Fuel Cells for Stationary Power Generation

A Comprehensive Analysis of Technology, Plant Construction, and Marketing Strategy for Small Buildings

The University of Oklahoma
Fuel Cell Corporation

April 29, 2004

Presentation Outline

Business Overview and Market Analysis
Kristen Martinez

Technology Overview
Thu Nguyen

Fuel Cell Analysis
Caroline Ihejiawu

Fuels and Gas Reforming
Justice Diven

Process Flowsheet and Equipment Costs
Eric Daugherty

Tax, Labor, and Transportation Analysis
Jennifer Treece

Mathematical Model and Economic Analysis
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The OUFCC Product

The OUFCC offers the following services with the purchase of at least one stationary 200-250 kW fuel cell:

- All fuel cell “plant” parts (reformer, power conditioner, etc.)
- On-site consultation to suggest infrastructure changes, determine the best source of fuel, and help customer choose fuel cell type.
  - *Phosphoric Acid Fuel Cell (PAFC)*
  - *Solid Oxide Fuel Cell (SOFC)*
  - *Proton Exchange Membrane Fuel Cell (PEMFC)*
- Delivery
- Trial-period of one year
- Warranty period of two years

Fuel Cell Advantages

The OUFCC will fill the need of supplying a source of electricity that has the following advantages:

- High efficiency and cogeneration applications
- Reliable
- Independent of a power grid
- Optionally dependent on fossil fuel
- Few maintenance costs
- Clean

The Market

Main customers:

- Hospitals
- Banks
- Post Offices
- Police Stations

Most Probable Location:

- High No. of Businesses
- High Air Pollution Levels
- High Electricity Price
- Away from markets already targeted

Our largest market is in the Southwest
(AZ, NM, OK, TX)

Technology Competitors

Technology	Commercially Available?	Cogen Available?	Cost ($/kW)	NOx Emissions (ppm)	Efficiency (%)
Fuel Cells	Yes	Yes	4000-4800	0	60-85%
Microturbines	Yes	Yes	700-1100	50	20-30%
Combustion Turbines	Yes	Yes	300-1000	150-300	20-45%
Reciprocating Engines (Generators)	Yes	Yes	300-900	45-200	25-45%
Stirling Engines	No	Yes	2000-50,000	Low	12-20%
Photovoltaic Systems	Yes	No	6000-10,000	0	5-15%
Wind Systems	Yes	No	1000	0	20-40%

The OUFCC's Goals

Current Goals:

Enter the stationary fuel cell market, make a profit, and establish a name and reputation.

Future Goals:

Develop a niche market. Eventually, as fuel cell technology becomes more widely accepted, compete as a leading provider of stationary fuel cells.

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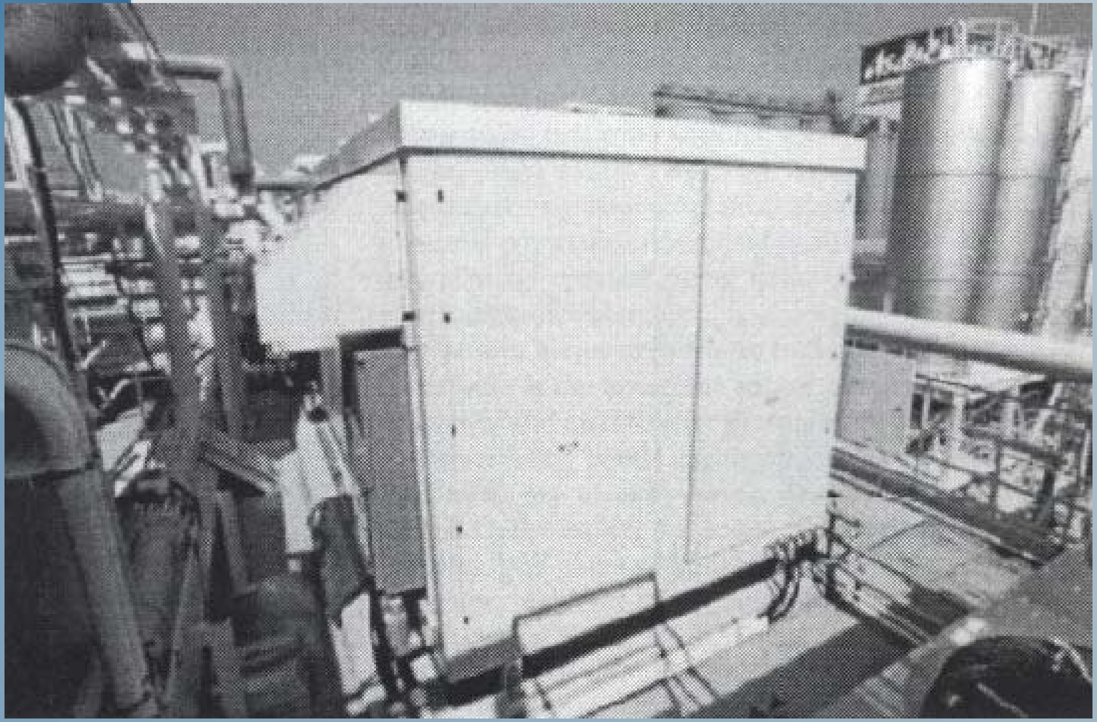
What are fuel cells?

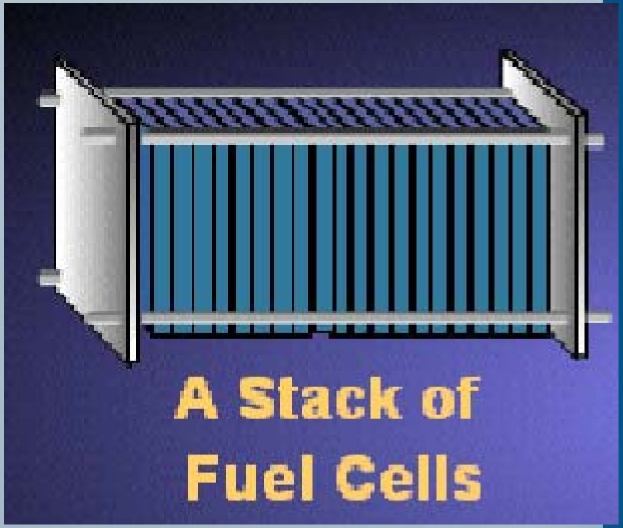
- Electrochemical devices
- Convert chemical energy directly to electricity and produce heat, with the help of catalyst
- Similar to batteries in operation
- Difference: batteries store energy while fuel cells produce electricity

History of Fuel Cells

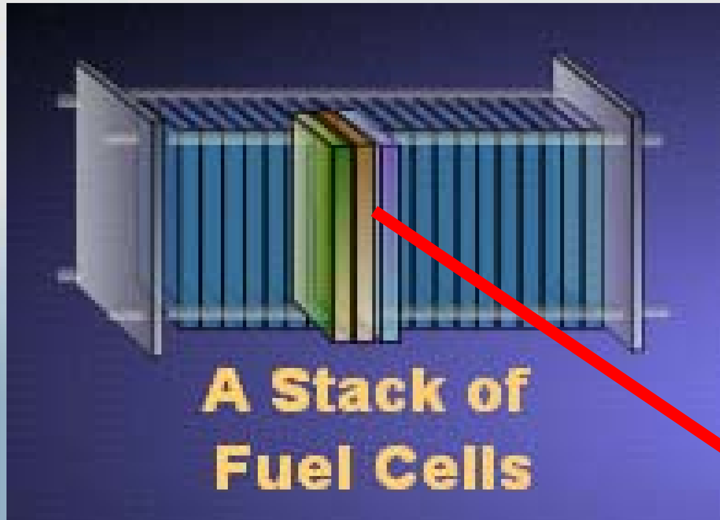
- 1932: First successful fuel cell device was developed.
- 1959: A practical 5-kW fuel cell system was demonstrated.
- In more recent decades, fuel cell energy has been expected to replace traditional power sources.

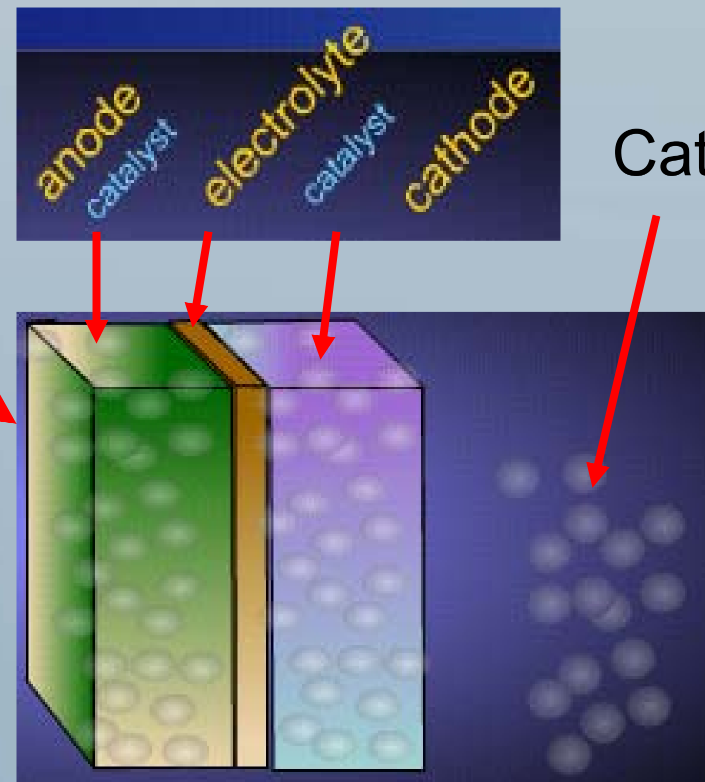
A Fuel Cell System





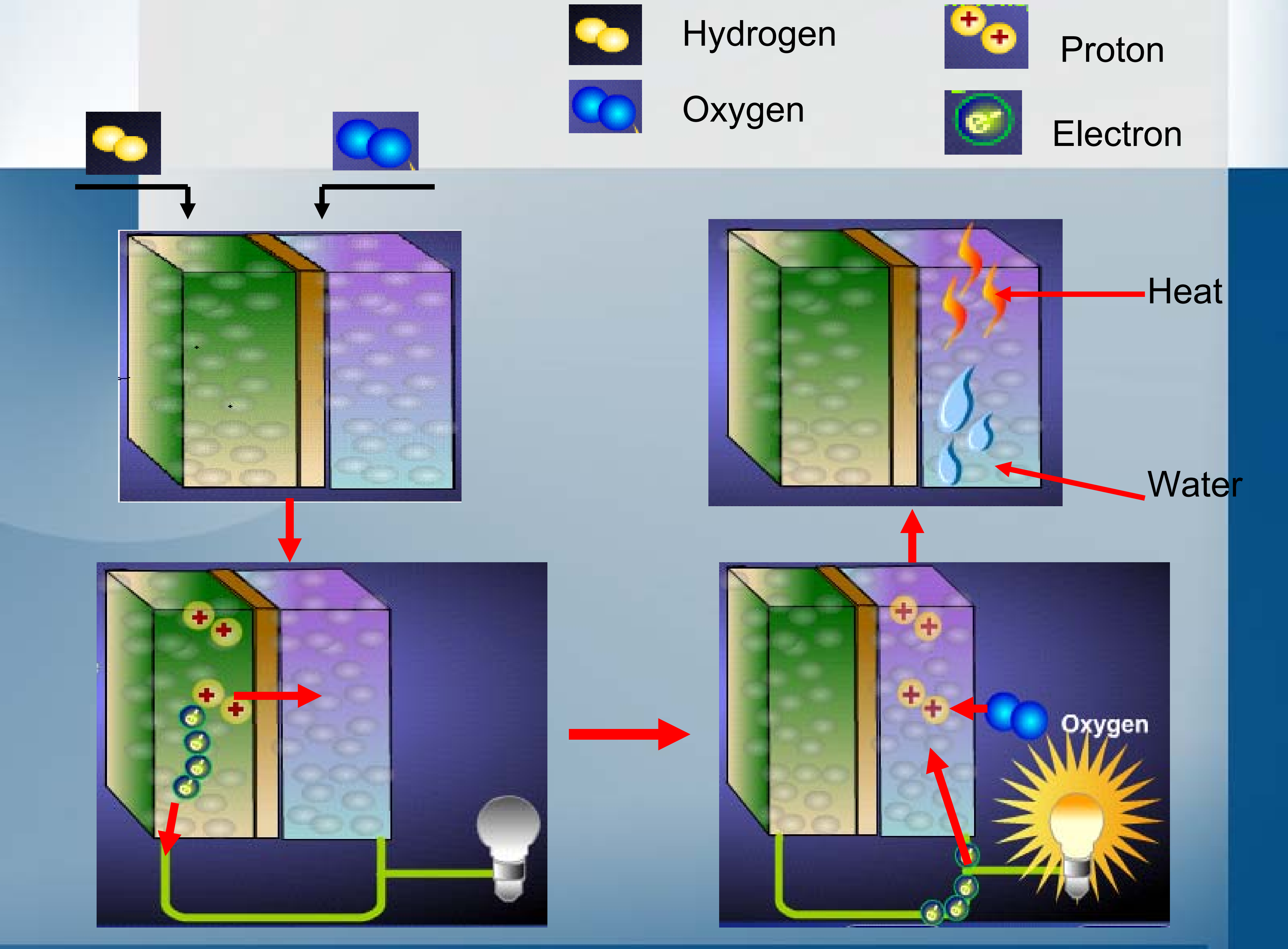
How Fuel Cells Work





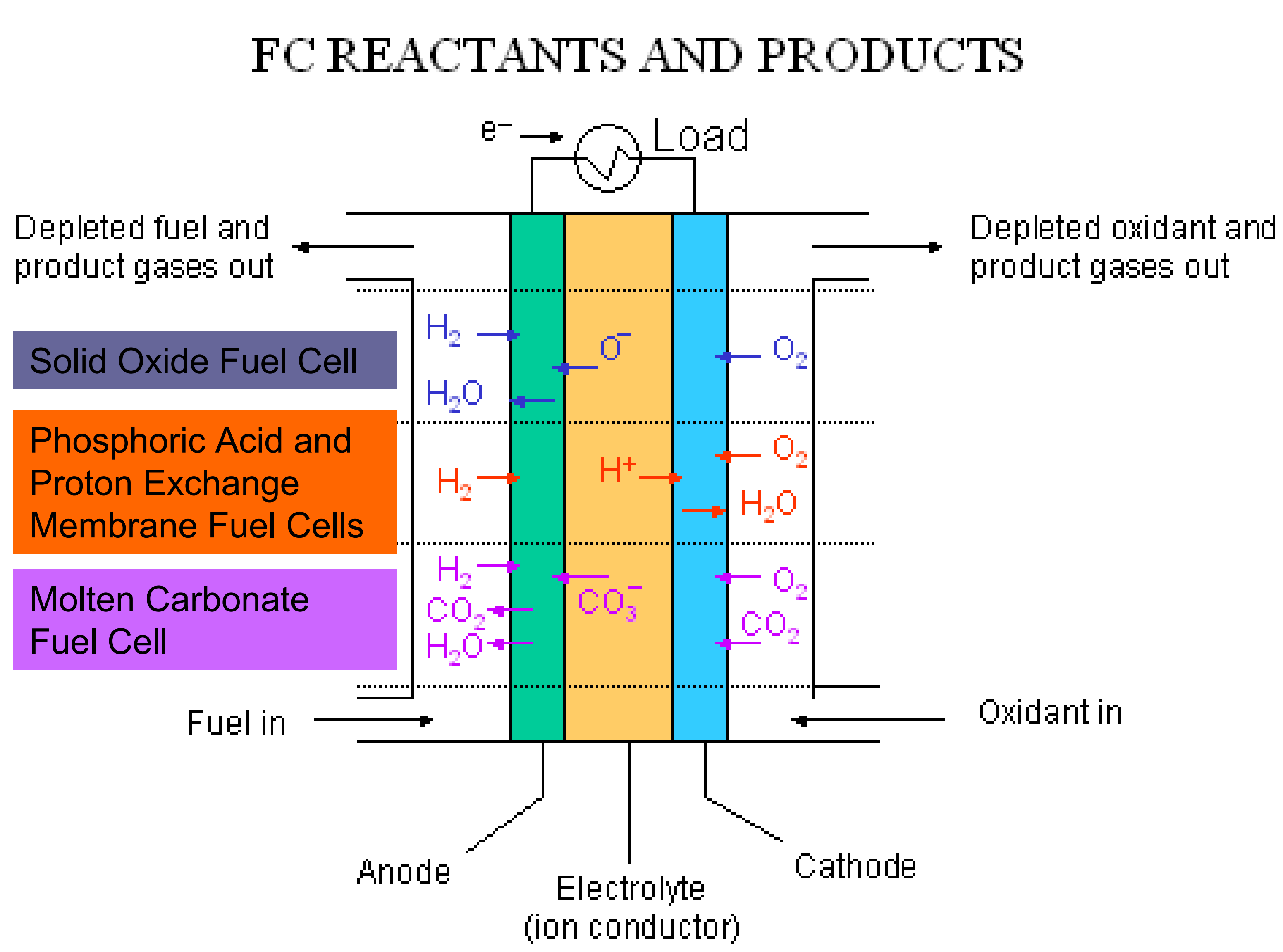
Catalyst

- Anode Side $$2H_2 \xrightarrow{Catalyst} 4H^+ + 4e^-$$
- Cathode Side $$O_2 + 4H^+ + 4e^- \xrightarrow{Catalyst} 2H_2O$$
- Net Reaction $$2H_2 + O_2 \rightarrow 2H_2O$$



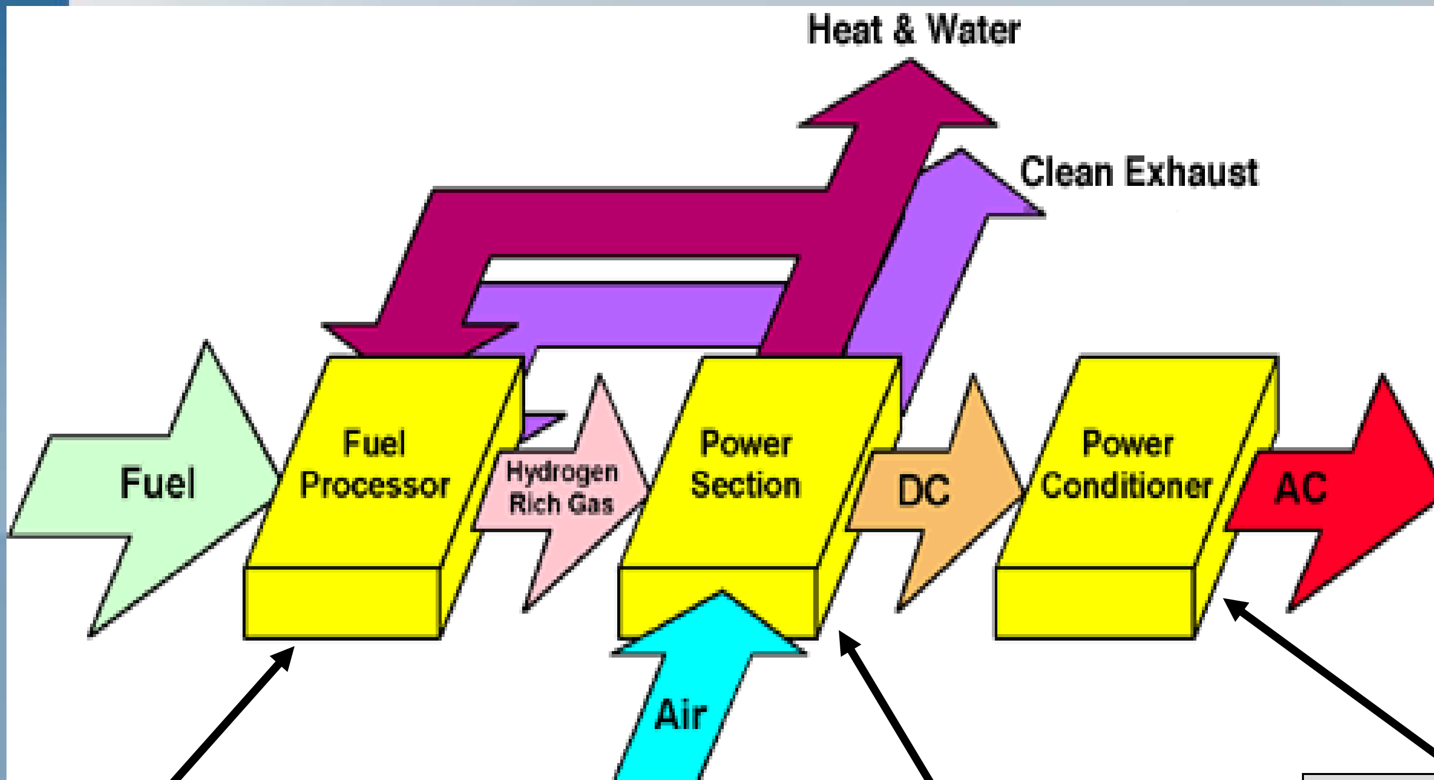
Hydrogen
Oxygen
Proton
Electron
Heat
Water
Oxygen

Electrochemical Reactions for Diff. Types of Fuel Cells



Courtesy of National Fuel Cell Research Center

Block Diagram of Fuel Cell System



Produces H_2-rich gas

Produces DC electricity

Converts DC to AC electricity

Courtesy of DoDFuelCell-Library Resources

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Fuel Cells: Stationary Power Generation

- Phosphoric Acid Fuel Cell (PAFC)
- Solid Oxide Fuel Cell (SOFC)
- Proton Exchange Membrane Fuel Cell (PEMFC)
- Molten Carbonate Fuel Cell (MCFC)

Fuel Cell Types

PHOSPHORIC ACID FUEL CELL (PAFC)

- Electrolyte: Concentrated Phosphoric Acid
- Most mature technology and widely diffused
- Supplied stationary power
  for 10 yrs
- Dimensions: 5.5m X 3m X 3m
- Manufacturing Cost: $575,000

Fuel Cell Types

SOLID OXIDE FUEL CELL (SOFC)

- Electrolyte: solid metal oxide
- Excellent cogeneration capabilities
- Most desirable
- Dimensions: 6m X 3m X 3m
- Mfg. Cost: $524,800

Courtesy of Global Thermoelectric Inc.

Fuel Cell Types

PROTON EXCHANGE MEMBRANE FUEL CELL (PEMFC)

- Electrolyte: solid perflurosulfonic acid polymer
- Newest technology
- Lower Operating Costs
- Quick Start-Up
- High Sensitivity to Fuel
- Dimensions: 5.4m X 3m X 3m
- Manufacturing Cost: $590,600

Fuel Cell Types

MOLTEN CARBONATE FUEL CELL (MCFC)

- Electrolyte: liquid lithium-potassium carbonate salt
- Electrode corrodes @ high temp.
- Currently in low demand
- Fuel and catalyst flexibility

Fuel Cell Analysis

Criteria	Phosphoric Acid	Molten Carbonate	Solid Oxide	Proton Exchange
Efficiency	37% - 42%	50% - 55%	50% - 60%	50%
Operating Temp.	370 - 410°F	1200°F	1800°F	175°F
Durability/Corrosion Issues	Catalyst poisoned @ low temp.	Electrode corrodes @ high temp.	No poison or corrosion	Catalyst poisoned @ low temp.
Start-Up Time	1 – 4 hr	8 – 10 hr	5 – 10 hr	6 min
Peak Power Density	~ 200 mW/cm^2	~ 160 mW/cm^2	~ 200 mW/cm^2	~ 700 mW/cm^2
Availability of Raw Materials	Massachusetts	limited	Ohio	Massachusetts
Cost of Raw Materials	$560/kW	$780/kW	$377/kW	$750/kW
Fuel	pure H_2	flexible	flexible	pure H_2

Fuel Cell Challenges

- Expensive System
- Conservative Market
- Unproven Market and Technology
- Fuel Supply

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Types of Products Manufactured
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Hydrogen Production Fuels

- Gasoline/Diesel
- Coal
- Biogas
- Electrolysis of H_2O
- Methanol/Ethanol
- Natural Gas

Natural Gas Reforming

- Availability
- Mature Infrastructure
- Low Emissions

Halias Natural Gas Reformer for 7.5 kW PEMFC, ChevronTexaco

Steam Reforming Process

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

$$CO + H_2O \rightarrow CO_2 + H_2$$

- Purpose
  - Center of reforming process convert CH_4 to H_2 using steam.
- Method
  - High Temperature ~ 800 ºC
  - Use H_2O to push equilibrium towards products
  - Nickel Oxide 4 hole cylinders

The Problem of Carbon Monoxide

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

- Purpose
  - Convert Carbon Monoxide Byproduct of Steam Reforming
- Method
  - Two reactors with different…
    - Temperatures (T_1 ~ 450 °C, T_2 ~ 225 °C)
    - Catalysts (chromia promoted iron oxide pellets, copper-zinc oxide pellets)

The Problem of Sulfur

$$(C_2H_5)_2S + 2H_2 \rightarrow 2C_2H_6 + H_2S$$

$$H_2S + ZnO \rightarrow ZnS + H_2O$$

- Purpose
  - – Reduce Sulfur content of gas
- Method
  - – Cobalt-Molybdenum extrudes
  - – ZnO spheres to remove H_2S
  - – 300-400 °C

Fuel Cell Design Requirements

- SOFC
  - Sulfur reduction to less than 1 ppm
- PAFC
  - Sulfur to less than 50 ppm
  - CO to less than 0.5 mole %
- PEMF
  - Sulfur to less than 1 ppb
  - CO to less than 10 ppm

To Build or Not to Build

- ✓ Benefits
  - ✓ Lower Per Unit Cost
  - ✓ Opportunities for Process Integration
  - ✓ Increased Design Flexibility
- ✘ Disadvantages
  - ✘ Increased Capital Investment
  - ✘ Catalyst Regeneration and Handling
  - ✘ Diffuse Market Focus

Potential Reformer Suppliers

- Ztek Corporation
  - East Coast
  - Flexible Fuel Stocks
    - Gasoline
    - Natural Gas
  - 4000 SCF H_2 produced per hour.
  - 2 m by 4 m by 2 m
  - Estimated cost of $125,000 based upon Department of Energy study.

- ChevronTexaco
  - West Coast
  - Fuel Stocks
    - Natural Gas
    - Propane
  - Currently under scaled
    - Only 250 SCF H_2 per hour
    - 1.5 m by 1 m by 1 m

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Fuel Cell Manufacturing Processes

- PAFC
  - Teflon bonded silicon carbide matrix suspends the phosphoric acid
- PEMFC
  - MEA is created through polymer processes
- SOFC
  - Cathode, anode, and electrolyte are all produced from powder solutions

SOFC Raw Materials

- Electrolyte – $ZrO_2(Y_2O_3)$ powder
- Cathode – doped $LaMnO_3$ powder
- Anode – Ni-$ZrO_2(Y_2O_3)$ powder
- Other Materials
  - Solvents
  - Binders
  - Plastisisers
  - Cr Alloy

Process Flowchart for SOFC

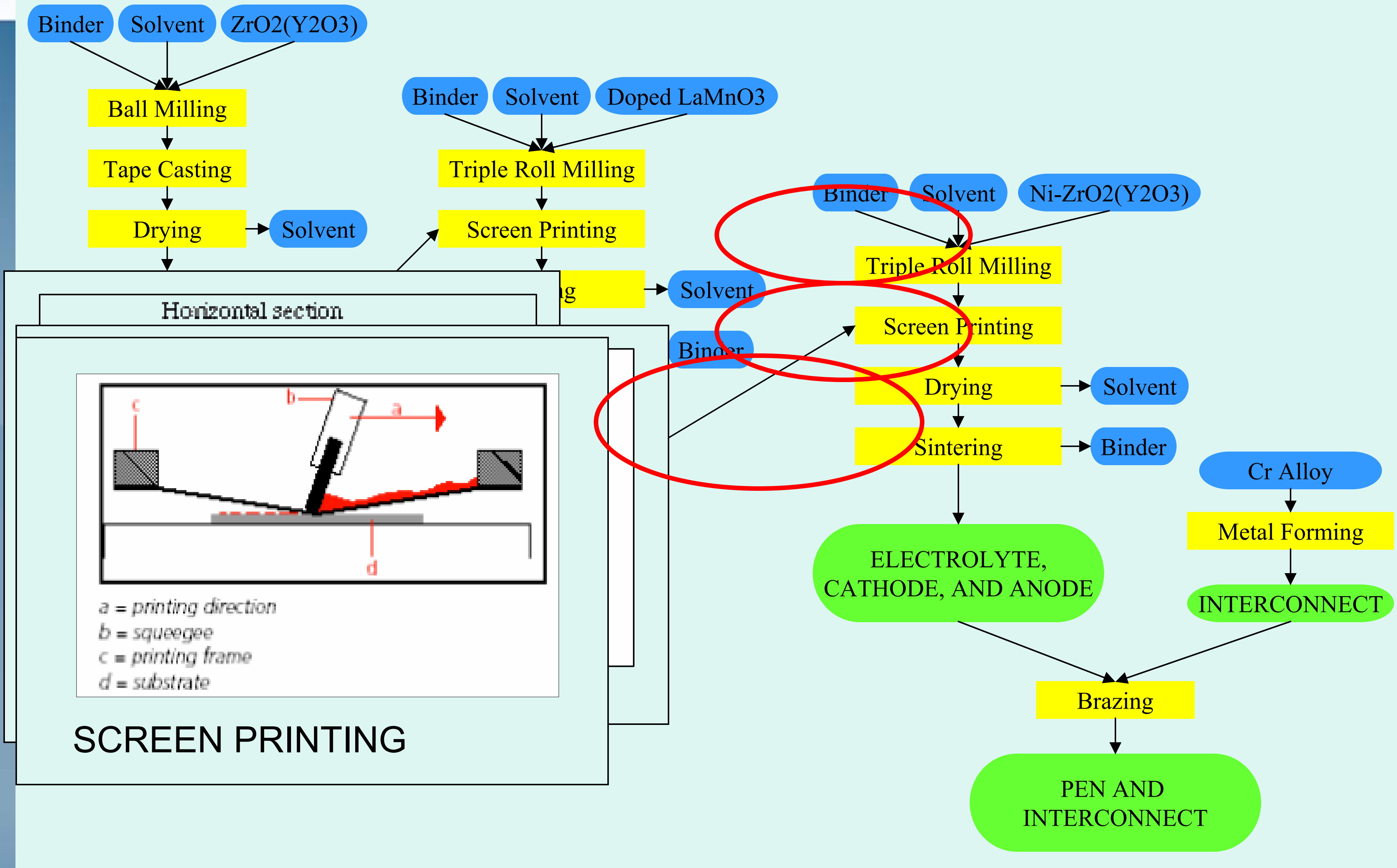
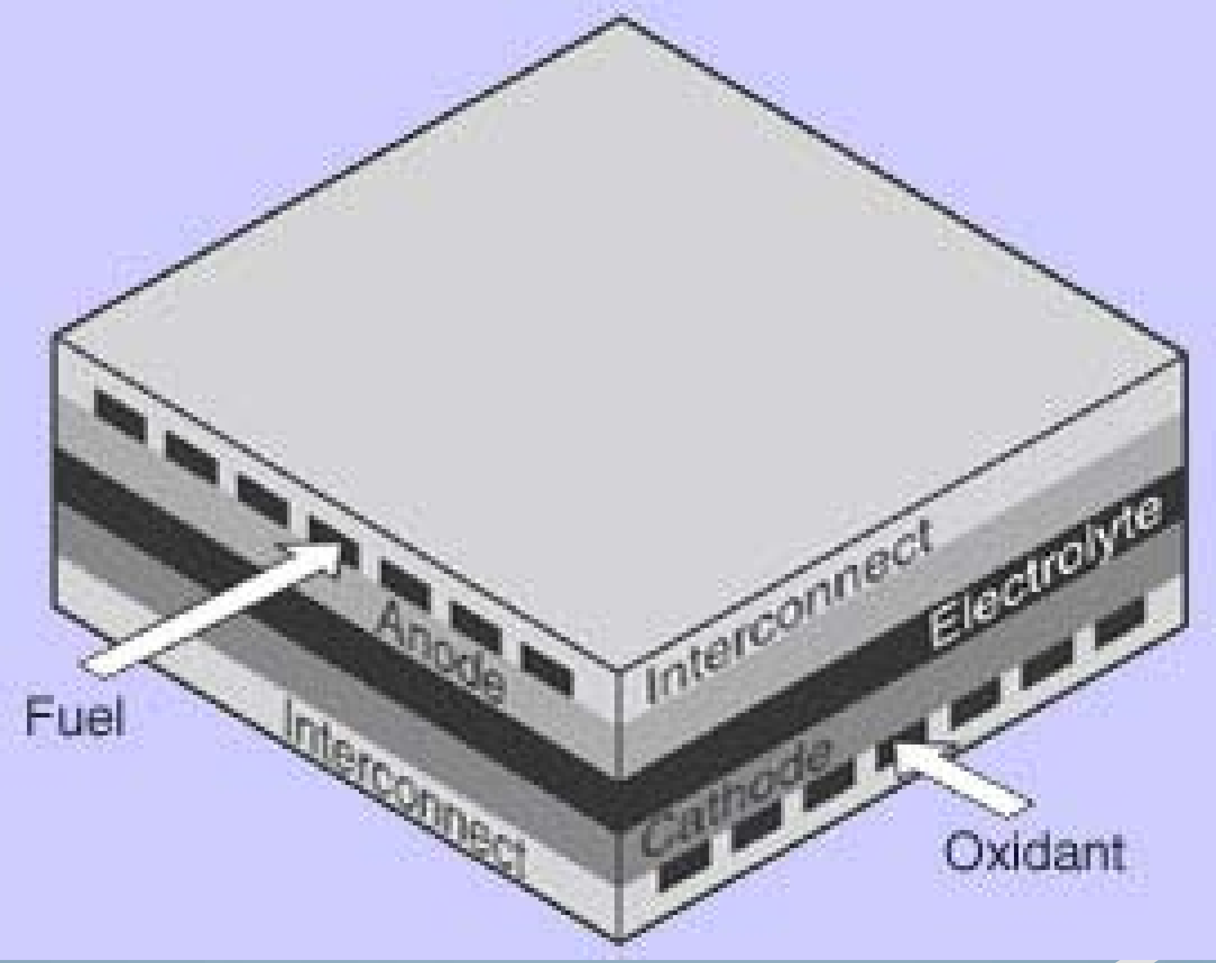
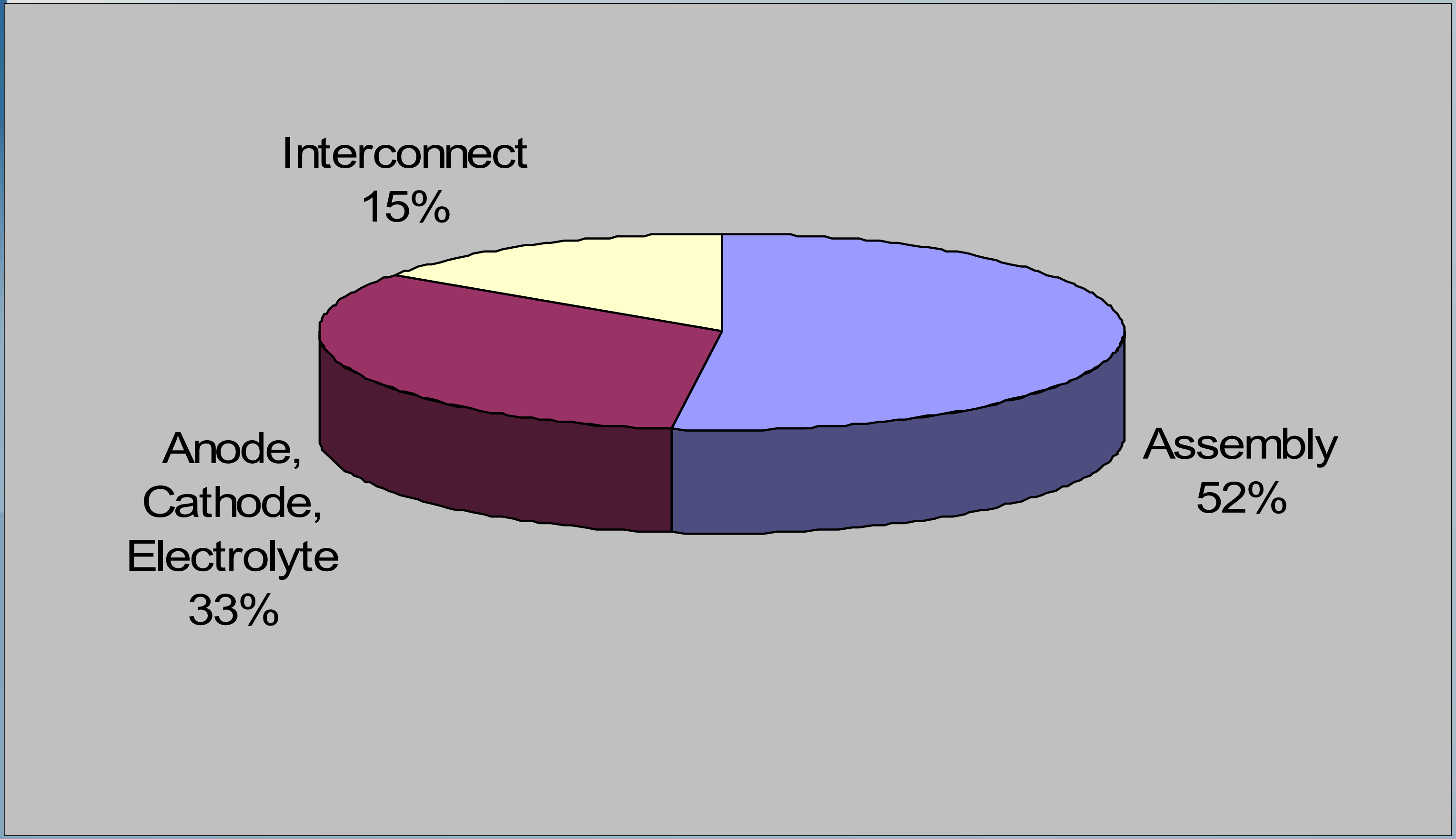


Diagram of the Unit Cell



Process Cost Break-Down



Factors: Labor, Power, Raw Materials

Equipment Cost

Process Description	Component	Equipment Description	Equipment Cost
Automated Tape Casting	Electrolyte	Tape Caster	$300,000
Screen Printing	Anode, Cathode	Manual Station	$20,000
Vacuum Leak Test	Fabrication	Inspection Machine	$300,000
Continuous Sinter	Fabrication	Sintering Furnace	$500,000
IC joining -Heat Treatment	Interconnect	Brazing Furnace	$400,000
Milling	Anode, Cathode, Electrolyte	Ball Mill, Roll Mills	$22,000

Courtesy of Department of Energy-Federal Energy Technology Center

Total SOFC Equipment Cost = $2.4 million

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Plant Location Analysis

- Origin of Raw Materials

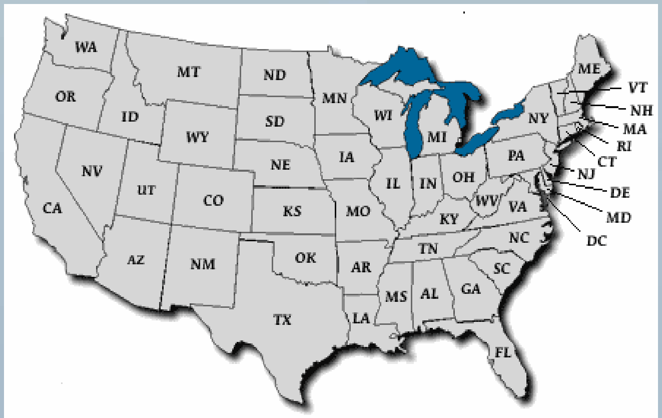
  MA and OH

- Possible Market Locations

  No. of Small Business

  Amount of Pollution

  Electricity Prices



- Low Tax Rates

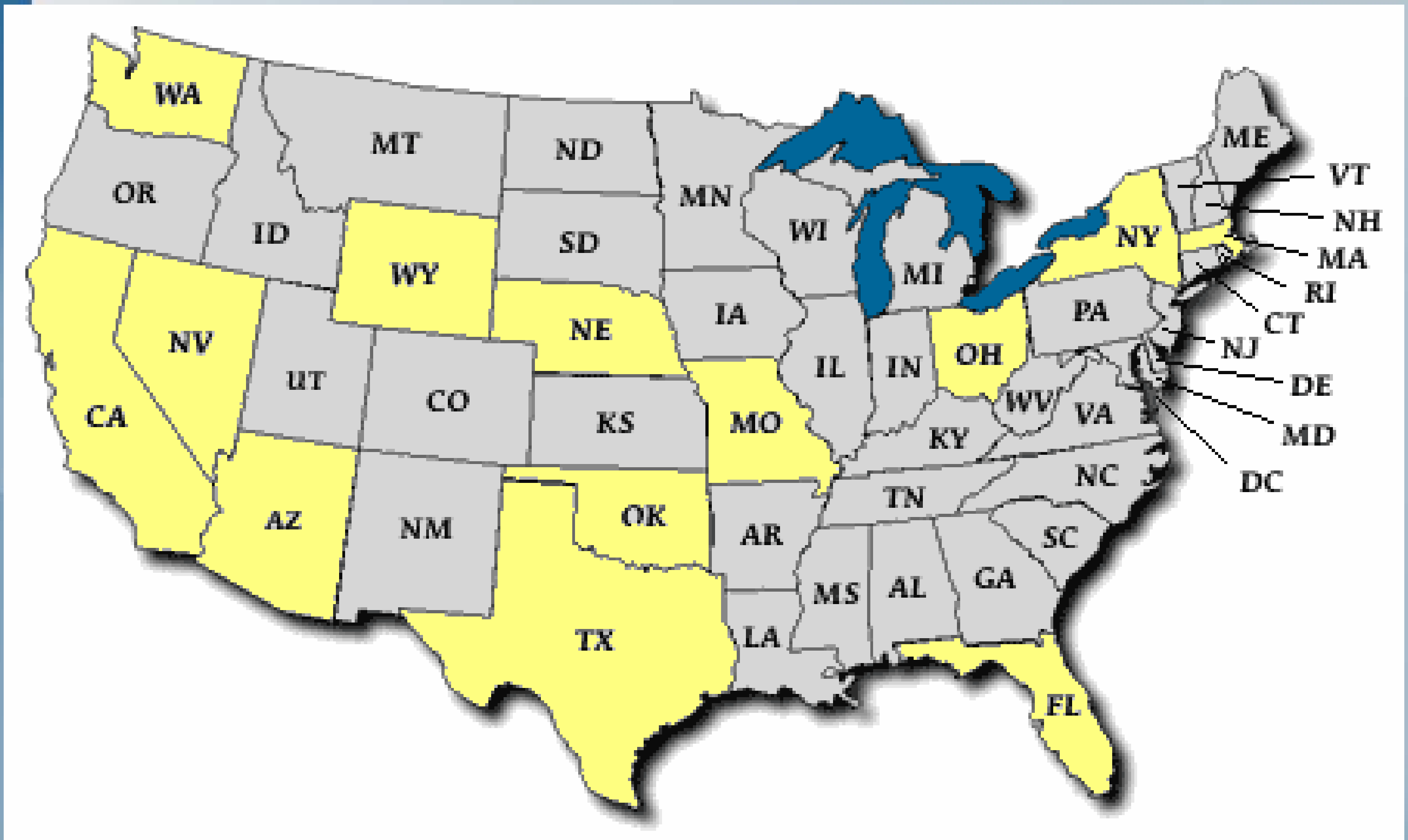
  Property, Sales, Federal, and State Taxes

- Low Cost of Labor

  Median Hourly Wage

- Only the Lower 48 States Were Considered

Plant Location Analysis



Labor & Tax Analysis

Labor

- Number of Employees
- Annual Salaries by Position
- 3 Shifts per Day / 341 Days per year

Taxes

- State Corporate Income Tax
- Federal Corporate Income Tax
- Sales Tax
- Property Tax

Transportation Analysis

Two options – American Freight Company or The OUFCC fleet

If AFC is contracted:

- We will be Packing, Crating and Addressing the Shipments
- $1.45 for each mile traveled
- Flat Fee - $668 per delivery
- Large City Surcharge of $100

Transportation Analysis

If The OUFCC purchases own fleet:

- Trucks - $55,000 each
- Truck Drivers - $40,000/yr
- Diesel
- Licenses, Tires, Insurance and Maintenance

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Mathematical Model

- Why use a model?
  - Consider multiple design options simultaneously.
  - Prediction of sales and added production over project lifetime.
- Type: General Algebraic Modeling System (GAMS)

Mathematical Model -GAMS

- Goal:
  - Determine plant and market locations
  - Determine annual production rate of each type
  - Maximize our objective function: NPW
- Types: Deterministic and Stochastic

Deterministic Model

- Input
  - Raw Materials
  - Utilities costs
  - Transportation
  - Taxes
  - Market demands
  - Maximum capacity
  - Selling price of fuel cells
- Output
  - Production rate
  - Increase production
  - Revenue
  - Cash Flow
  - FCI,TCI
  - Objective Function: NPW

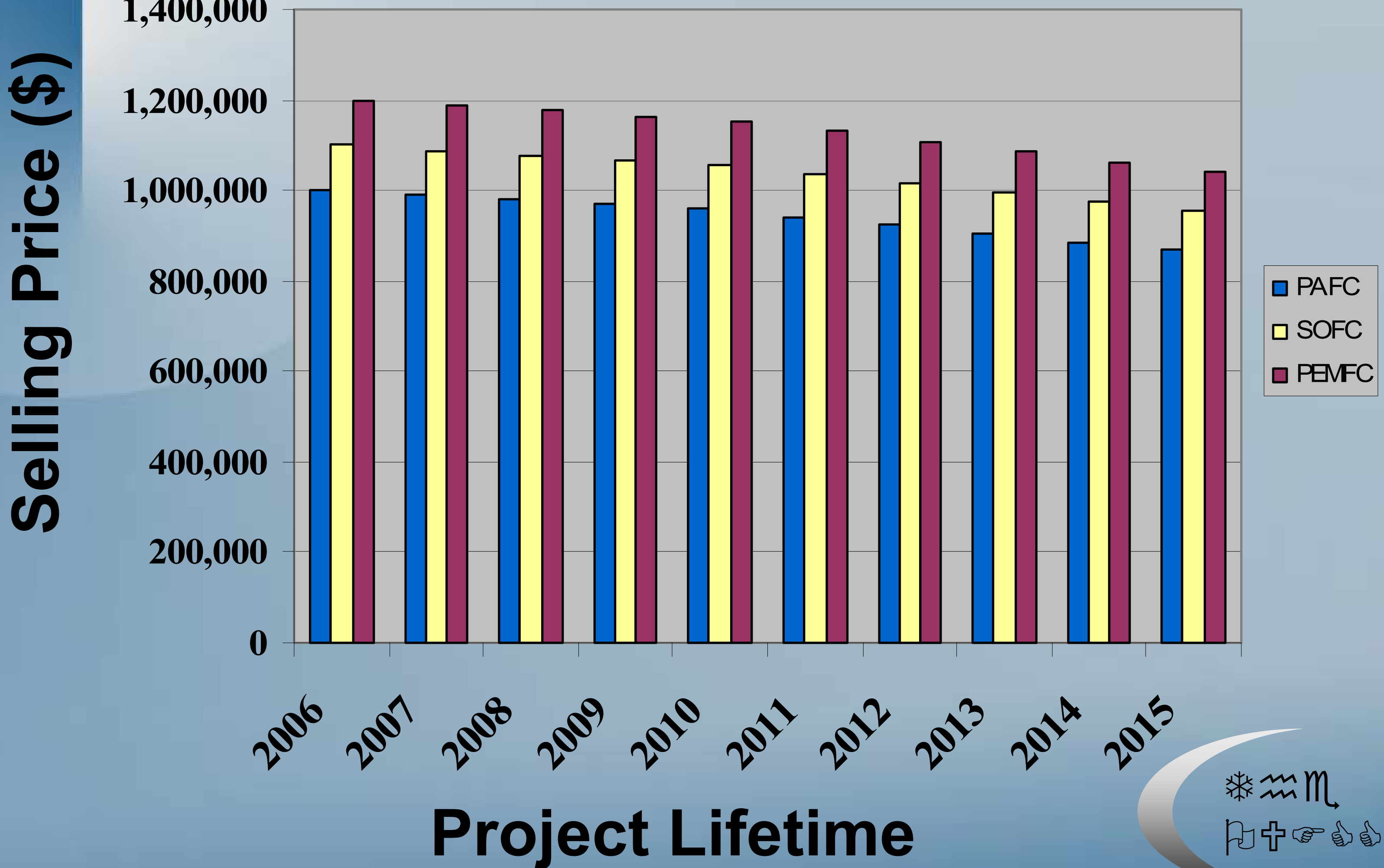
Deterministic Model

- Constraints
  - Decision variable for plant location
  - Maximum Capacity
  - Market demand

Parameters

- Locations: 13
  - AZ, CA,FL,MA,MO,NE,NV,NY,OH,OK,TX,WA, WY
- Labor: 71 workers
- Operating Period: 341 days/yr; 24 hrs/day
- Project Life:10 years
- Selling Price: Varies over time
  - $1.0 million for PAFC
  - $1.1 million for SOFC
  - $1.2 million for PEMFC

Selling Price



Mathematical Equations

- FCI

$$FCI_i = FxCost_{i,t} + \sum_k \alpha * \mathrm{AddProd}_{i,k,t}$$

- Revenue

$$\mathrm{Re}\,v_{i,t} = \sum_j (Sell(k) * x(i,j,k,t) - TOC_{i,t})$$

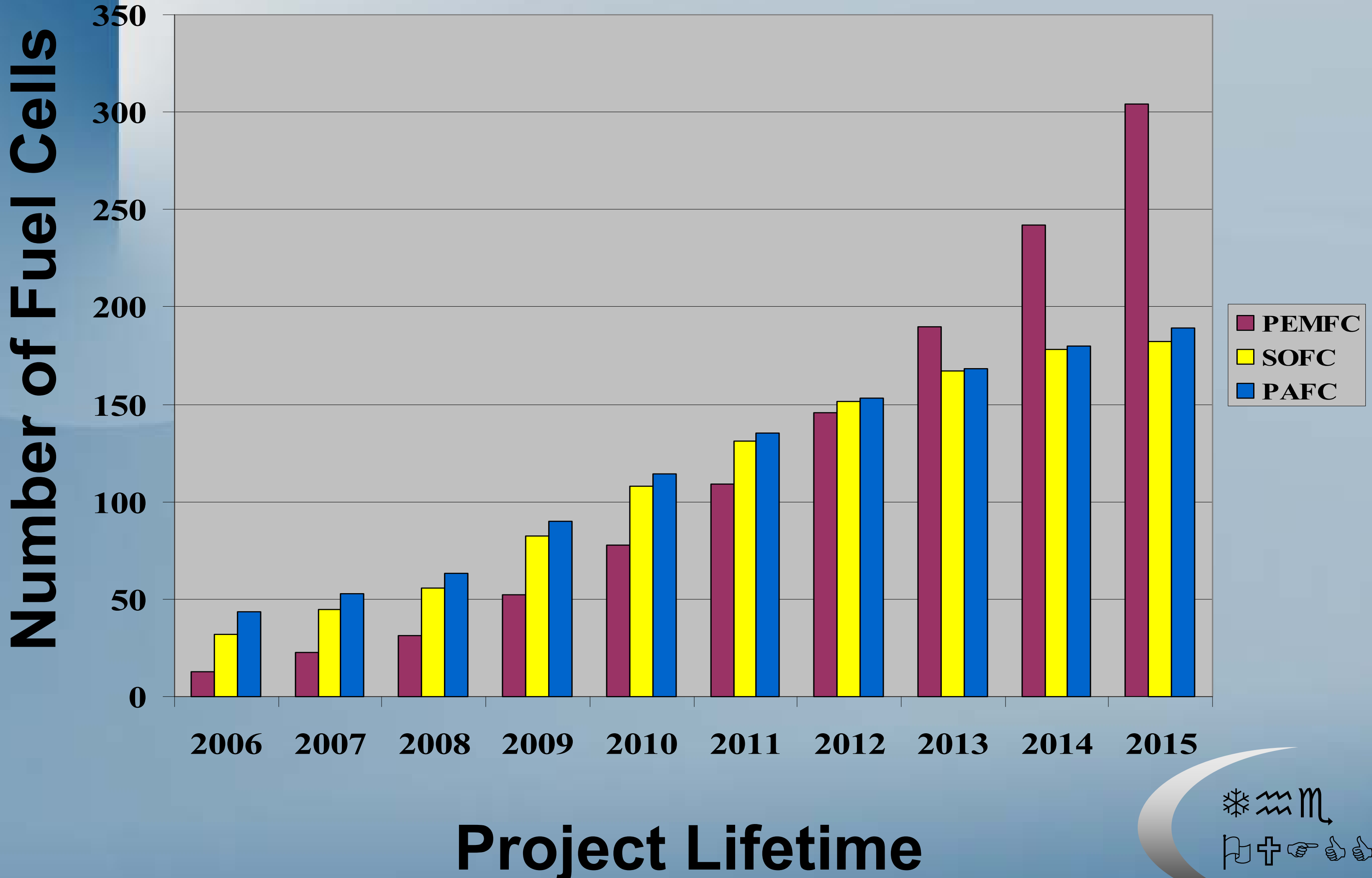
- Cashflow

$$CF_{i,t} = [\mathrm{Re}v_{i,t} - (\mathrm{Re}v_{i,t} - Dep * FCI_i) * Tax_i] - TOC_{i,t}$$

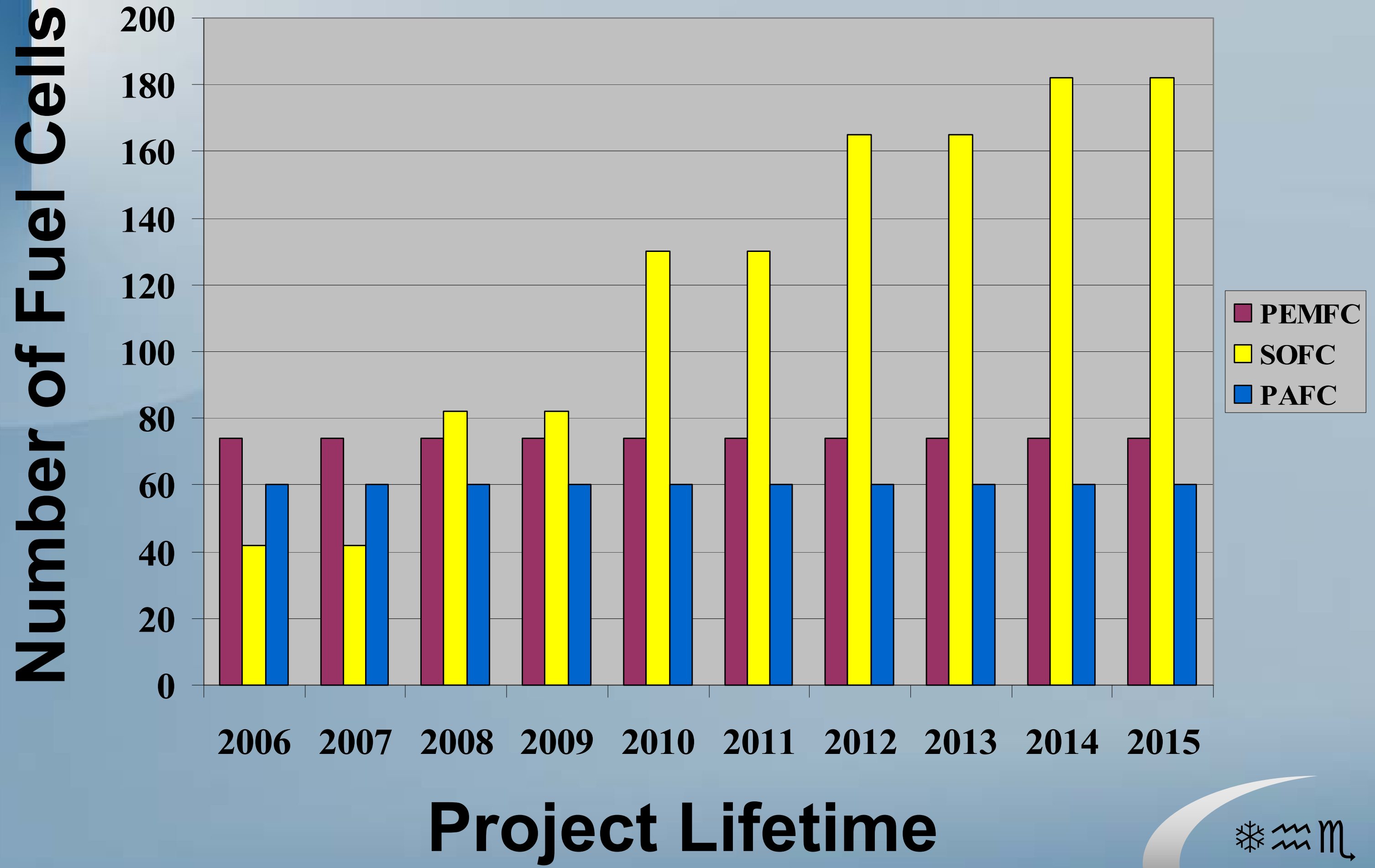
- Net Present Worth

$$NPW = \sum_i \sum_t (CF_{i,t} - TCI_i) / (1 + \mathrm{int}^{Time_t})$$

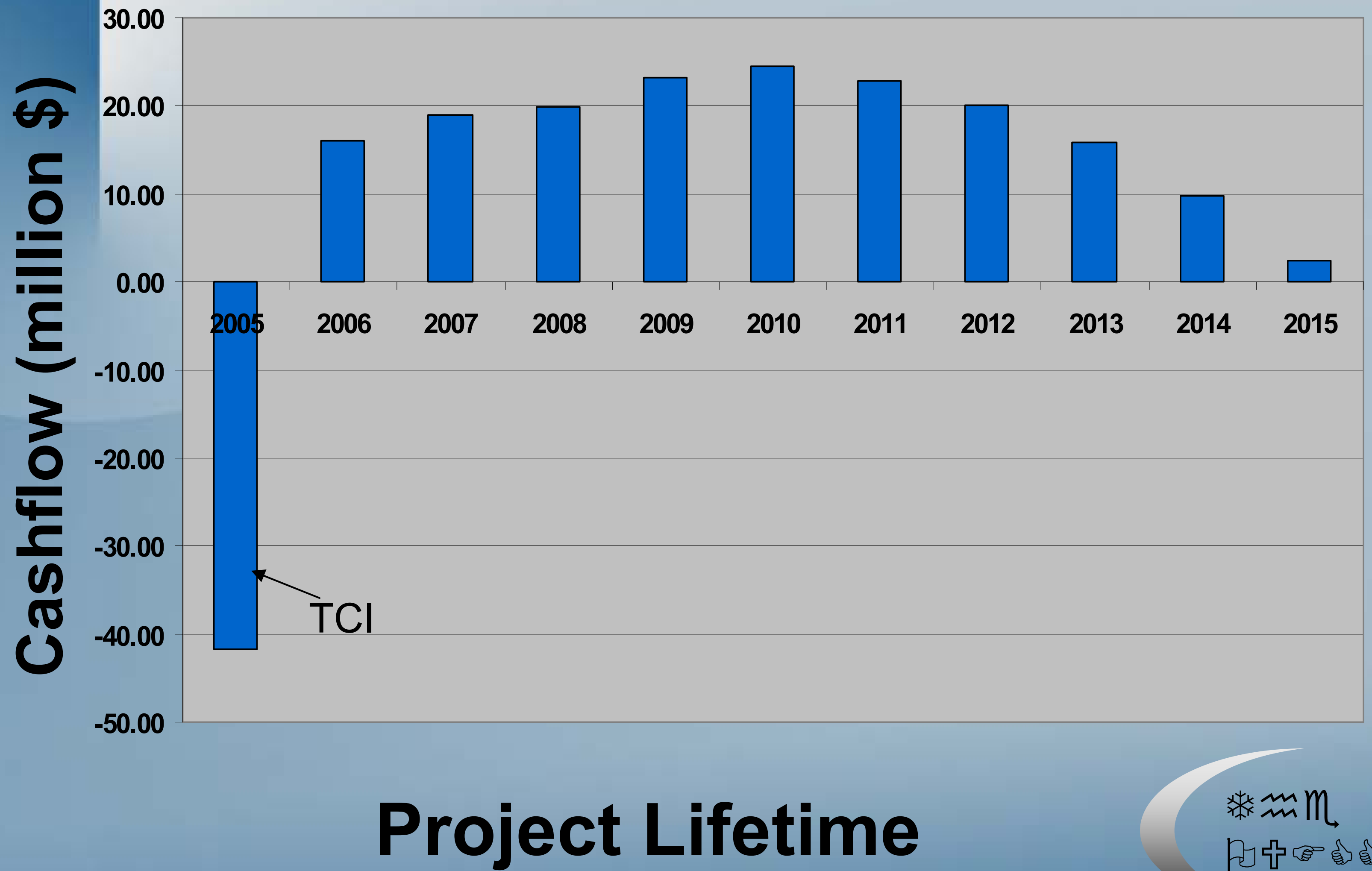
Market Demand



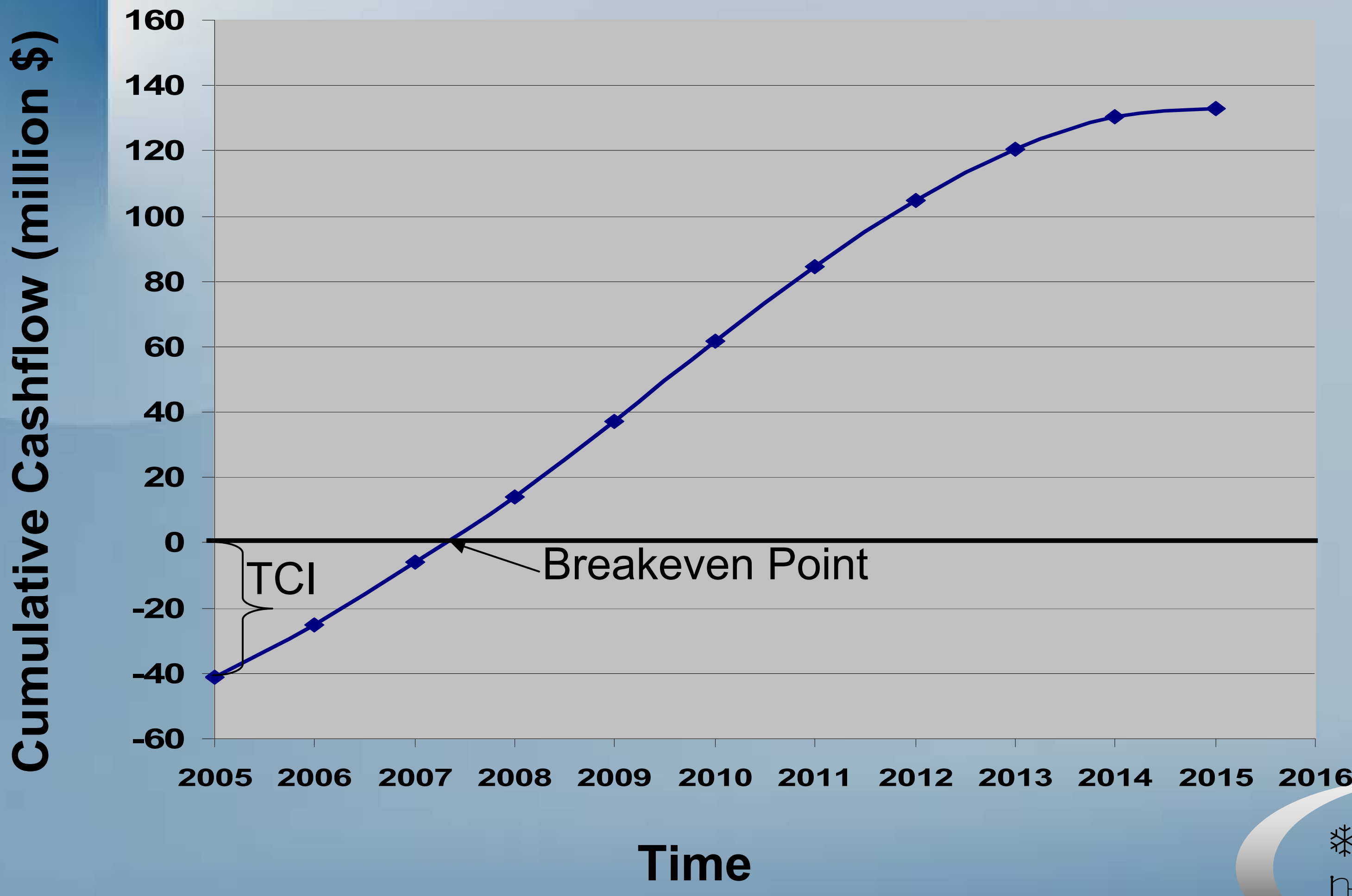
Projected Sales



Cash Flow Predictions



Breakeven Chart



Deterministic Model Results

- Plant Location: Wyoming
- Plan to increase production other year
- FCI: $35,789,500
- TCI: $41,157,930
- NPW: $83,154,900
- ROI: 23%

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Risk and Uncertainty

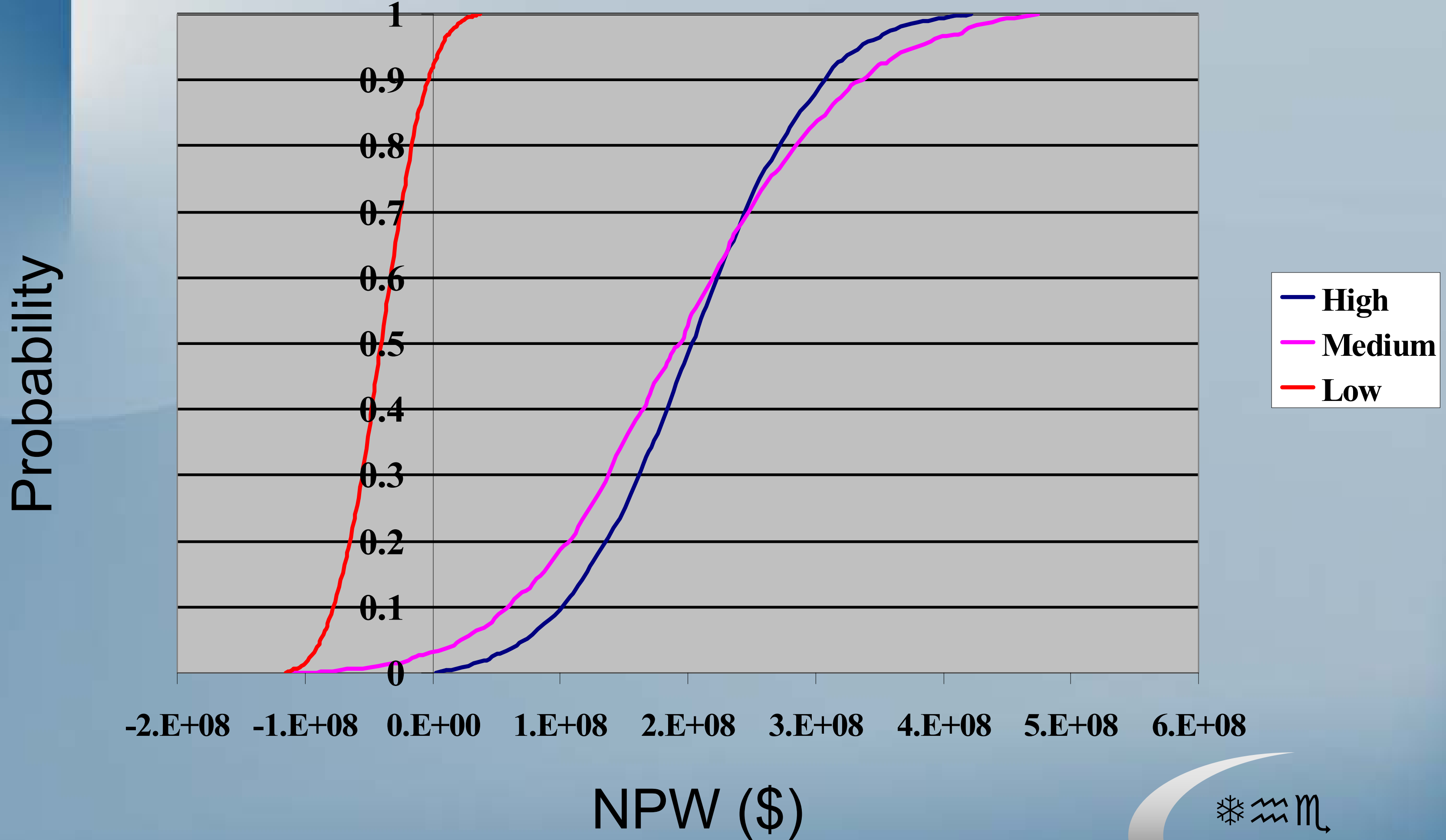
Uncertain Parameters

- Raw Material Costs
- Equipment Cost
- Selling Price

Examined 3 Scenarios

Deviated 20% around the mean values

Risk Analysis

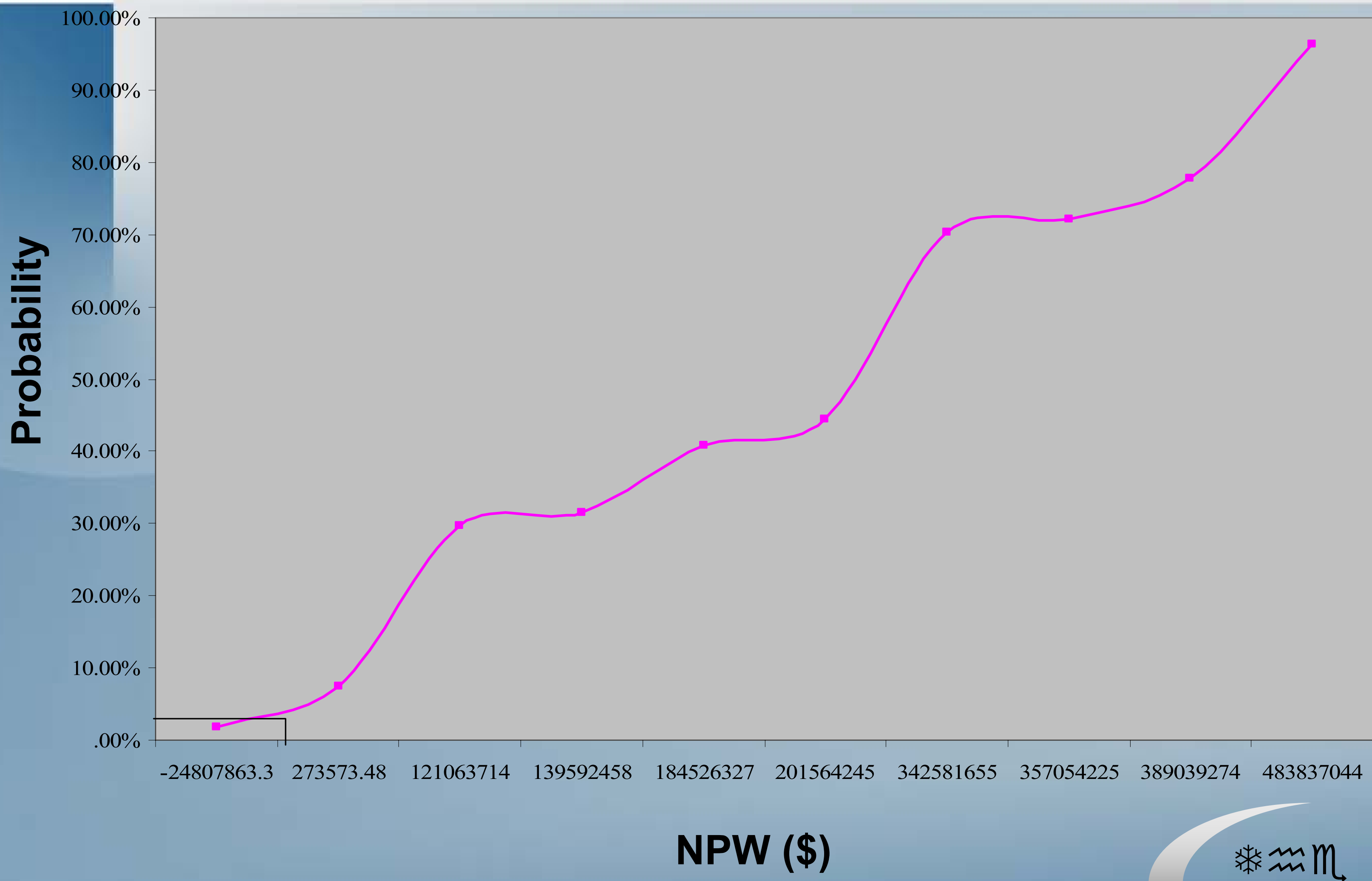


Stochastic Modeling

MAXIMIZE

Net Present Value considering all possible scenarios of the uncertain parameters

Stochastic Analysis

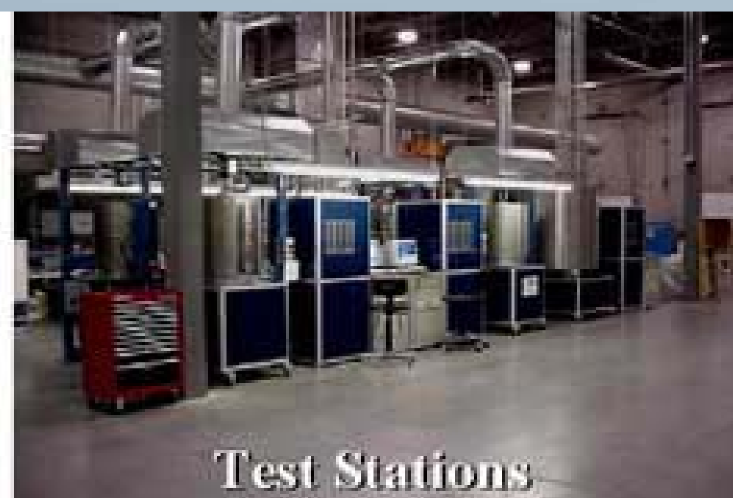


Thank you.

Any Questions?

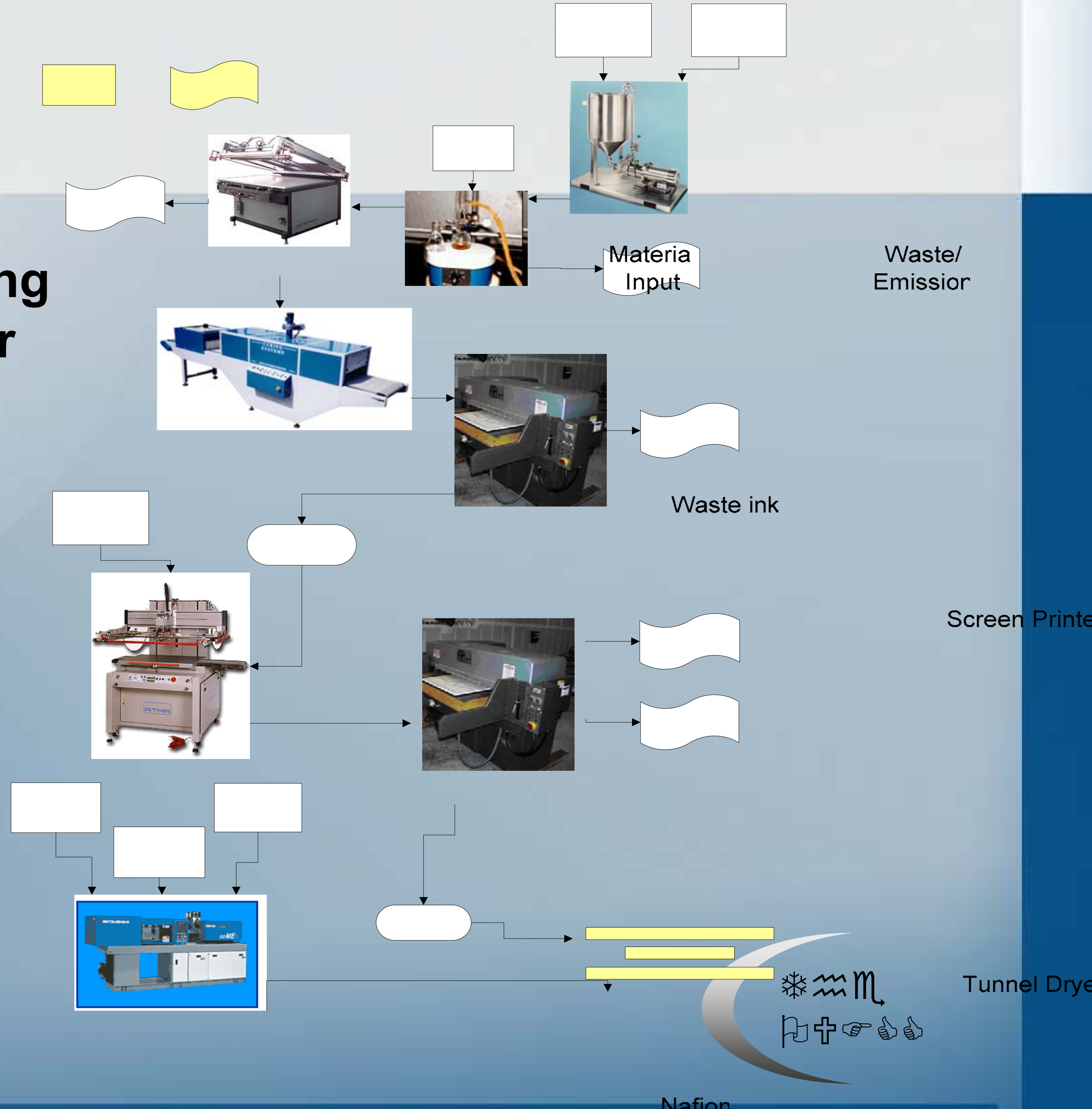
Extra Slides

Process Equipment



Courtesy of Global Thermoelectric Inc.

Manufacturing Process for PEMFC

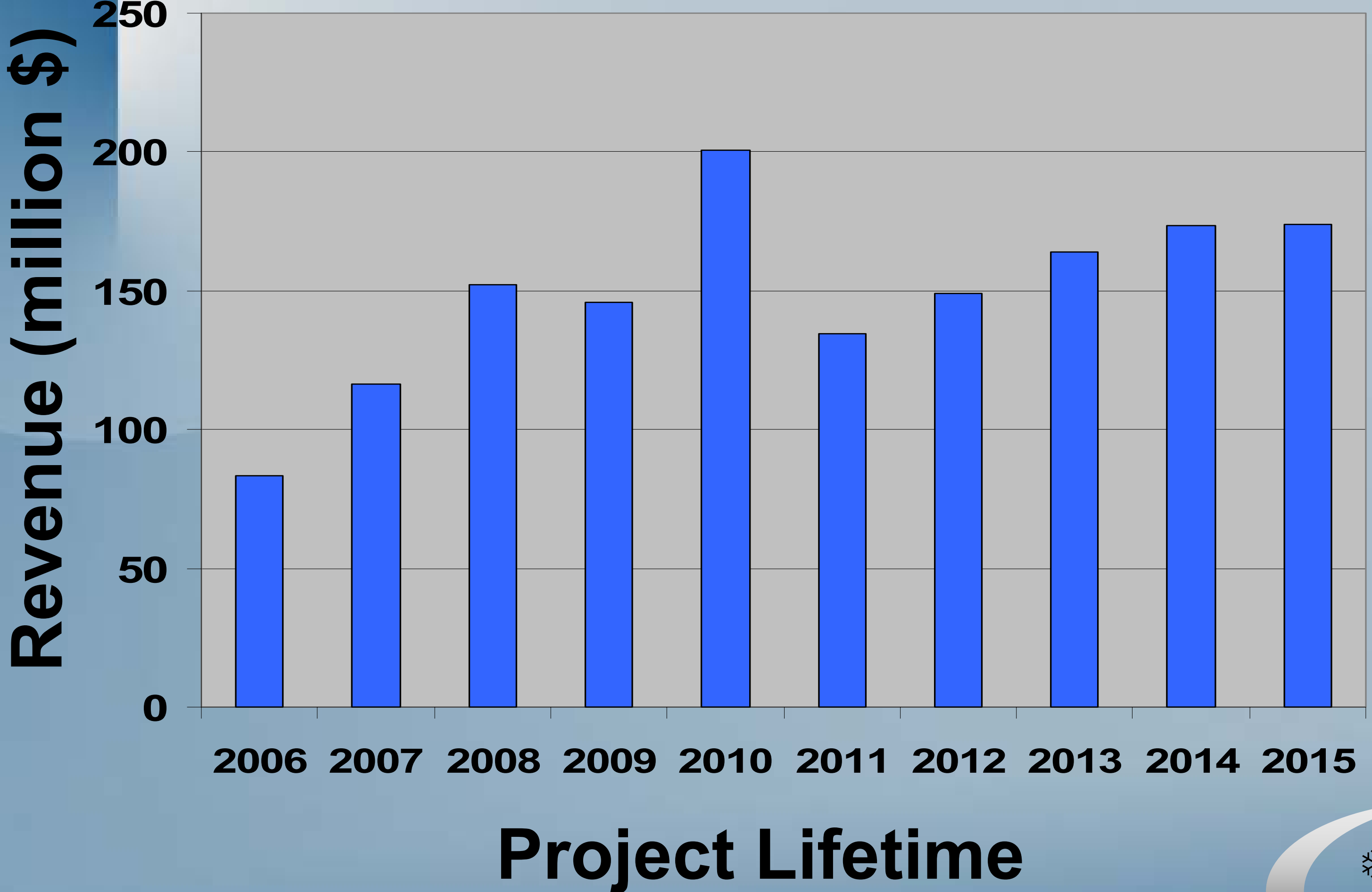


Raw Materials for PEMFC

Component	Cost ($)
Hardware	187,500
Electrode	17,400
Catalyst	2,700

Total manufacturing cost = $576,600

Revenue Predictions



Still more questions?