design/ engineering is needed to lower cost of peripheral systems.

Cost Study Updates

Additional A.D.Little Study Activities:

- ❑ Yearly updates of baseline system for three years
- ❑ Baseline cost model updated to operate at high ambient temperature
- ❑ High power design – model optimized for power, not efficiency
- ❑ Study to determine the dependence of cost ($/kW) versus total system power

Directed Technologies Inc. (DTI) Study:

- ❑ Direct hydrogen fuel cell system cost study

A.D. Little study available at:
www.ott.doe.gov/oaat/library.html

Future Activities

Focus on removing the critical barriers to commercialization relating to *cost, durability* and *performance*

DOE Solicitation Focusing on these activities will be released in November (CBD available now): www.doeal.gov/cpd/readroom.htm

- Manufacturing Process R&D - electrodes and bipolar plates
- Fuel Processing - catalyst and fuel processor subsystem development. Off-board reforming.
- Membranes - Operation at increased temperature
- Auxiliary components–compressors / expanders, sensors, etc.
- Studies to examine platinum usage, codes & standards, etc.

Summary

- **Autothermal Fuel Processing**
  - Simple control (oxygen-to-fuel ratio) of process thermodynamics is advantageous
  - Complexity of the system is a major control and cost issue.
- **Costs of Fuel Cell Systems**
  - Material and purchased parts dominate the total cost
  - Platinum loading significantly contributes to the estimated cost of $300/kW for high volume, year 2000 fuel cell systems
  - Improved power density is necessary to reduce costs

[redacted]