1902 – Flywheel Generators

1905 – Transmission Switches
1912 - Steam Turbine

1920 - Westinghouse Generator
1936 - Cold Guy Fixing Power Pole

1942 – 2500 KW Generator
1964 – World’s Fair, Fuel Cell & Gas Turbine

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Really!

Not Kidding.
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Really!

Not Kidding.
History of Fuel Cell Technology

- First attempts more than 150 yrs ago
  - William Robert Grove (1811 -1896)
    - Invented wet cell battery, 1838 “Grove Cell”
  - Friedrich Wilhelm Ostwald (1853 -1932)
    - Provided theoretical understanding of fuel cells electrodes, electrolyte, oxidizing and reducing agents, anions, and cations
  - Francis Thomas Bacon (1904 -1992)
    - World War II, developed FC for Royal Navy submarines
      - No relation to Kevin Bacon
Environmental Benefits!

Comparison of Power Plant Emissions

<table>
<thead>
<tr>
<th>Type of Power Plant</th>
<th>Pounds of Particulates (per MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>fuel cell</td>
<td>0</td>
</tr>
<tr>
<td>gas fired</td>
<td>2</td>
</tr>
<tr>
<td>oil fired</td>
<td>4</td>
</tr>
<tr>
<td>coal fired</td>
<td>8</td>
</tr>
<tr>
<td>EPA limits</td>
<td>12</td>
</tr>
</tbody>
</table>

Environmental Benefits?

Fuel Cell Air Emissions
PC25 Emissions From One Year of Operation

- Fuel cell
  - Nitrogen Oxides (NOx): 41,437 pounds
  - Carbon Monoxide (CO): 3,000 pounds

- Average U.S. fossil fueled plant
  - Nitrogen Oxides (NOx): 4,500,000 pounds
  - Carbon Monoxide (CO): 1,200,000 pounds
Additional Benefits…

• High power reliability
  – good for computer facilities, hospitals, data processing centers, high-tech manufacturing facilities, etc…

• Freedom from “Gridlock”
  – usable in remote locations
  – Impervious to power fluctuations

• Cogeneration possibilities
  – other waste gases used to generate electricity and heat

Evolution of Fuel Cell Technology

• Alkali Fuel Cells
• Molten Carbonate
• Phosphoric
• PEM (Proton Exchange Membrane)
• Solid Oxide (SOFC)
Evolution of Fuel Cell Technology

- Alkali Fuel Cells
  - highly efficient, up to 70%
  - potable water is produced as by-product
  - must use pure hydrogen, to avoid CO ‘poisoning’
  - requires large amount of platinum, expensive
- Molten Carbonate
- Phosphoric
- PEM (Proton Exchange Membrane)
- Solid Oxide (SOFC)

Evolution of Fuel Cell Technology

- Alkali Fuel Cells
- Molten Carbonate
  - able to use variety of fuels
  - not prone to CO ‘poisoning’
  - can use nickel instead of platinum, cheaper
  - uses a liquid electrolyte, problematic
  - needs CO₂ injections, to replenish Carbonate ions
- Phosphoric
- PEM (Proton Exchange Membrane)
- Solid Oxide (SOFC)
Evolution of Fuel Cell Technology

- Alkali Fuel Cells
- Molten Carbonate
- Phosphoric
  - uses phosphoric acid as electrolyte, stable
  - all components must be resistant to acid corrosion
  - Less susceptible to CO₂ ‘poisoning’
  - efficiency approximately 40-50%
- PEM (Proton Exchange Membrane)
- Solid Oxide (SOFC)

Evolution of Fuel Cell Technology

- Alkali Fuel Cells
- Molten Carbonate
- Phosphoric
- PEM (Proton Exchange Membrane)
- Solid Oxide (SOFC) – Siemens
  - operates at high temperatures
  - hydrogen conversion not required
  - not affected by CO
  - efficiency approximately 60%
Evolution of Fuel Cell Technology

- Alkali Fuel Cells
- Molten Carbonate
- Phosphoric
- PEM (Proton Exchange Membrane) - Ballard
  - small & light **
  - able to operate at low temperatures
  - efficiency approximately 40-50%
  - hydrogen conversion required
- Solid Oxide (SOFC)
Industry Leaders:

- Ballard Power Systems (PEM)
  - XCELLSiS (recently acquired by Ballard)
- Siemens Westinghouse (SOFC)
- Plug Power (PEM)
- UTC, formally ‘International Fuel Cells’ (PEM)
- H-Power, manufactured by SeCeSpol (PEM)
  - 1st major commercial distribution

Ballard Power Systems (PEM)

- Stationary Power Generators
  - 250kW Stationary Generator
    (field trials are underway)
Ballard Power Systems (PEM)

• Bus and Automotive Propulsion
  – Ford
  – Daimler Chrysler
  – GM
  – Honda
  – Nissan
  – Volkswagen
  – Chicago Transit Authority
  – TransLink

Ballard Power Systems (PEM)

• “Nexa™ Power Module”
  – portable fuel cell module
    • Weight = 12 kg (27 lbs)
    • Size = 56 x 25 x 33 cm
    • Rated Net output = 1200 watts
    • DC Voltage = 26 Volts
      (at rated net output)
    • Lifetime = 1500 hours
Fuel Cell Transportation:

• NEBUS (New Electric BUS)
  – operating range up to 250 km
  – fuel cell consists of
ten stacks of 25 kW each

• NECAR 5 (New Electric CAR)
  – Top speed 90 mph *
  – Range 280 miles *

* figures from NECAR 4, NECAR 5 info not avail
Fuel Cell Transpo: Nissan

- Xterra-FCV
  - unchallenged in category
  - fleet testing began 2001

Fuel Cell Autos: Toyota

- FCHV-5
  - hydrogen extracted from sulfur-free gasoline
  - uses small battery for on-demand power
    (to minimize compressor noise)
  - top speed of 95 mph and a range of 155 miles
Fuel Cell Autos: Ford

• Ford Focus FCV
  – scheduled for market in 2004
  – range of about 100 miles
Biomass Energy

- Energy generated by burning plant matter:
  - Fast-growing trees and grasses, like hybrid poplars or switchgrass
  - Agricultural residues, like corn stover, rice straw, wheat straw, or used vegetable oils
  - Wood waste, such as sawdust and tree prunings, paper trash and yard clippings
- Does not contribute to global warming
  - because CO$_2$ would be released anyway

California leads nation in use of biomass energy
- more than 1.4 trillion pounds each year
- 2.8% of all of California's electricity
Biomass Fuels “Biofuels”

- The term biofuels refers to fuels for electricity generation and fuels for transportation.
- Biofuels are alcohols, ethers, and other chemicals made from cellulose biomass.
- Sources of cellulose biomass include:
  - herbaceous and woody plants
  - agricultural and forestry residues
  - municipal solid and industrial waste

MC’s Biomass Uncertainties

- Might lead to increased air pollution
- Land use issues, tradeoff between:
  - potential for biomass energy
  - potential for agriculture
  - wilderness preservation
- Could encourage use of GMO crops