

# Team Daedalian

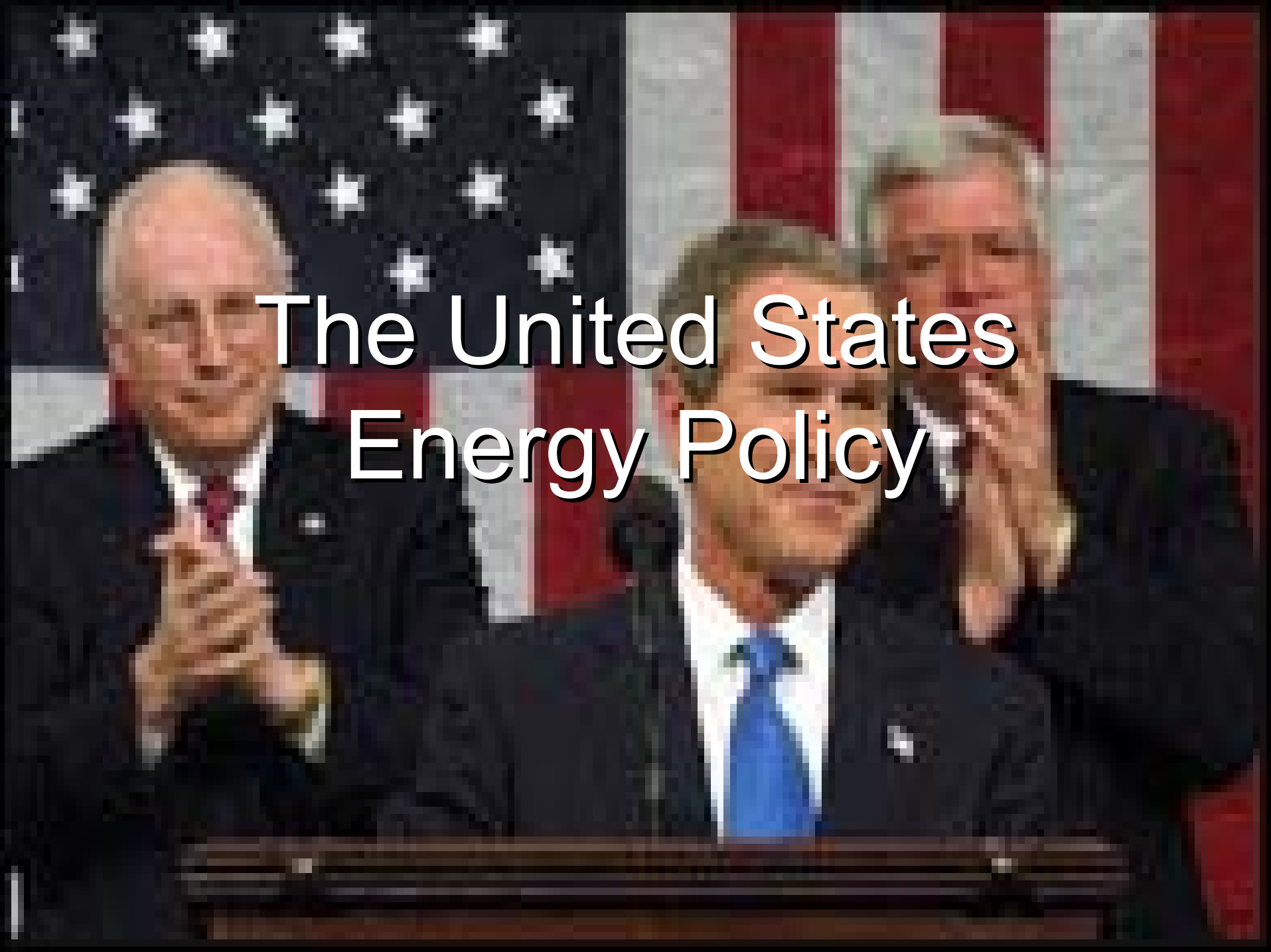


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Are We Running out of  
Energy/Resources?

A photograph of three men in dark suits and ties, standing behind a wooden podium and clapping. The man on the left is older with thinning hair, the man in the center is younger with dark hair, and the woman on the right has blonde hair. They are all smiling. Behind them is a large American flag with its stars and stripes clearly visible.

# The United States Energy Policy

# Solar Energy



<http://www.singleton.nsw.gov.au/visitors/profilepubfacpower.html>



<http://www.turner.com/planet/static/captain.html>



# Solar Energy

Issues to consider:

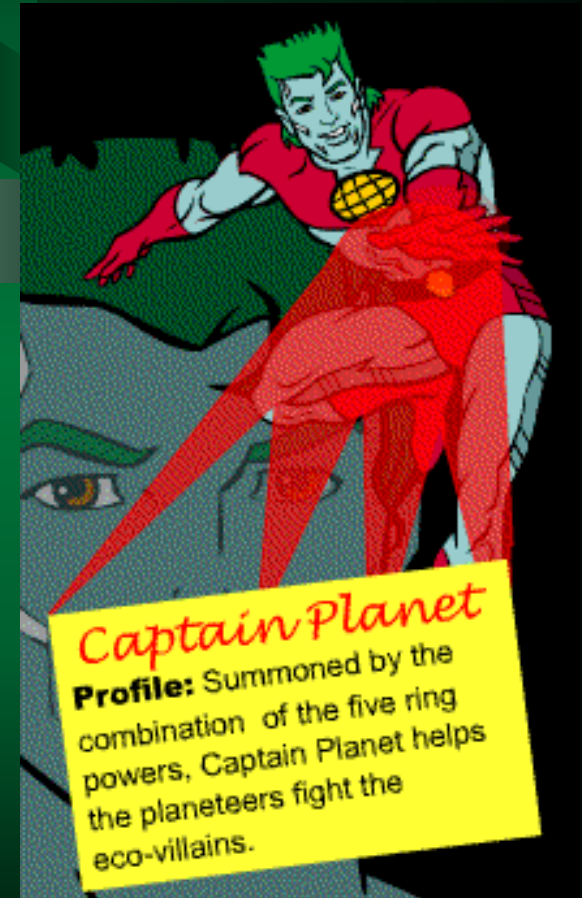
What is it?

How does it work?

Is it useful?

What does it cost?

When/Where to use?



<http://www.turner.com/planet/static/captain.html>



# Solar Energy

- ✓ Energy from the sun
- ✓ Collected and stored by many means
- ✓ Plant life, wind, water
- ✓ Passive and active systems





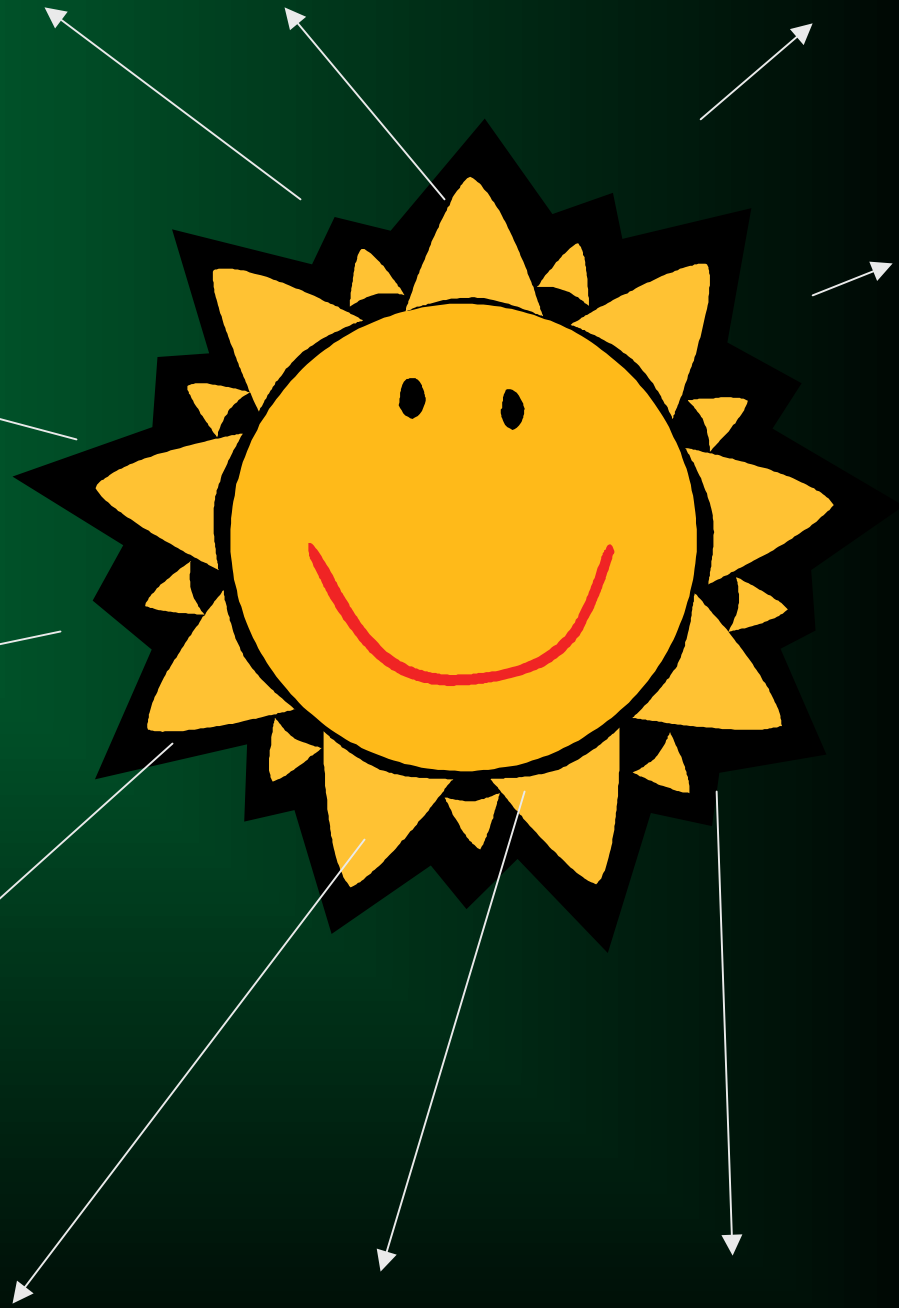
# Solar Energy

- ✓ Sun loses mass  $\sim 4$  million tons / second
- ✓ (English or Metric units?)
- ✓ Theoretical max energy converted from mass through fusion process:
  - ✓  $E = mc^2$
  - ✓ Energy =  $(3.6 \times 10^9 \text{ kg})(2.998 \text{ m/sec})^2$
  - ✓  $\sim$  a very big number



# Problem

- ✔ Less than one-billionth actually reaches earth
- ✔  $\sim 5.5 \times 10^{24}$  Joules



Smil, Vaclav. Energies



# Solar Energy

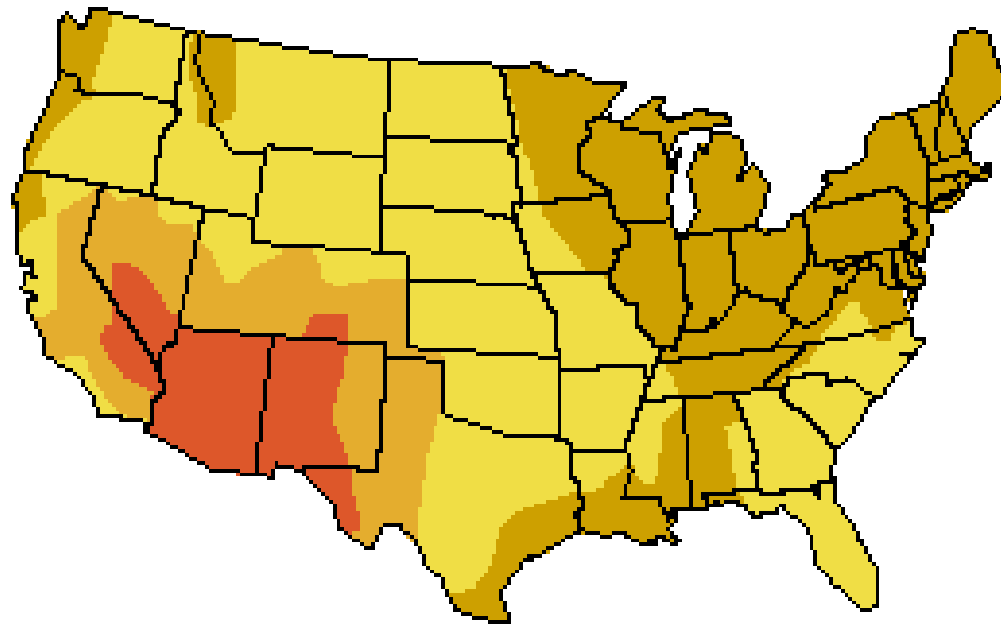
- ✓ The sun can provide about 1 kW/m<sup>2</sup> on a perfectly clear day on earth
- ✓ Clouds, dust, and particles can reflect 80% of the Sun's radiation (Commoner, 126)
- ✓ (Mostly visible light reaches surface)
- ✓ 99% is converted to heat

<http://www.iclei.org/EFACTS/PASSIVE.HTM>



# Average Solar Energy in U.S.

## Solar Insolation Resources



Resource Potential

- 7+ kWh/M<sup>2</sup>/day
- 6+ kWh/M<sup>2</sup>/day
- 4+ kWh/M<sup>2</sup>/day
- 3+ kWh/M<sup>2</sup>/day



# Brief History

- ✓ The use of the Sun as a source of power has been used for thousands of years.

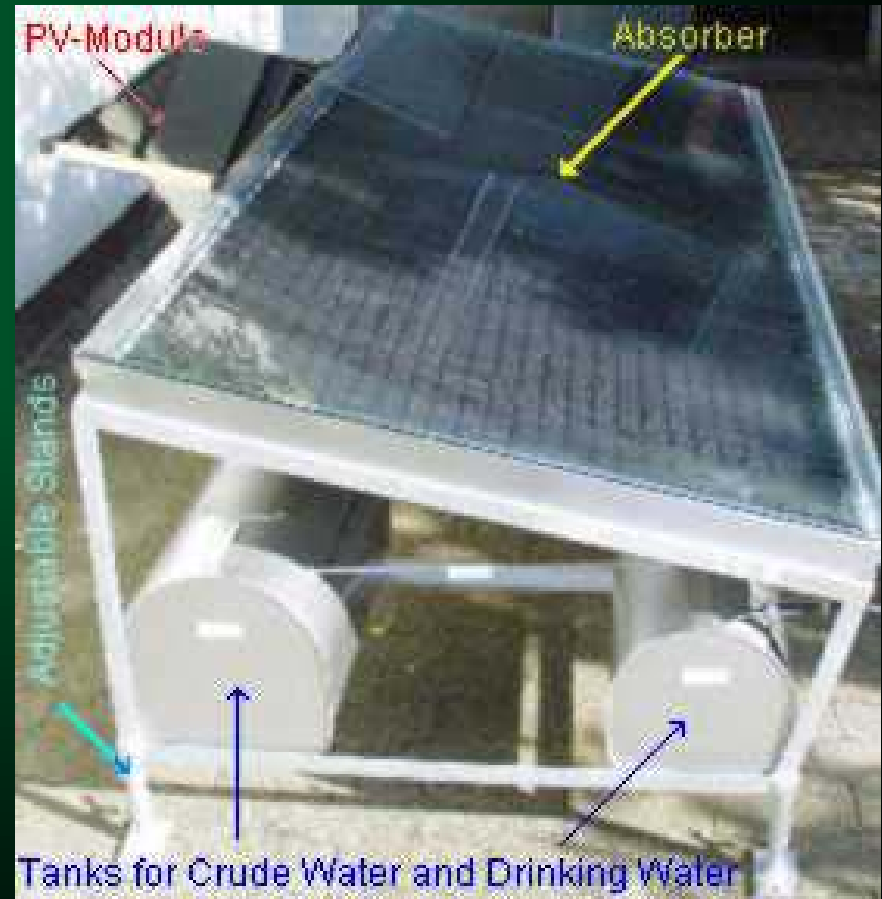






# Water Desalination

- ✔ Can produce drinking water from saltwater
- ✔ 100 € per cubic metre. → 4.06 € per cubic metre
- ✔ using Rosendahl's solar water treatment with flat collectors.



[http://www.mueller-solartechnik.de/desa\\_eng.htm#beispiele](http://www.mueller-solartechnik.de/desa_eng.htm#beispiele)



# Solar Engine

- In 1860, Auguste Mouchout, a math teacher at Lyce de Tours, decided to build a solar motor due to his belief that coal would be exhausted.
- In 1861, he received a patent for his solar engine. The engine trapped solar radiation in a glass-covered iron box which boiled water to create pressurized steam.
- By 1872, his refined engine had a max power of  $\frac{1}{2}$  horsepower (about 370 Watts).
- In 1878, William Adams produced a 2.5 hp solar engine, although he lacked skills to create a business.

[http://www.solarenergy.com/info\\_history.html](http://www.solarenergy.com/info_history.html)



# Solar Engine

- ✔ Aubrey Eneas formed the Solar Motor Co. in 1900.
- ✔ He utilized a parabolic mirror, which heated boiled water to steam, which pumped 1400 gallons of water per minute for irrigation.
- ✔ Although a major milestone for solar energy, the system was eventually a business failure.



# Solar Engine

- ✓ In 1904, Henry Willsie built a 15 hp solar engine which collected and stored solar power as heated water, which could be used to run the engine during the night.
- ✓ (It too, was a business failure).
- ✓ In 1912, Frank Shurman's solar irrigation plant could generate more than 55 hp.
- ✓ Unfortunately combat in WW 1 destroyed his plant in Cairo, Egypt and he soon died a few years later



# Late History

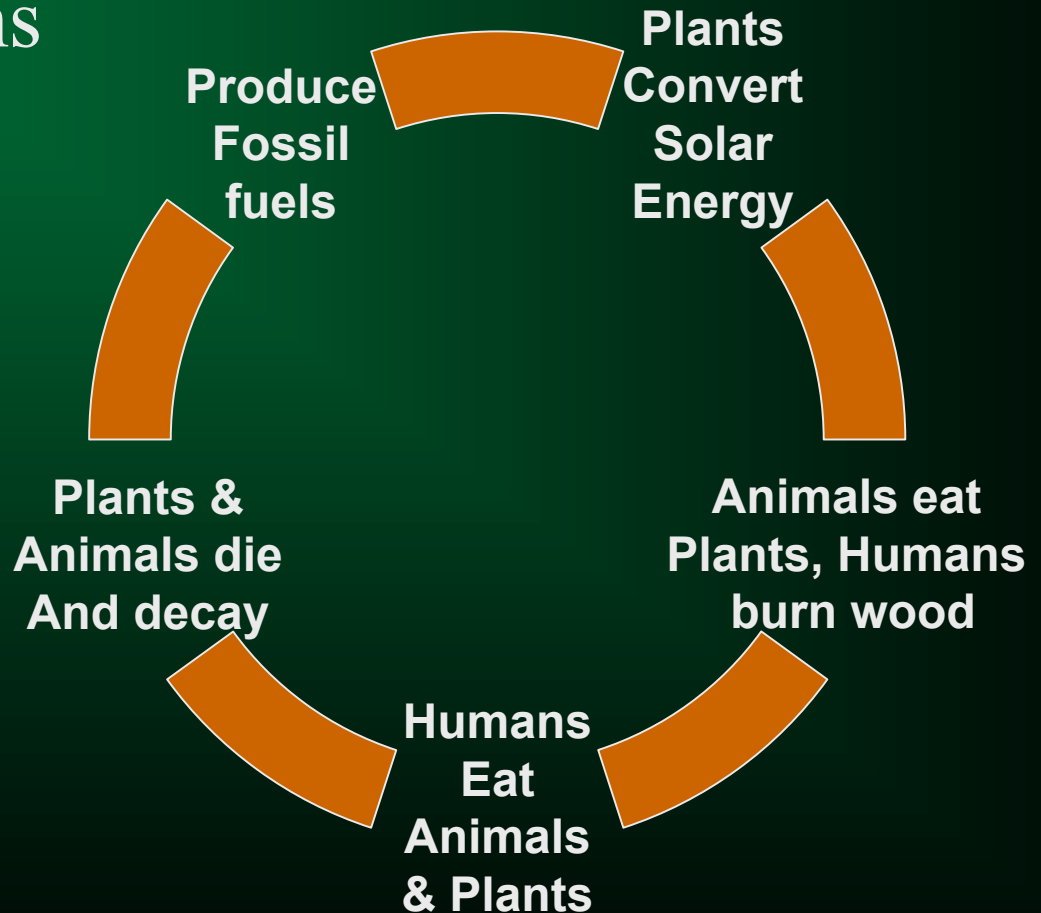
- ✓ In 1900's inexpensive fossil fuels dominated energy useage.
- ✓ Solar electricity emerged in the 2<sup>nd</sup> half of the 20<sup>th</sup> century as an unlimited source for satellites in outer space.
- ✓ In 1970's, oil embargo forces America to consider renewable energies.
- ✓ In 1996, solar energy was used to heat swimming pools for Olympics.



# Forms of Solar Energy

✓ Natural Systems

✓ Photosynthesis





# Hydro Power

- ✓ Water evaporates to higher elevations
- ✓ Potential energy



<http://www.hooverdam.com>

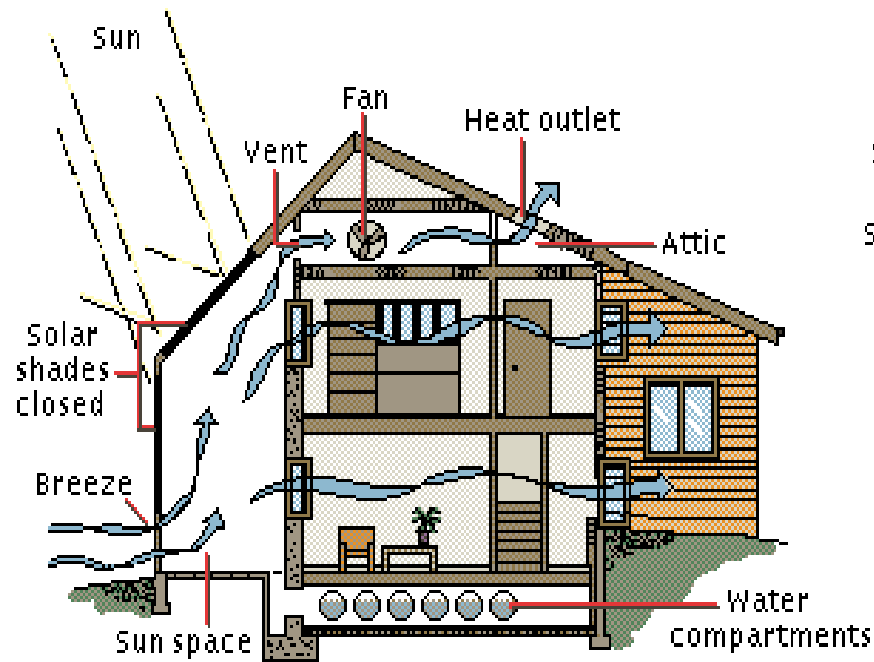




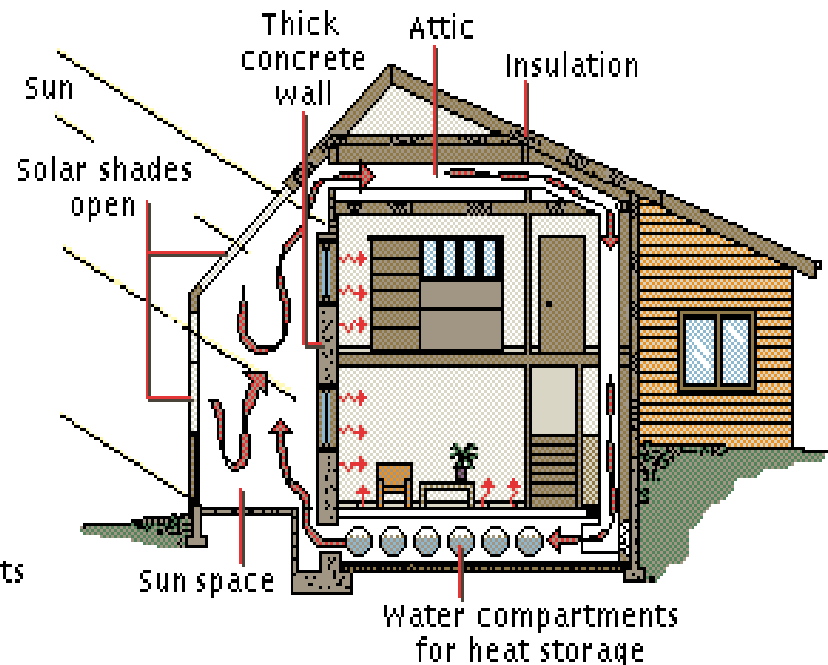
# Passive Solar Systems

- ✓ Structure with windows facing sun
- ✓ Standard windows not enough insulation
- ✓ Provides light and
- ✓ Greenhouse-like heat

# Passive Cooling and Heating

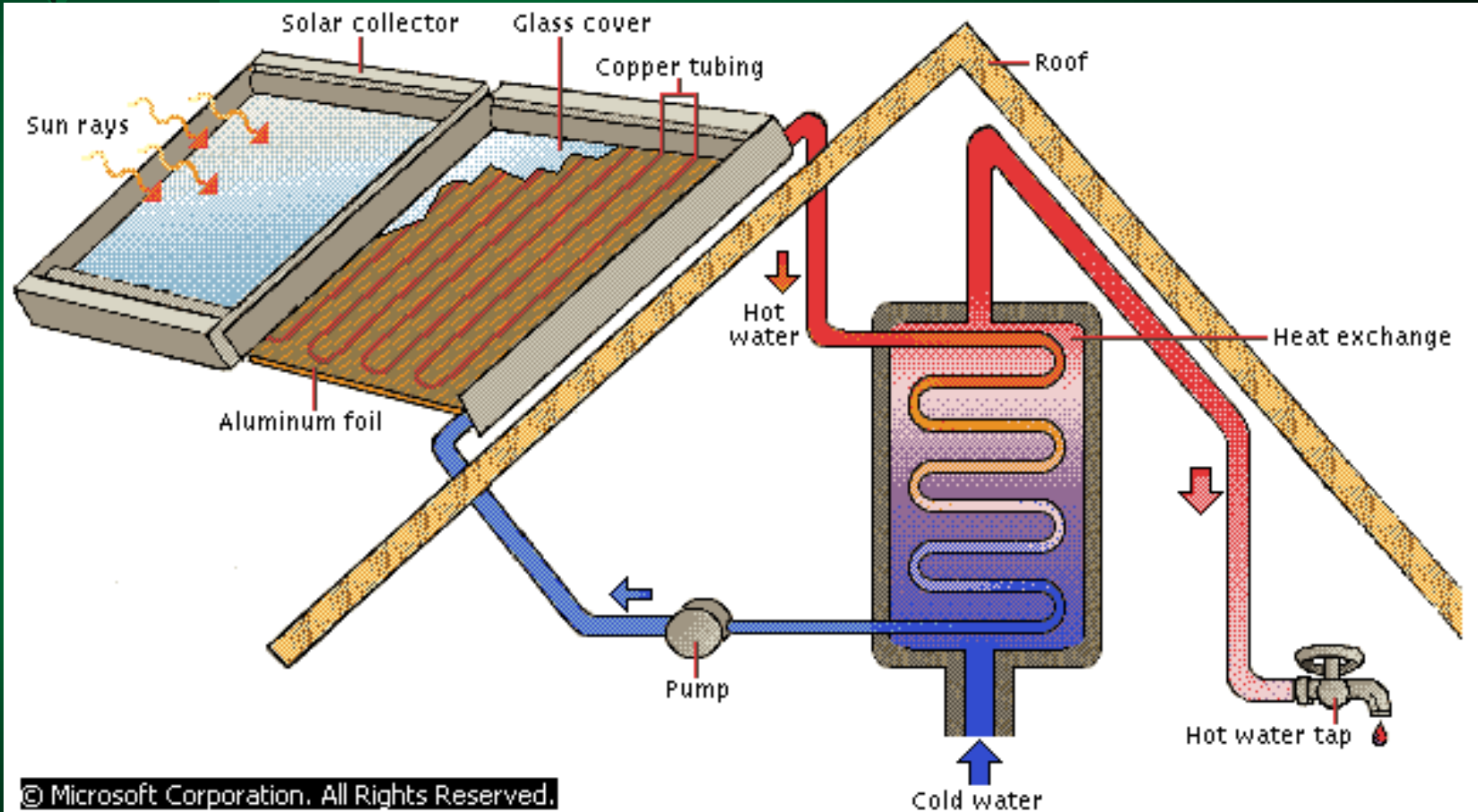


**Passive solar cooling  
(Summer)**



**Passive solar heating  
(Winter)**

# Passive Solar Systems





# Active Solar Energy

- ✓ Have moving parts and/or controls
- ✓ Use a coolant to transfer energy from collector to point of use
  - ✓ (Cassedy, Introduction to Energy, 11)
- ✓ Used for hot water heating, space, heating, cooling, and generation of electricity



# Mirrors

- ✓ Sun can be concentrated with parabolic mirrors
- ✓ Boils water or another liquid
- ✓ Least expensive solar solution
- ✓ Cool Fact: Surface of Sun → 10,000 °F
- ✓ French Solar Furnace in Pyrenees → 6000 °F



# Photovoltaic Cells

- Companies are working to build 10 MW modules to produce electricity at 12 to 15 cents per kWh. The Energy Sourcebook, 176
- Currently used for some applications →  
calculators, radios, outdoor home lighting
- Also used to pump water, supply heat and electricity to remote homes and communities
- Electricity for satellites





# PV Cells

- ✓ Electromagnet radiation excites electrons and forces movement
- ✓ Many different types of cells
- ✓ Each type of cell can only absorb a select range of frequencies of light



4+/- charge  
(stable)

Simple Periodic Table

1A																	8A			
1																	18			
1 H 1.008	2A															2 He 4.003				
3 Li 6.941	4 Be 9.012															6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31	3B	4B	5B	6B	7B	8B				1B	2B			16 S 32.07	17 Cl 35.45	18 Ar 39.95			
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.70	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80			
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc 98	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3			
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po 209	85 At 210	86 Rn 222			
87 Fr 223	88 Ra 226	89 Ac 227	104 Rf 261	105 Db 262	106 Sg 266	107 Bh 262	108 Hs 265	109 Mt 266	110	111	112	metals nonmetals metalloids								

P type

P type

N type

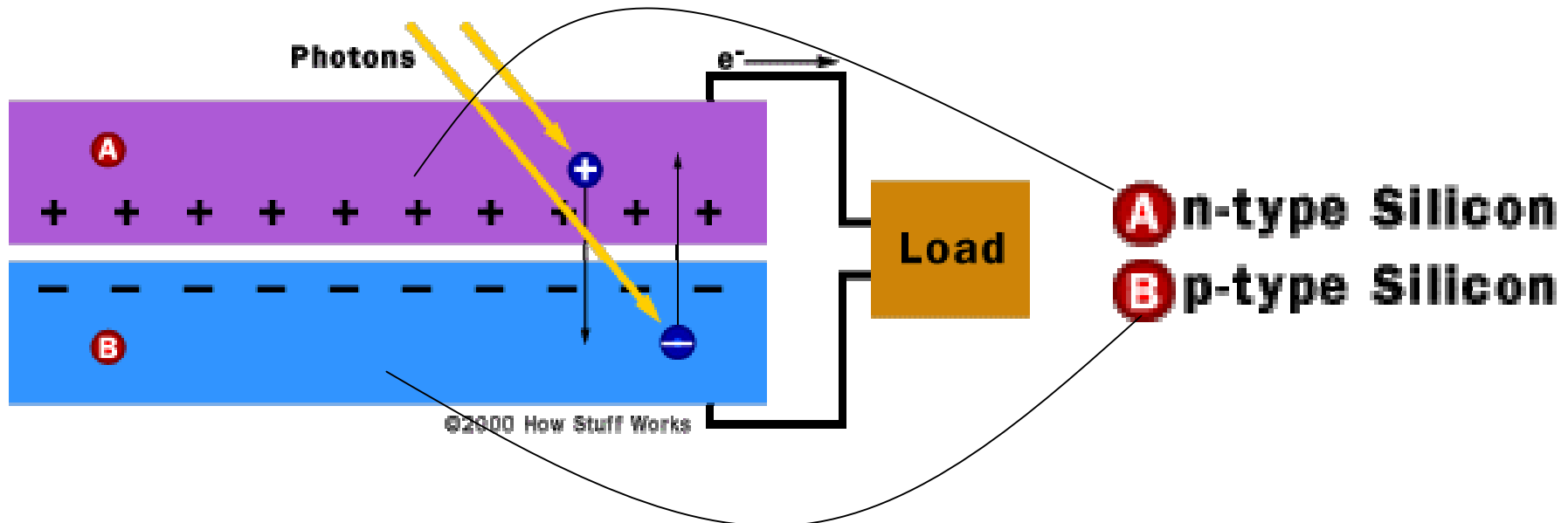
Chart from

<http://www.hartnell.cc.ca.us/faculty/scharnic/periodictable.html>



# PV Cells

- One layer is doped with a group 3 element
- Other layer is doped with a group 5 element
- P-type layer has “holes” that travel through the semiconductor to be filled by electrons, which creates a hole in a different part.





# PV Cells

- ✓ PV cells absorb a selected range frequencies of light, decided by desired voltage and current
- ✓ Proposals to absorb more light:
  - Multilayered PV cells
  - Using different materials
  - Different crystal structures

# Facts

- PV cells will cost 30-40 cents per kWh
- Current energy costs 3.4 – 6.3 cents / kWh  
<http://www.swenergy.org/factsheets/UTfactsheet.pdf>
- 10 to 20 % efficient
- “Solar energy accounts for 1 percent of renewable electricity generation and 0.02 percent of total U.S. electricity supply
- National Energy Policy, May 2001
- Report of the National Energy Policy Development Group



# Goals

- ✓ Production increases from 2 MW in 1976 to 288 MW in 2000 (Vital Signs 2002)
- ✓ For 2010 to 2030:
- ✓ An optimistic price of 6 - 10 cents per kWh
- ✓ Systems currently last 20 to 30 years
- ✓ Systems will last  $> 30$  years
- ✓ Renewable Power Pathways, 66
- ✓ 15 to 30 % efficiencies



# Facts

- ✓ Solar technology is emission free
- ✓ Can be installed on existing buildings for heating and electricity
- ✓ Passive solar systems can save up to 50% on heating costs  
(<http://www.solaraccess.com/education/solar.jsp?id=passive>)
- ✓ Like other technologies, will be cheaper when mass produced



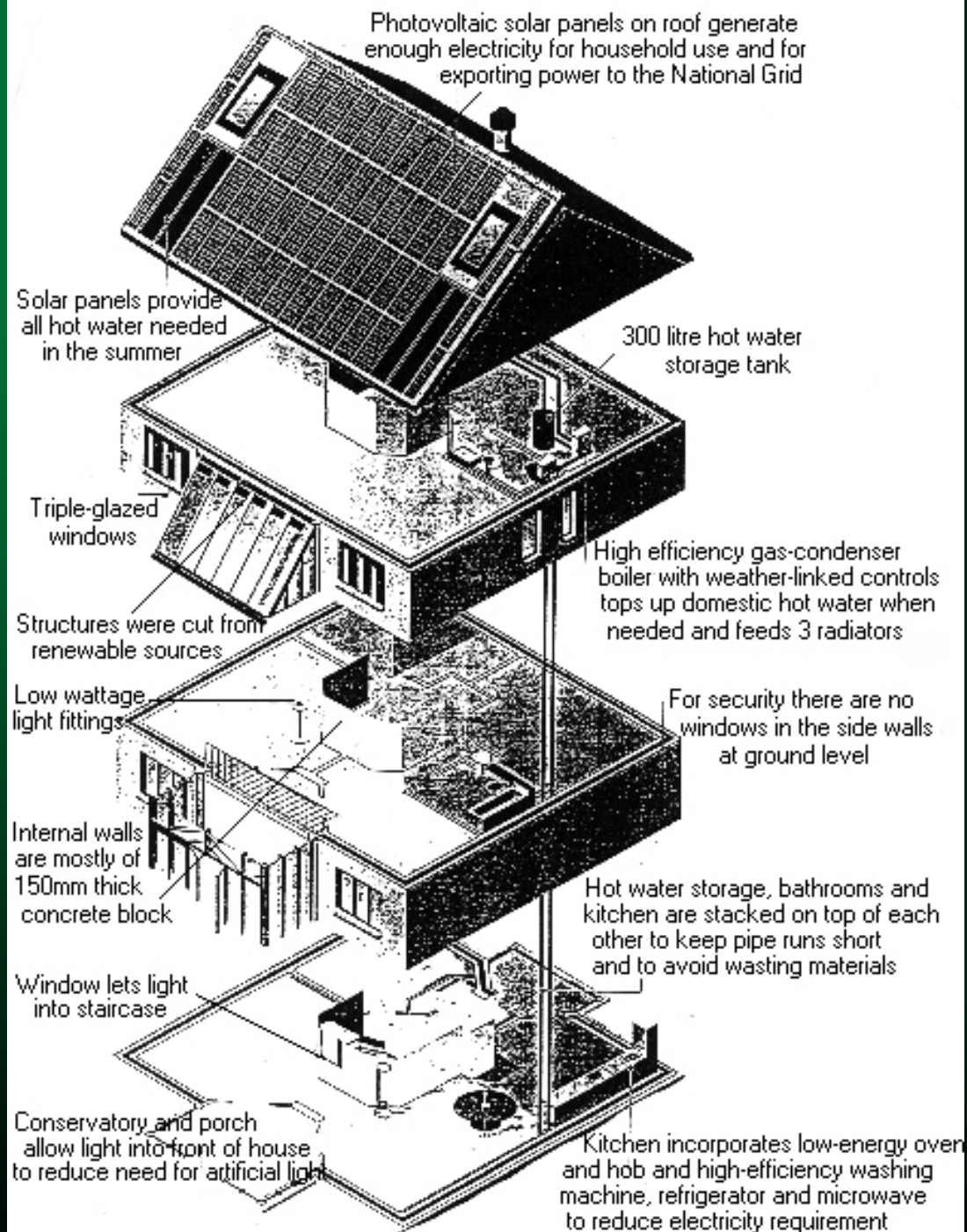
# Case Study

- ✓ The Oxford Solar house
- ✓ Energy needs provided by solar cells in daytime
- ✓ Built for efficiency



<http://www.tve.org/ho/doc.cfm?aid=224&lang=English>









# Facts and Figures

- ✓ Costs of PV system: £21,150
- ✓ Energy Consumption: 2964 kWh / year
- ✓ Owner buys from utilities :1524 kWh / year
- ✓ But owner sells to utilities:1692 kWh / year
- ✓ She pays £0.070 / kWh → £106.60
- ✓ She earns £0.027 / kWh → £45.60
- ✓ She pays £61.00 for consuming 2964 kWh
- ✓ \$94.86
- ✓ This includes charging the electric car!

# Hydropower



Utility/Industrial hydro



Small scale hydro

# History

- Ancient Greeks used water power 2000 years ago.
- American and European industries used the water wheel to power machines.
- First hydro plant was built at Niagara Falls
- 80,000 dams in U.S., but only 3% are used for electricity generation

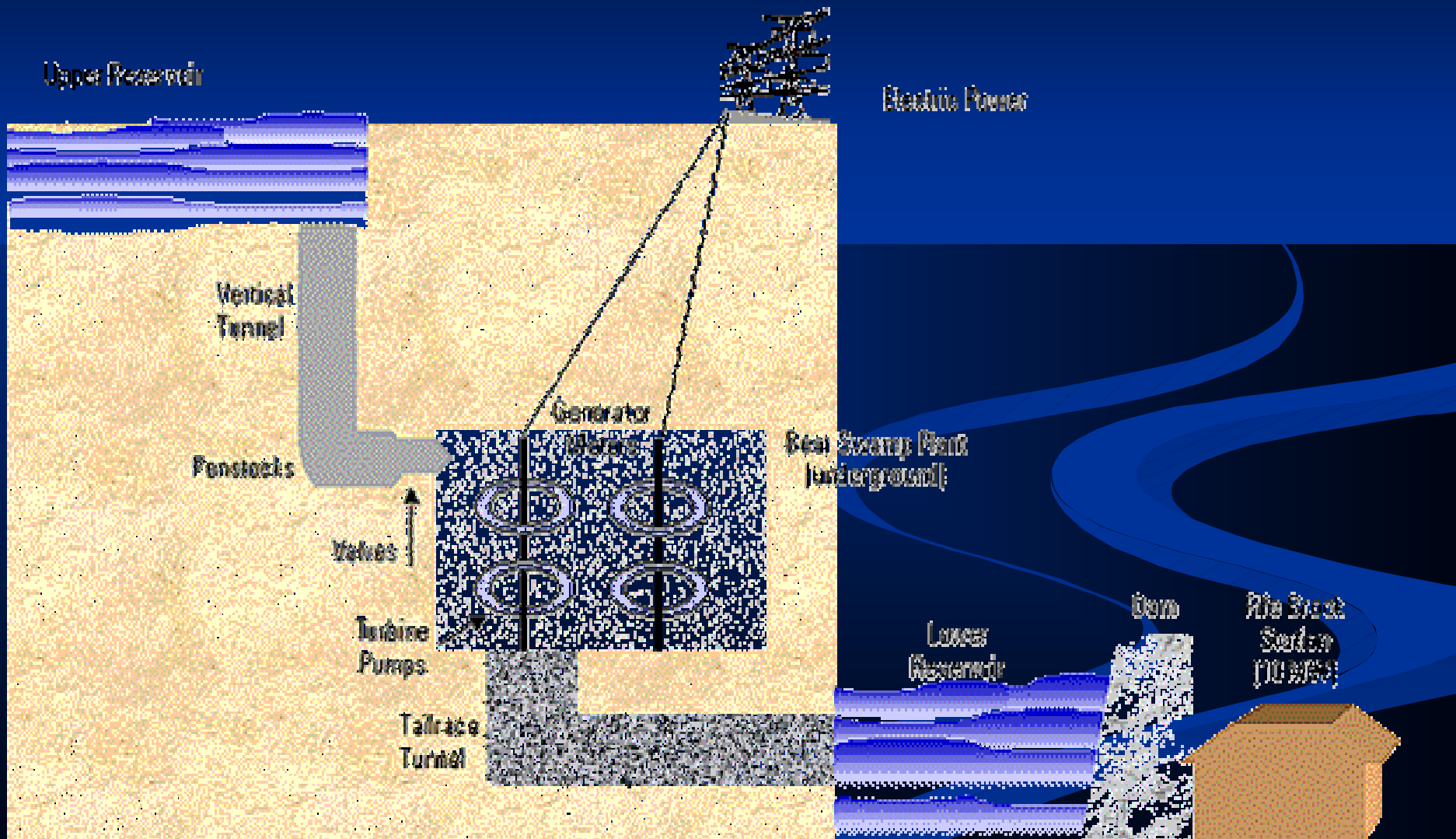
# Hydroelectric Power

- What is it?
  - Conversion from kinetic energy of water to mechanical energy to electrical energy.
- Hydropower plants dam a flowing body of water
- The water is then stored reservoir.
- When the water is released from the reservoir, it flows through a turbine, causing it to spin and activating a generator to produce electricity.

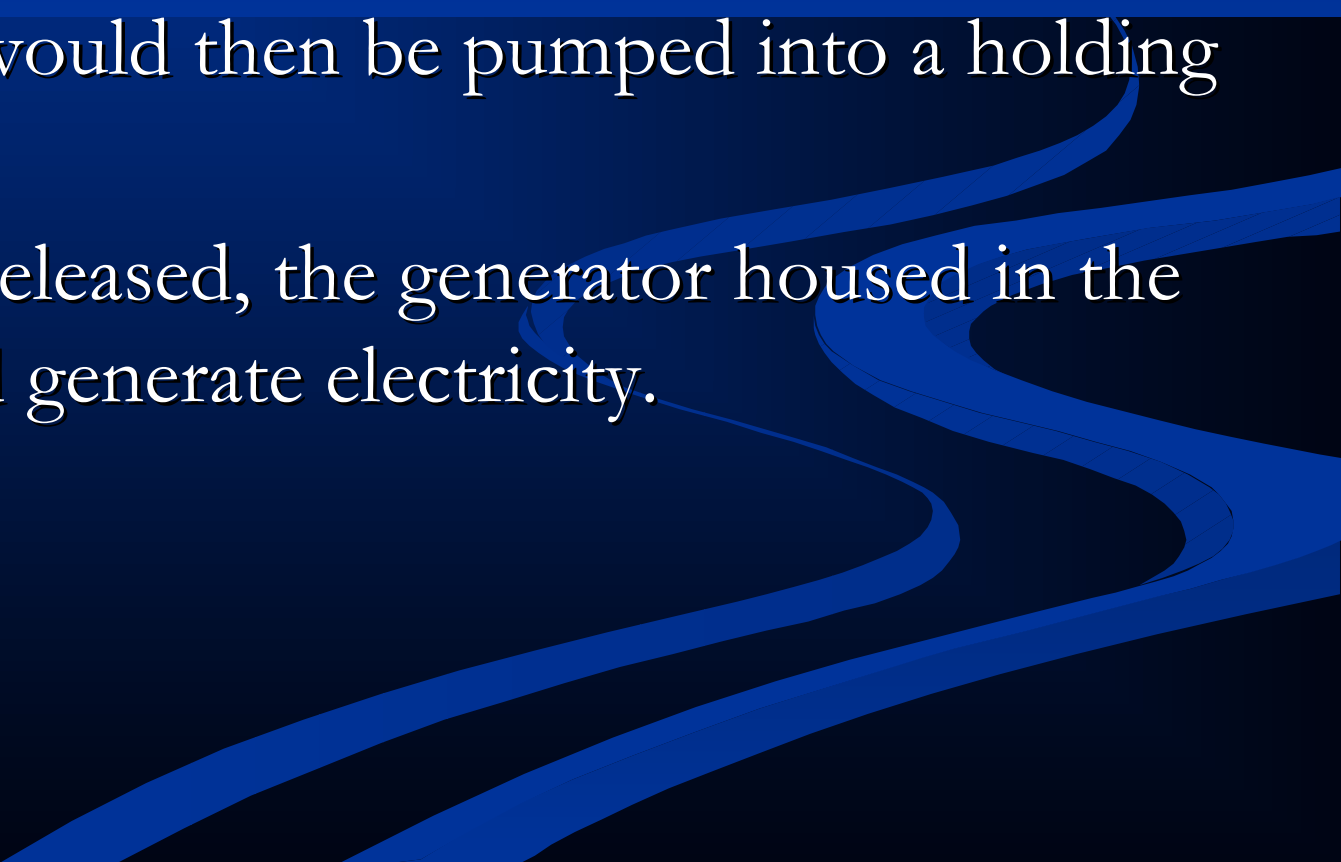
# How it works

- A dam blocks the water, holds it in a reservoir.
- Pipes called the penstock bring water from the reservoir to the powerhouse.
- The drop in elevation in the penstock is call the “head.” The force created is the force need to create electricity.
- Higher volume of water and a higher force of the head create a greater amount of energy.
- The powerhouse contain the turbines. The turbines move from the force of the head as it flows down the penstock.
- The rotating turbines turn a shaft that drives generators that produce electricity.
- Water not used for producing energy is released over the spillway of the dam.”
- [http://www.eere.energy.gov/state\\_energy/technology\\_overview.cfm?techid=7](http://www.eere.energy.gov/state_energy/technology_overview.cfm?techid=7)

# Hydro power conversion process



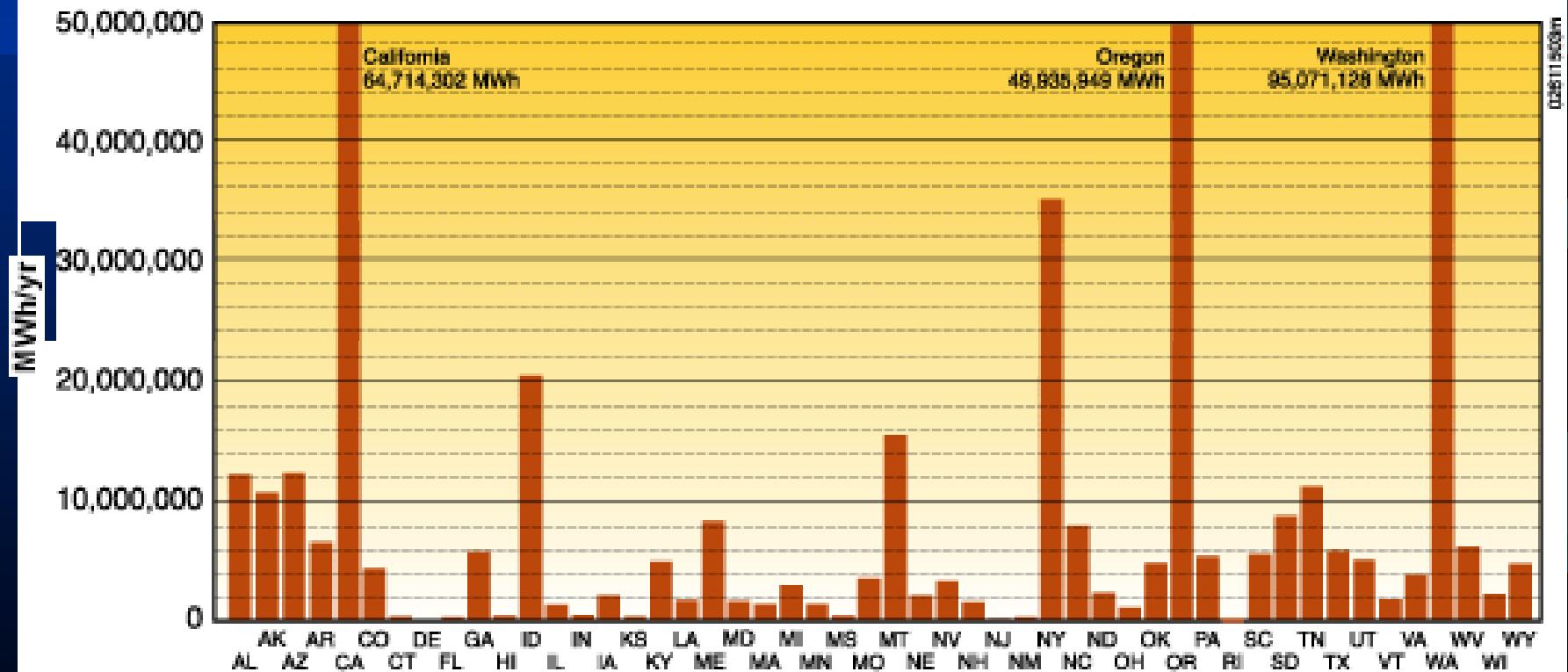
# Dams aren't always necessary

- Some hydro power comes from channeling a portion of the river into a canal.
  - The water would then be pumped into a holding area.
  - When it is released, the generator housed in the canal would generate electricity.
- 

# How much does PA use?

- PA uses very little,

**Hydropower Resource by State**



Source: Energy Information Agency and the Idaho National Engineering and Environmental Laboratory.



# Energy Potential

- The U.S. is the 2<sup>nd</sup> largest producer and consumer of hydro power in the world. (Canada is the first)
- In the early 1900's hydro power generated around 40% of the nation's electrical needs.
  - 1/10 of the nation's energy.
- 81% of renewable energy generated
- Large dams can generate 10,000 MW
- In PA. 5,525,646 MWh capacity
  - Only about 3%

# Viable Conditions

- High volume of moving water.
- Change in elevation gradient.
- Mississippi isn't great although it has a large volume of water.
- Mountain regions would be good, because of the drastic drop in elevation
- Washington, Oregon, and California have the most hydro power.

# Economics of Hydro Power

- It is the cheapest form of renewable energy presently used in the U.S.
- 85-92% efficient
- Washington and Oregon get 85% each year... efficient and cheap
- Only 0.6 cents is needed to pay for operating and maintaining the plant.
  - 2.2 cents/kWh at nuclear plants
  - 2.1 cents/kWh at coal plants.

# Economics Continued

- Hydropower is the cheapest way to generate electricity today.
- dependable and long-lived
  - maintenance costs are low compared to coal or nuclear plants
- In 1994 it cost less than one cent per kWh (kilowatt-hour) to produce electricity at a typical hydro plant.
  - Hydro power costs 6 cents per kWh
  - <http://lsa.colorado.edu/essence/texts/hydropower.htm>

# World Values

- 650,000 MW installed across the world
    - 135,000 are currently being installed
      - <http://www.damsreport.org/docs/kbase/contrib/eco078.pdf>
  - Operating life 50+ years
  - Capacity factor 31 MW
- 
- A decorative graphic consisting of several thick, wavy blue lines that flow from the right side of the slide towards the bottom left, creating a sense of movement and depth against the dark blue background.

# How we will combat current problems?

- “installing fish ladders to allow fish to migrate upstream to their spawning grounds;
- modifying turbine designs to reduce fish mortality and detrimental effects to water quality (for example, by changing the concentration of dissolved gases); and
- regulating water levels to provide suitable conditions for the downstream migration of young fish and to provide wildlife habitat for waterfowl.”

[http://www.eere.energy.gov/state\\_energy/technology\\_overview.cfm?techid=7](http://www.eere.energy.gov/state_energy/technology_overview.cfm?techid=7)

# Benefits of Hydro Power

- 300 billion kilowatt-hours of electricity are produced in the U.S. each year
- 160 million tons of coal would be required to generate that same amount.
- No discharge of pollutants into the environment.
- Existing dams used for flood control can be converted into hydro dams.



# Hydo – NO!

- ✔ Valuable assets to the land are destroyed.
- ✔ Changes in turbidity, water temperature, concentration of gases and nutrients.
- ✔ Potential farmland, habitat, and native vegetation are lost.
- ✔ Not all developers have an sense of intrinsic value.
  - historic and cultural sites; fisheries; wildlife habitat; legal issues; and geologic, recreational, or scenic attributes.



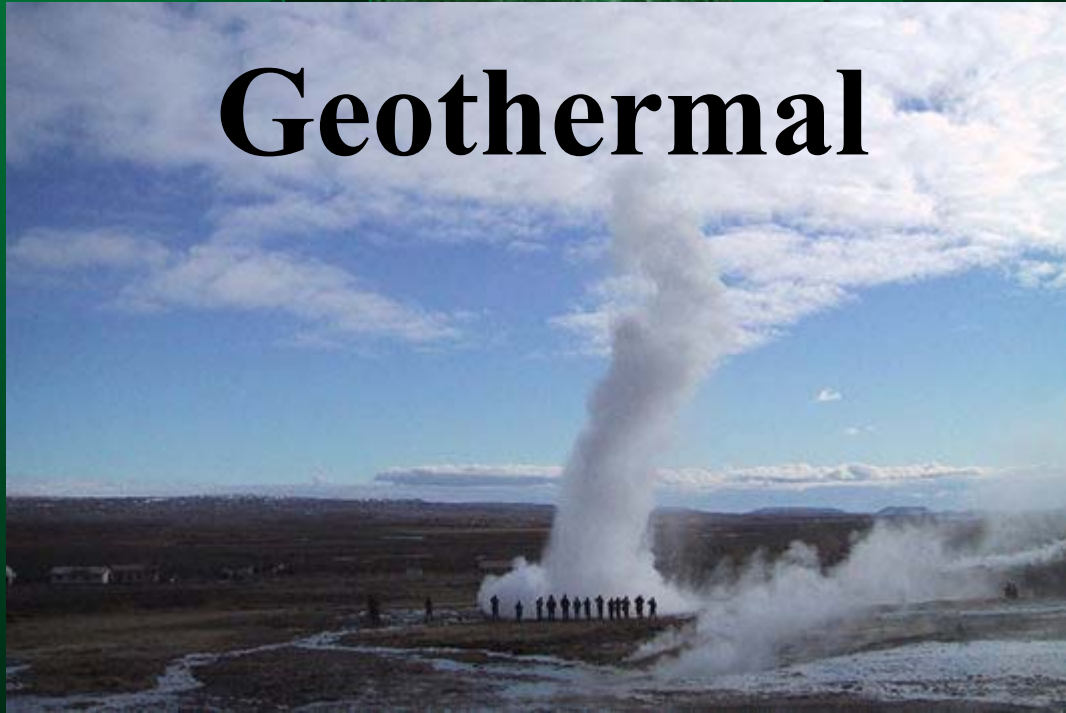


# Future Problems

- ✓ As the climate changes what could happen with hydro power?
  - Problems with precipitation flux can eliminate once viable hydro sources.
  - Low reservoir levels could lead to disease breeding
  - High fish deaths!- kills the industry
  - Continual erosion will lead to silt deposition against the dam – shortens life expectancy
  - Snow pack melt
    - High/ Low



# Geothermal

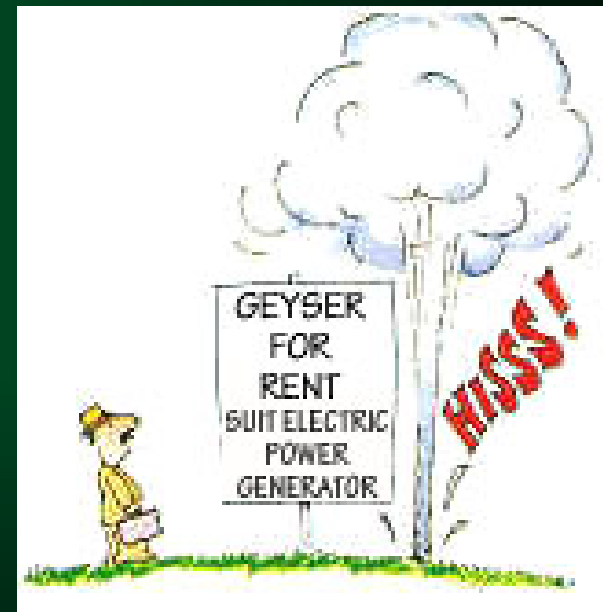


Tapping in...

# Geothermal Energy

geothermal energy = energy derived from the natural heat of the earth

- ✓ Heat contained in the rock and fluid, derived from radioactive decay deep in earth
- ✓ Certain geologic processes allow us to “tap” the heat in a less diffused state
  - Geysers
  - Hot springs
  - Thinned continental crust
  - Rift systems
  - Volcanic regions





# Geothermal Resources

- ✓ Depends upon the fluid phase
- ✓ hydrothermal resources
  - vapor-dominated reservoirs (steam only)
  - liquid-dominated reservoirs (steam and water, or water only)
- ✓ Hot Dry Rock (HDR)
  - No water, just hot, deep-seated rock



# Geothermal Resources

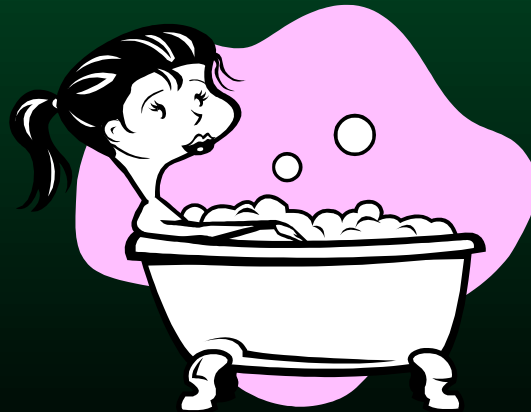
- Geothermal resources are classified by temperature:
  - low temperature
    - (less than 90°C or 194°F)
  - moderate temperature
    - (90°C - 150°C or 194 - 302°F)
  - high temperature
    - (greater than 150°C or 302°F).





# Direct Use

- ✓ Low to moderate temperature resources
  - ( $>20^{\circ}$ - $150^{\circ}$  C)
- ✓ uses the heat in the water directly without a heat pump or power plant
- ✓ Applications



Greenhouses and aquaculture:

<http://www.eere.energy.gov/geothermal/geodirectuse.html>



# Ground-Source Heat Pumps (GHP)

- ✓ Low to moderate temperatures resources
  - (90°-150° C)
- ✓ Uses more diffuse heat from the very shallow subsurface with underground or underwater pipe systems
- ✓ Cooling and Heating (sink and source)
- ✓ Heat exchanger uses long pipes in vertical well bores (400 ft/ton capacity) or deep horizontal trenches (800ft/ton capacity)
- ✓ Applications





# Geothermal Power Generation

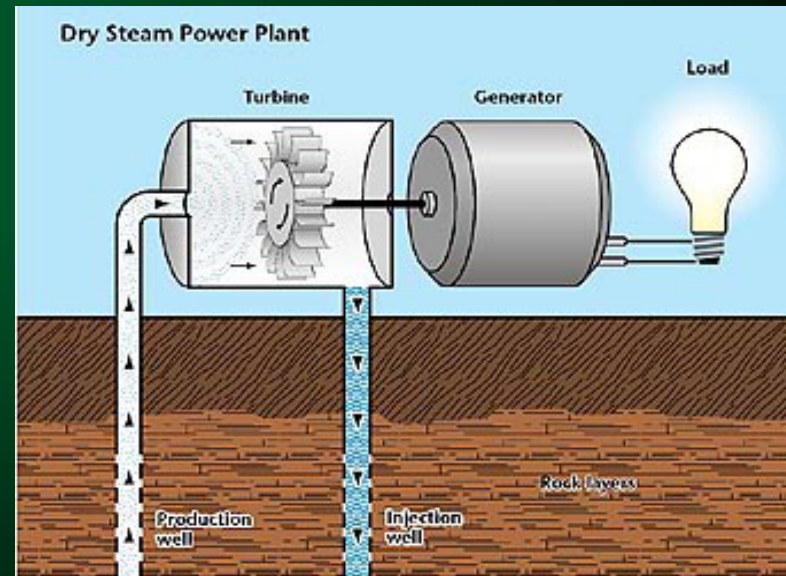
- ✓ Requires moderate to high temperature gradients ( $> 180\text{ }^{\circ}\text{C}$  )
- ✓ Presently generates 2700 megawatts (MW) of electric power in US per year
- ✓ 3<sup>rd</sup> largest renewable source
- ✓ No hidden cost for clean-up or waste disposal





# Dry Steam Power Plant

- ✔ first type of geothermal power generation plants built
- ✔ Steam extracted from the geothermal reservoir through well
- ✔ Routed directly through turbine/generator units to produce electricity
- ✔ Geysers and hot springs

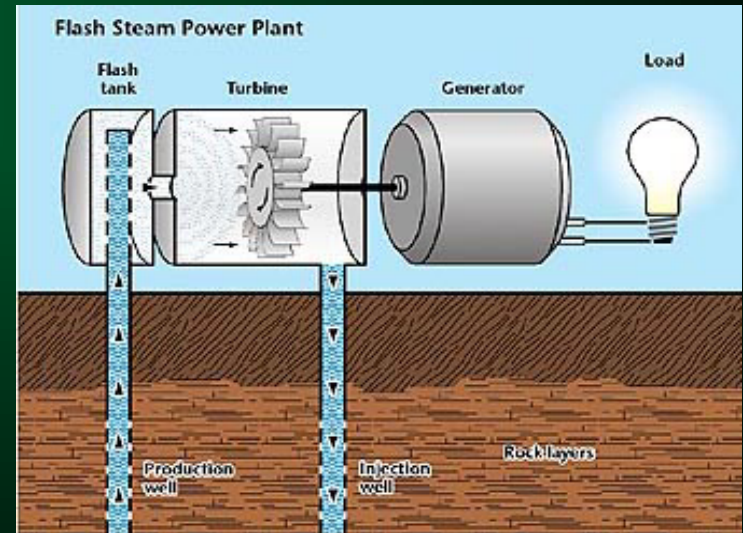


<http://www.eere.energy.gov/geothermal/geopowerplants.html>



# Flash Steam Power Plants

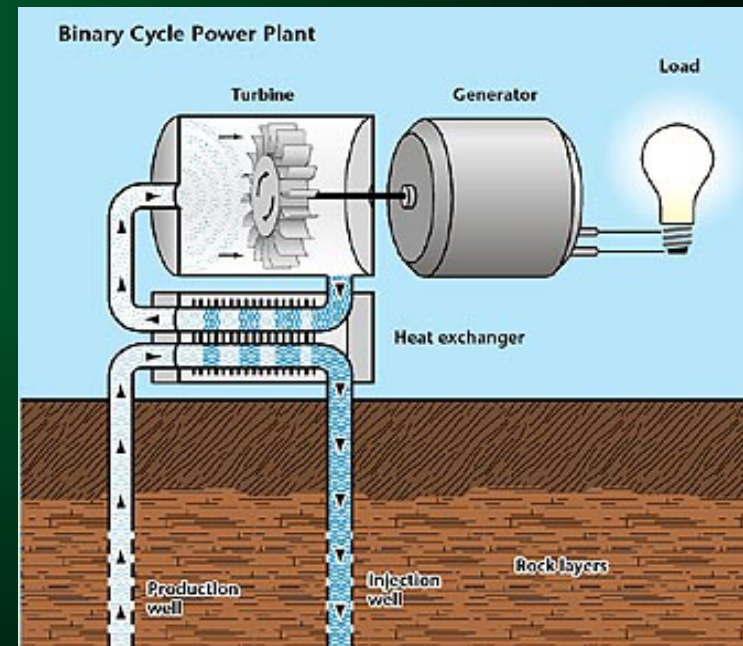
- Flash steam plants are the most common type of geothermal plant
- Hot water is pumped under high pressure to surface where reduced pressure “flashes” the water to steam
- steam directed through a turbine
- Remaining hot water pumped back into reservoir



<http://www.eere.energy.gov/geothermal/geopowerplants.html>

# Binary Cycle Power Plants

- ✓ geothermal reservoir never comes in contact with the generator
- ✓ water from the reservoir is used to heat another "working fluid" which is vaporized and used to turn the turbine/generator units. Both systems of water are confined in their own "closed loops"
- ✓ Can operate with lower temp. geothermal waters by using working fluids with lower boiling point than water such as isobutane
- ✓ produce no air emissions



<http://www.eere.energy.gov/geothermal/geopowerplants.html>



New this  
century!!

# Hot Dry Rock Power Plants

- Invention of the 21<sup>st</sup> century
- Uses a man-made or enhanced hydrothermal reservoir
- Artificial fractures are made in hot, impermeable rock
- Cold water is injected from the surface into the fractures where the water is heated
- A production well intersecting the man-made reservoir returns the heated water to the surface for use in direct-use or geothermal power applications.

"All that is necessary to open up unlimited resources of power throughout the world is to find some economic and speedy way of sinking deep shafts." — Nikola Tesla, 1931

New this  
century!!

# Geopressure Power Plants and Magma Technology

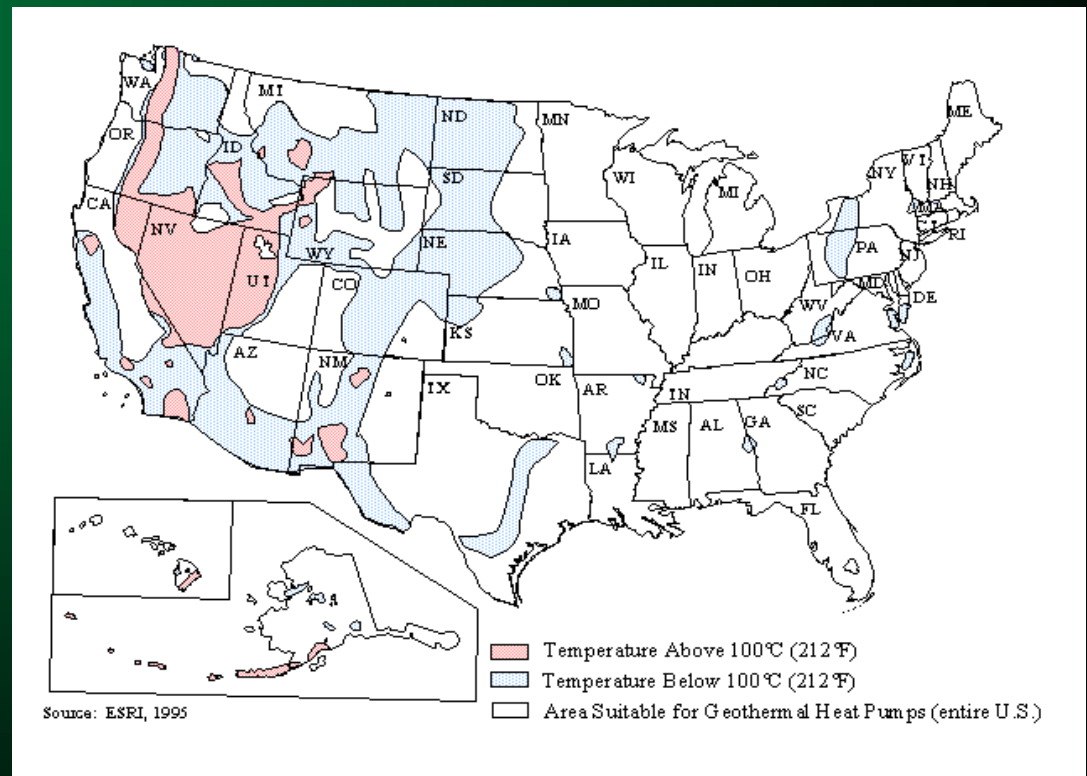
- ✔ **Geopressured geothermal technologies**
  - would harness the mechanical energy from the high pressures
- ✔ **Magma geothermal technologies**
  - May be able to extract thermal energy directly from shallow magma intrusions





# Geographical Possibilities

- Western USA
  - Top 3 states:
    - Nevada
    - California
    - Utah
- Alaska, Hawaii
- Iceland
- New Zealand
- The Philippines
- South America



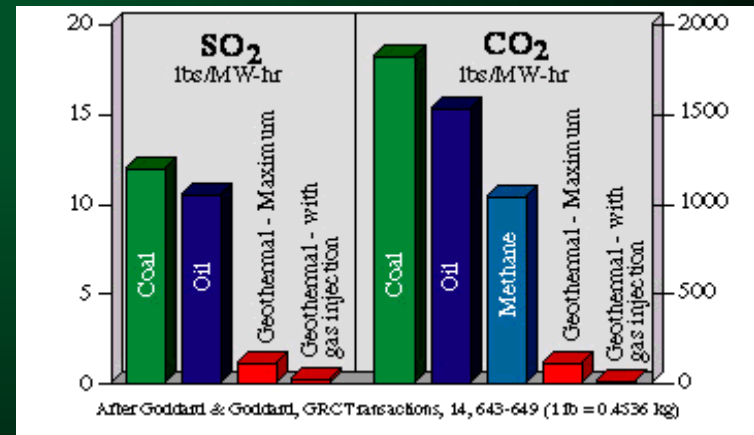
<http://geoheat.oit.edu/colres.htm>





# Environmental Benefits

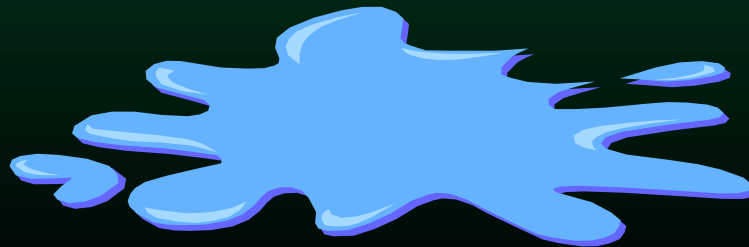
- Electricity produced from geothermal resources in the U.S. prevents the emission of:
  - 22 million tons of carbon dioxide
  - 200,000 tons of sulfur dioxide
  - 80,000 tons of nitrogen oxides
  - 110,000 tons of particulate matter
- Meet the most stringent clean air standards
- Minerals contained in geothermal fluid are recycled so that little or no disposal or emissions occur.





# Environmental Benefits

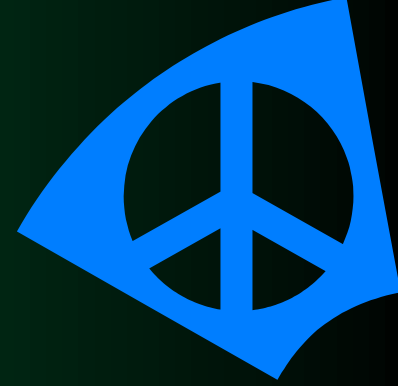
- ✓ Byproducts
  - Sulfuric acid production
  - Silica
  - Zinc
- ✓ Not land hogs!
- ✓ A typical geothermal plant requires several wells, but minimal impact
- ✓ Desalination







# Environmental Obstacles



## ✓ It ain't perfect!

- some applications produce carbon dioxide and hydrogen sulfide emissions
- require the cooling of as much as 100,000 gallons of water per megawatt per day, and dispose of toxic waste and dissolved solids.



# Home Economic Benefits

- ✓ Greenhouse growers can cut their heating costs by up to 80%
- ✓ Home heat pump
  - Save ~\$15/month
  - Electricity consumption reduced by 30% - 60%
  - Operable for 30 years +
  - Low maintenance
  - Hot water at no cost in summer and at small cost in winter.
- ✓ geothermal electricity costs ranges from about 4 to 8 cents per kilowatt-hour.
- ✓ hopes to achieve 3 cents per kilowatt-hour.



# Geothermal Economics

- ✔ second largest grid-connected renewable electricity source, after hydropower
- ✔ third most energy of all renewables, after hydroelectricity and biomass.
- ✔ The U. S. government receives about \$41 million annually in royalty and lease payments from geothermal energy production on Federal lands.
- ✔ Nearly, 2,300 MWe (megawatts electric) of geothermal power, producing 14 to 17 billion kilowatt-hours per year of electricity worth about \$1 billion in annual utility sales, are generated in California, Hawaii, Nevada, and Utah
- ✔ Geothermal power plants are on line an average of 97% of the time
  - coal plants average 75 % and nuclear plants average 65% of on-line time
- ✔ Construction time for geothermal power plants is as little as 6 months for plants in the range of 0.5 to 10 MWe and as little as 2 years for operations totaling 250 Mwe or more.
- ✔ 21 countries generate 7,000 Mwe of electricity from geothermal resources.
- ✔ In 1994, 1,200 Mwe of geothermal electricity were installed overseas by U. S. companies, representing a \$2.5 billion investment.
- ✔ The U. S. geothermal industry has contracted for 3,000 Mwe of new geothermal capacity in the Philippines and Indonesia, representing \$6 billion in new business.
- ✔ For each 1000 houses using geothermal heat pumps, a utility can avoid installing 2 to 5 megawatts of capacity.



# Research and Development

## ✓ Geoscience and Supporting Technologies

- Core Research
- Enhanced Geothermal Systems
- Seismic Exploration
- Detection and Mapping



# Research and Development

## ▼ Drilling Research

- Innovative Subsystems
- Near-Term Technology Development
- Diagnostics-While-Drilling



# Goals

- ✓ **Goals and Objectives to make Geothermal economically feasible by 2010 (DOE)**
  - Double the number of states with geothermal electric facilities to eight by 2006
  - Reduce the levelized cost of generating geothermal power to \$0.03 - \$0.05 per kilowatt-hour
- ✓ **Supply the electrical power or heat energy needs of 7 million homes and businesses in the United States by 2010**

# Obstacles - Reality



- Limited to a handful of locations
  - Regions of sufficient quality to produce economic electricity are rare
  - Many regions are located in protected wilderness areas
- Would need to "harvest" geothermal power through non-traditional means
  - deep-crustal drilling
  - acquisition of heat from magma

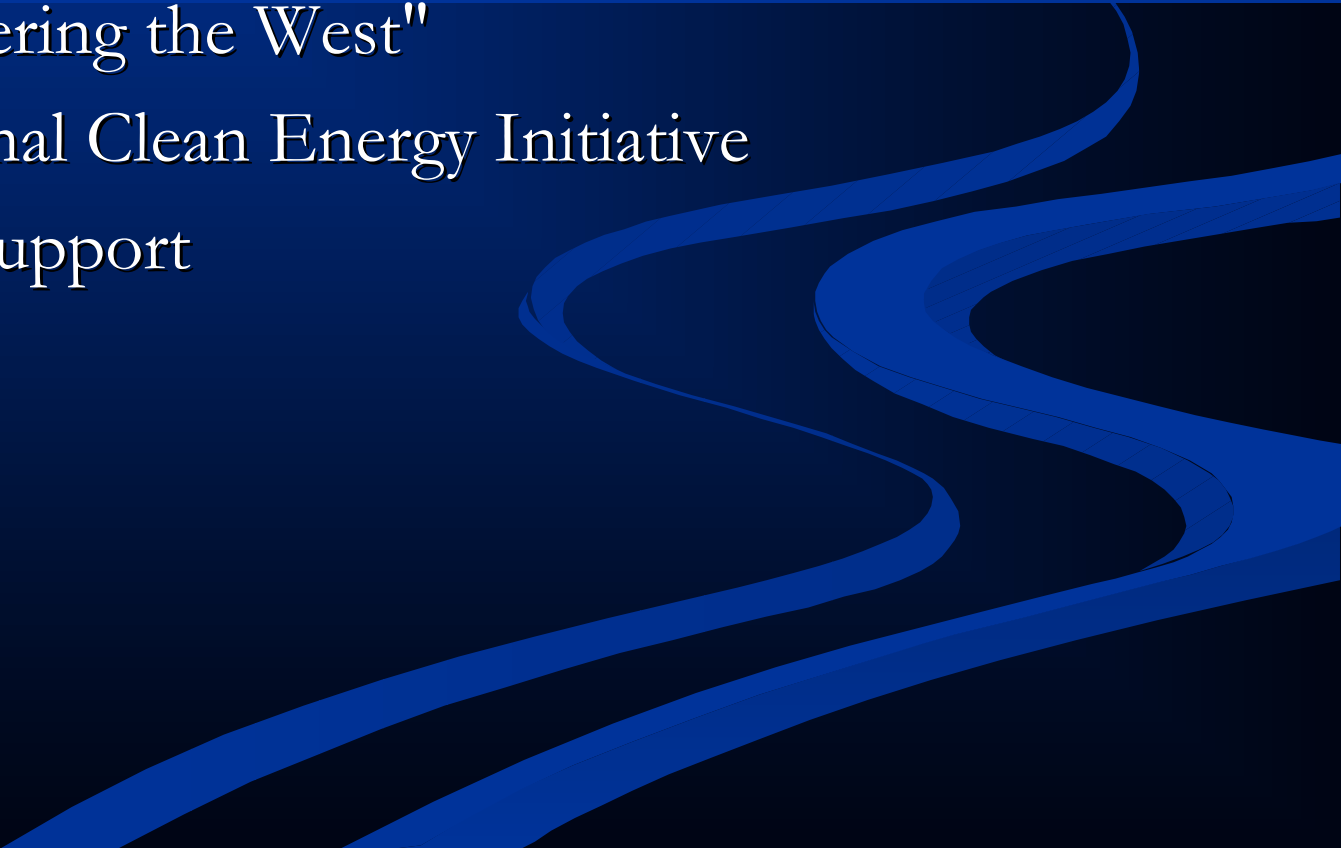
# Obstacles



- High equipment and installation costs
- Technology doesn't exist to generate power everywhere
- Earth's heat isn't intense enough to produce power for the electrical distribution grid; it is only sufficient to reduce the draw from the grid.
- Natural Gas
- Infrastructure!!!



# Necessary Advancements

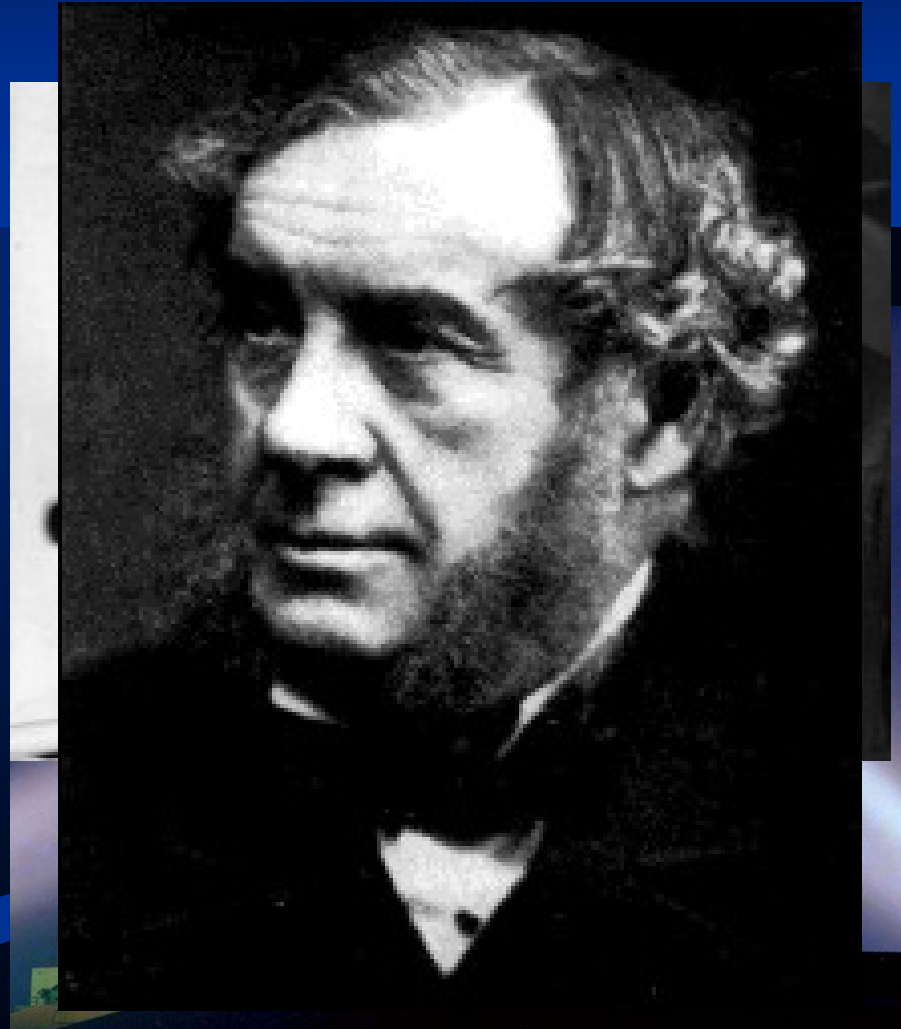
- Energy Systems Research and Testing
    - Advanced Plant Systems
    - "GeoPowering the West"
    - International Clean Energy Initiative
    - Industry Support
- 
- Decorative wavy lines in shades of blue and white, flowing from the bottom right towards the center of the slide.

# Fuel Cells

The future of energy or wishful  
thinking?

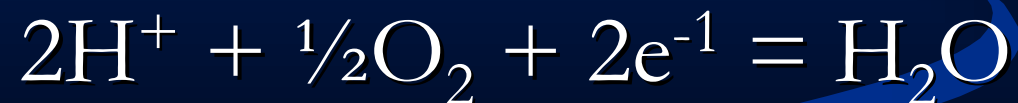
# Brief History

- First Developed in 1839 by William Grove
- Improved upon by Francis Thomas Bacon 1930s-1950s
- First Commercial use by NASA
  - Pratt and Whitney
  - Apollo space vehicles

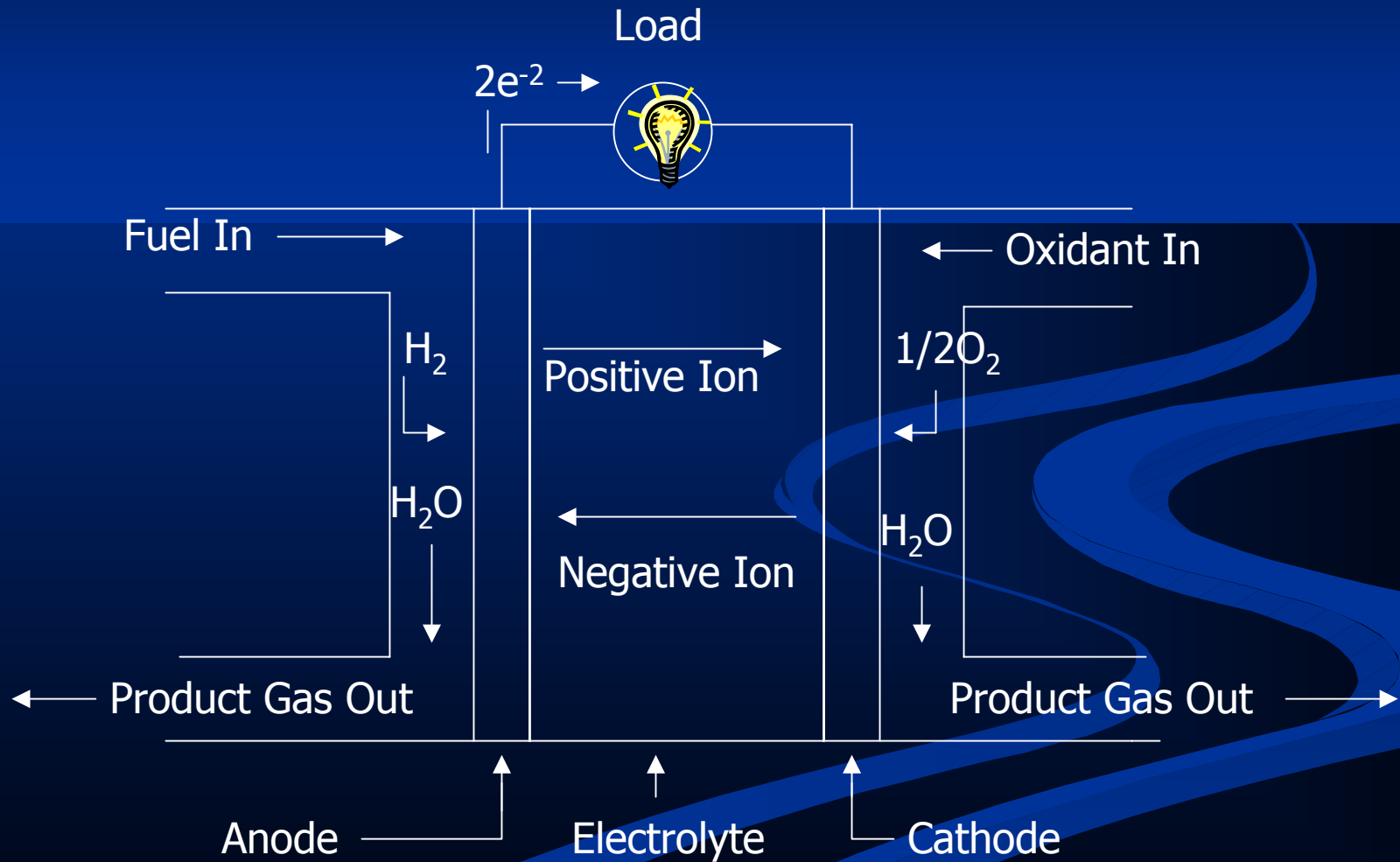


# Technology

“Fuel cells are electrochemical devices that convert the chemical energy of a reaction directly into electrical energy.”



# Fuel Cell Schematic



# How does a Fuel Cell Work?

[http://www.utcfuelcells.com/fuelcell/how\\_fl.shtml](http://www.utcfuelcells.com/fuelcell/how_fl.shtml)

The bottom half of the slide features a dark blue background with several thick, flowing, wavy lines in a lighter shade of blue that originate from the right side and curve towards the left, creating a sense of motion or a stylized landscape.

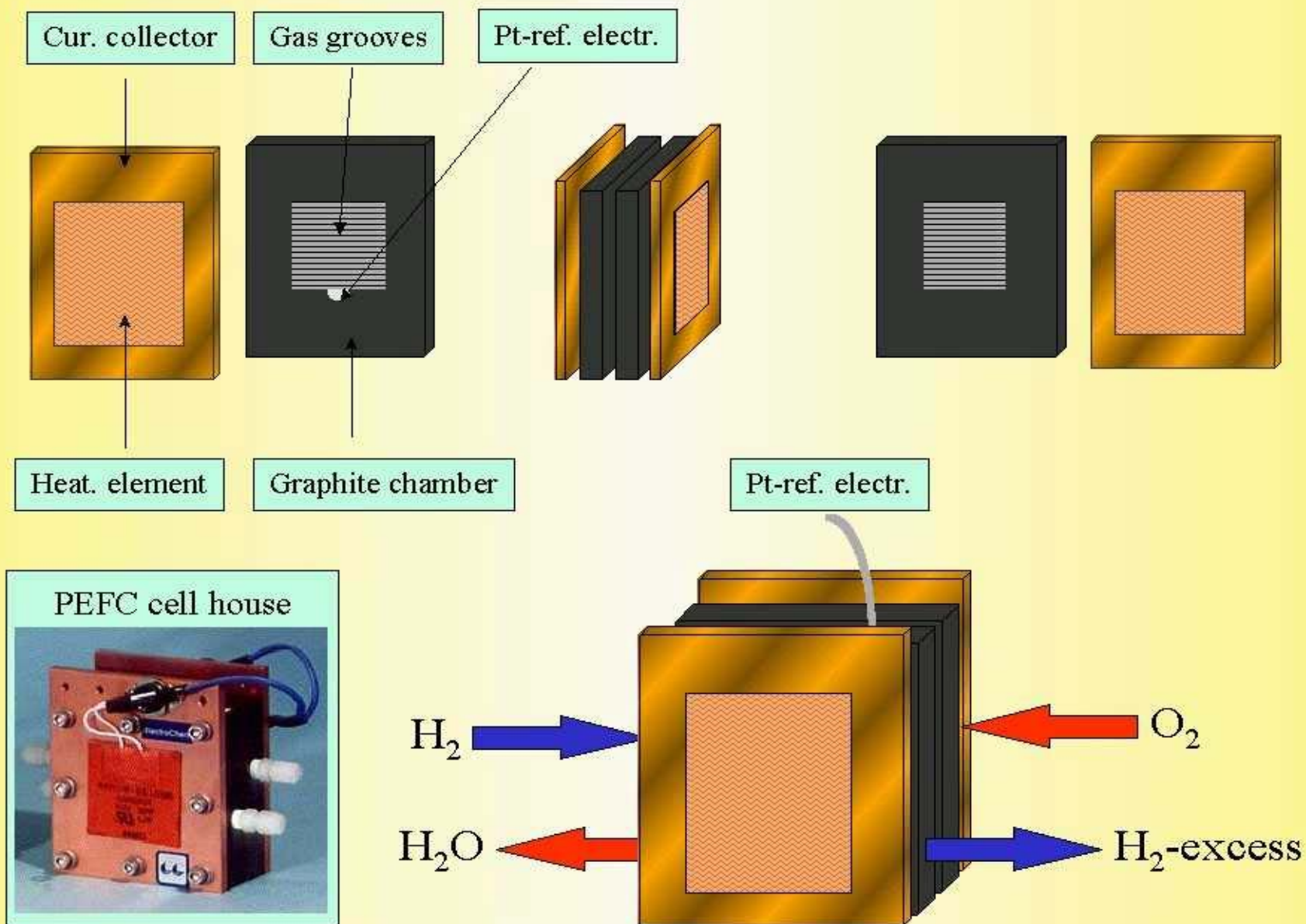
# Types of Fuel Cells

- Polymer Electrolyte Fuel Cell (PEFC)
  - Proton Exchange Membrane Fuel Cell (PEMFC)
- Alkaline Fuel Cell (AFC)
- Phosphoric Acid Fuel Cell (PAFC)
- Molten Carbonate Fuel Cell (MCFC)
- Solid Oxide Fuel Cell (SOFC)
  - Intermediate Temperature (ITSOFC)
  - Tubular (TSOFC)
  - Flat Plate (FPSOFC)

# Major Differences

	PEFC	AFC	PAFC	MCFC	ITSOFC	TSOFC
<b>Electrolyte</b>	Ion Exchange Membrane	Potassium Acid	Liquid Phosphoric Acid	Liquid Molten Carbonate	Ceramic	Ceramic
<b>Operating Temperature</b>	80°C	65-220°C	205°C	650°C	600-800°C	800-1000°C
<b>Charge Carrier</b>	H <sup>+</sup>	OH <sup>-</sup>	H <sup>+</sup>	CO <sub>3</sub> <sup>2-</sup>	O <sup>2-</sup>	O <sup>2-</sup>
<b>Cell Components</b>	Carbon-based	Carbon-based	Graphite-based	Stainless-based	Ceramic	Ceramic
<b>Catalyst</b>	Platinum	Platinum	Platinum	Nickel	Perovskites	Perovskites





# Advantages/Disadvantages AFC

- Excellent performance with  $H_2$ 
  - Cathode:  $O_2 + 2H_2O + 4e^{-1} \rightarrow 4OH^{-1}$
  - Anode:  $H_2 + 2OH^{-1} \rightarrow 2H_2O + 2e^{-1}$
- Wide range of electrocatalysts
- Low tolerance of impurities
  - $CO_2 + 2KOH \rightarrow K_2CO_3 + H_2O$
- Very Corrosive

# Advantages/Disadvantages

## PAFC

- Tolerance of CO<sub>2</sub>
- Less Complex Fuel Conversion
- Rejected heat and can be recycled
- Lower efficiency (37-42%)
- High Cost for precious metal catalysts
- Electrochemical Reaction:
  - Anode:  $\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$
  - Cathode:  $\frac{1}{2}\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{O}$

# Advantages/Disadvantages MCFC

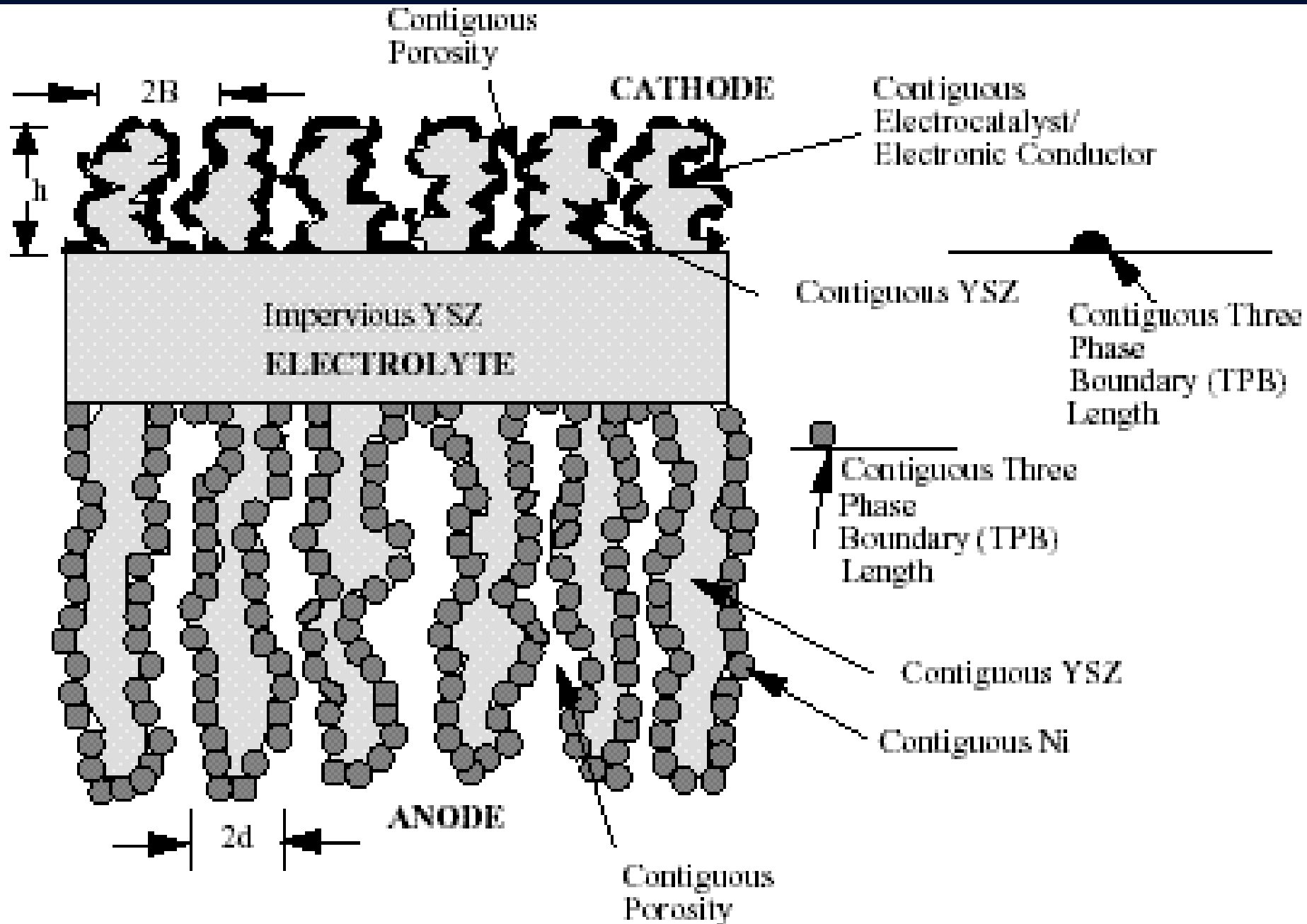
- Advantages of Higher Operating Temperature
- CO<sub>2</sub> tolerance
- Corrosive and mobile electrolyte
- Material problems
- Electrochemical Reaction:
  - Anode:  $\text{H}_2 + \text{CO}_3^{2-} \rightarrow \text{CO}_2 + 2\text{e}^{-1}$
  - Cathode:  $\frac{1}{2}\text{O}_2 + \text{CO}_2 + \text{e}^{-1} \rightarrow \text{CO}_3^{2-}$

# Advantages/Disadvantages

## SOFC

- No corrosion or mobility
- Fast cell kinetics
- Internal reforming
- Thermal expansion mismatches ( $\sim 1000^{\circ}\text{C}$ )
- Sealing problems
- Material constraints
- Electrochemical Reaction:
  - Anode:  $\text{H}_2 + \text{O}^{2-} \rightarrow \text{H}_2\text{O} + 2\text{e}^{-}$
  - Cathode:  $\frac{1}{2}\text{O}_2 + 2\text{e}^{-} \rightarrow \text{O}^{2-}$

# Schematic of Anode Supported Cell

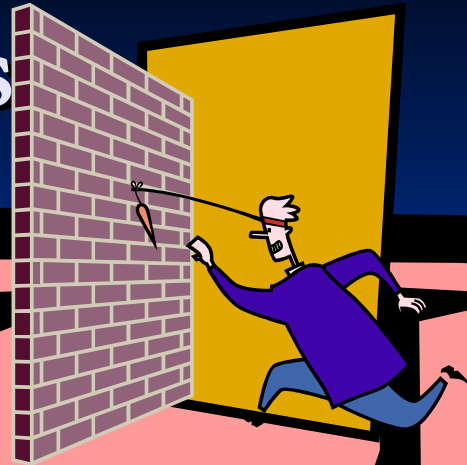


# Advantages/Disadvantages ITSOFC

- Ceramic used for electrodes and electrolytes
- Internal reforming
- No corrosion or mobility
- Electrolyte conductivity and electrode kinetics drops

# Barriers

- Infrastructure
- Hydrogen Source
- Hydrogen Distribution and Storage
- Market Acceptance



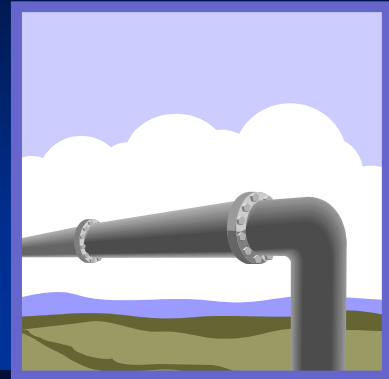


# Infrastructure

- Fueling Stations
- Pipelines
- A mechanic that knows how to fix your car?
- Parts

“Hydrogen filling stations capable of supplying 100 vehicles a day, built in sufficient numbers to realize respective economics of ~~could sell the fuel at a price of~~ to that of gasoline.”

-For



# Hydrogen Source

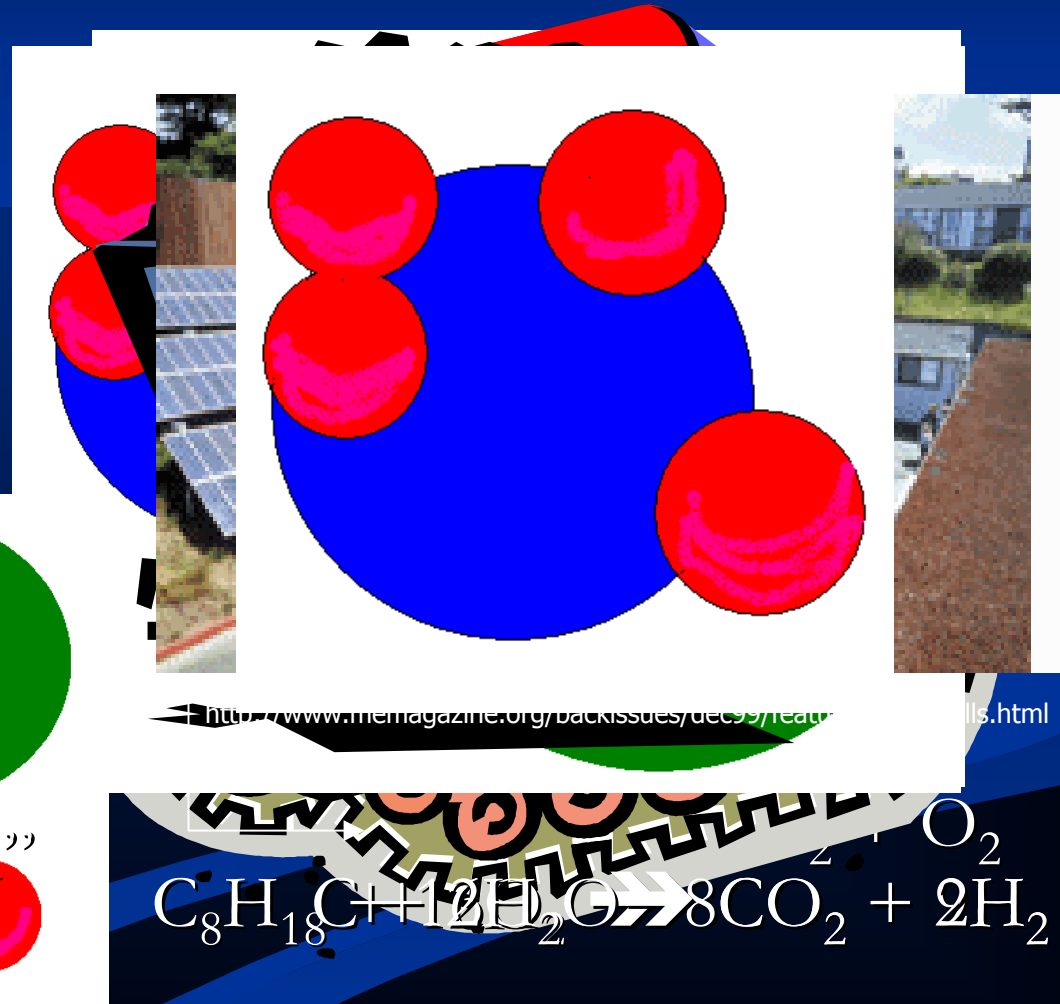
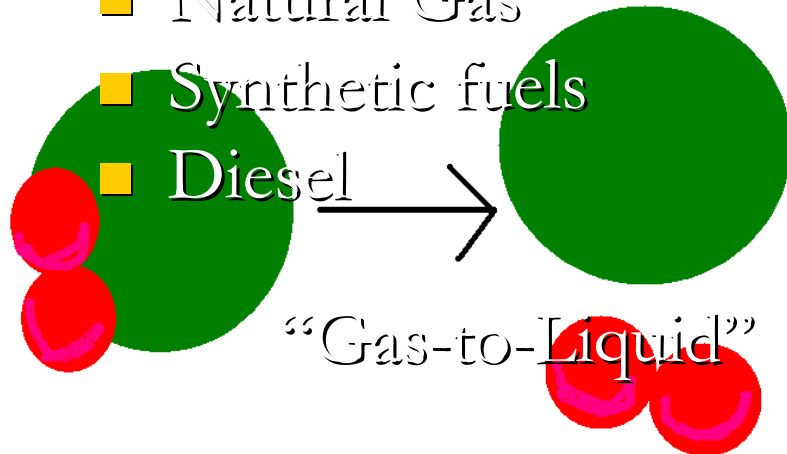
Hydrogen is not found naturally, so where is it coming from?

- Ethanol
- Methanol
- Electrolysis
- Gasoline

- Natural Gas

- Synthetic fuels

- Diesel



# Hydrogen Distribution and Storage

- Compressed Hydrogen
- Liquefying Hydrogen
- Metal Hydride
- Carbon Nanotubes
- Glass Microspheres
- As of present, automotive hydrogen storage volume not been

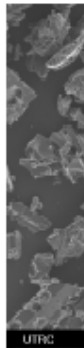
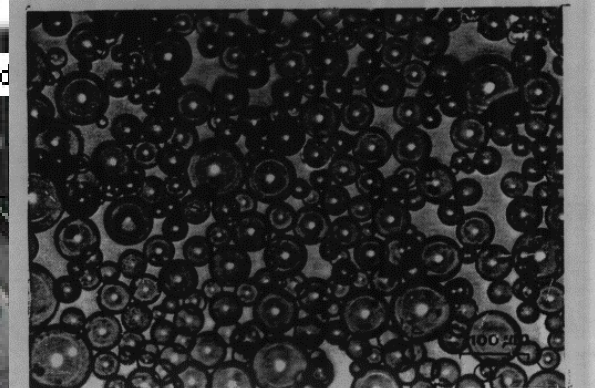
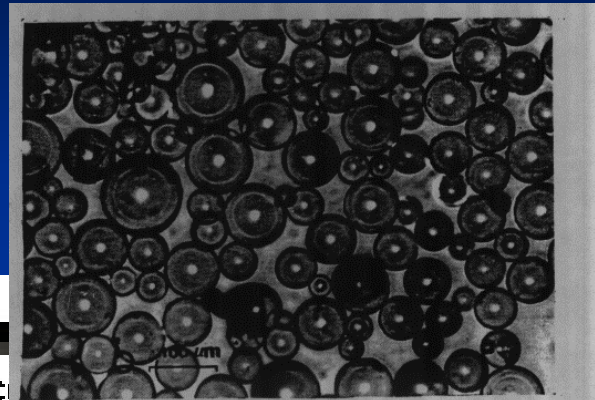
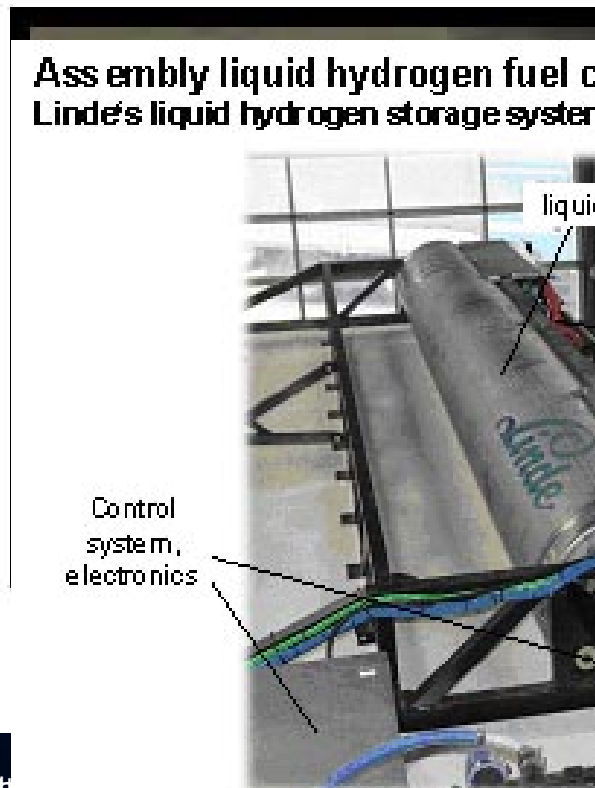


Figure 1



Hollow Glass Microspheres

Figure 3

# Market Acceptance

## ■ Hydrogen Misconceptions

"35 people died in the flames - and nobody knew why. Sabotage? A bolt of lightning? The mystery surrounding the disaster has never been resolved - until now. In many years of research, a NASA scientist at Cape Canaveral has found proof that **neither the hydrogen in the hull nor a bomb was to blame**, but the fabric of the Hindenburg's outer skin and a new protective coating. A single spark of static electricity was enough to make it burn like dry leaves. The 'infallible' German engineers had designed a flying bomb just waiting to explode."



<http://www.vidicom-tv.com/tohiburg.htm>

# Market Acceptance

- Cost will be a major factor in the acceptance of fuel cell technologies
- Technology and performance need to be competitive with conventional technologies



# Fuel Cells: The Future

- “Fuel-cell technology is going to take a long time to bring to some sort of affordable fruition. There is not going to be a silver bullet. It is a long, slow haul, requiring a lot of consistent work in the areas of research and infrastructure, but there will be some very exciting episodes along the way with very small fleets built.”
  - Richard Parry-Jones, Ford Group Vice President
- Ford is looking 15-25 years into the future before the fuel cell is a viable alternative to the internal combustion engine

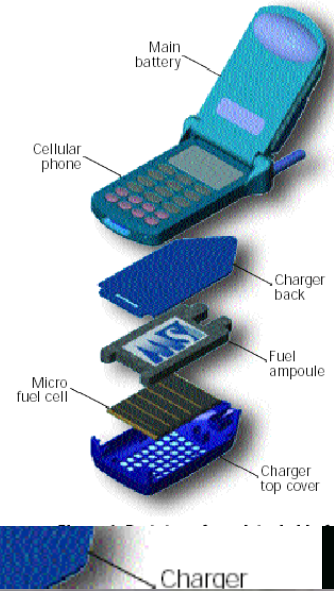


# Fuel Cells: Technology for Today



# Current Uses

- ✓ Appliance Applications
- ✓ Residential
- ✓ Commercial
- ✓ Transportation



<http://www.ballard.com/tD.asp?pgid=32&d>



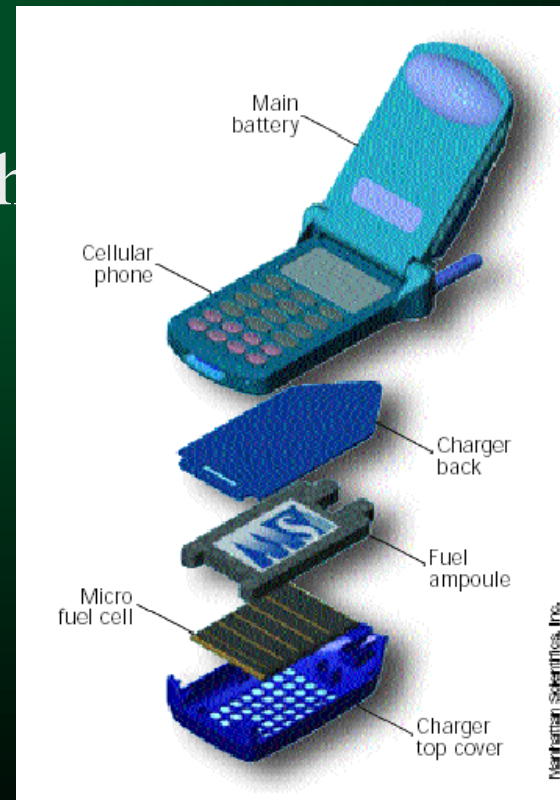
<http://www.hfcletter.com/letter/february00/index.html>





# Appliance Application

- ✓ Replace the Battery in Portable Electronics
  - Cell Phones
  - Labtops
- ✓ Fuel Cell runs 20X longer than cadmium batteries





# Residential

- ✓ Solid Oxide Fuel Cells
- ✓ Stationary Fuel Cells for Homes
- ✓ UTC Fuel Cells: 5kW Proton Exchange Membrane (PEM) power plant -- called the *Energy Center*



# Commercial Case Study: UTC Fuel Cells

- First National Bank of Omaha
- Anchorage Mail Processing Center
- Conde Nast Building NY, NY
- City of Portland





# Transportation

- ✓ PEMFC
- ✓ Georgetown University
- ✓ DaimlerChrysler: Mercedes-Benz and Jeep



■ <http://www.fta.dot.gov/research/equip/buseq/fucell/fucell.htm>



[http://www.daimlerchrysler.com/index\\_e.htm?/news/top/2000/t01107a\\_e.htm](http://www.daimlerchrysler.com/index_e.htm?/news/top/2000/t01107a_e.htm)

# Case Study: Ballard

- ✓ CaFCP
  - ZEBus Demonstration Program
- ✓ Chicago and Vancouver Demonstration Programs
- ✓ European Fuel Cell Bus Project



<http://www.ballard.com/tD.asp>



<http://www.ballard.com/tD.asp?pgid=28&dbid=0>



<http://www.ballard.com/tD.asp?pgid=30&dbid=0>





# Building an Infrastructure

- ✓ Hydrogen Filling Station in Munich, Germany
- ✓ Hydrogen Filling Station plan unveiled in Reykjavik, Iceland

## Hydrogen as Alternative Fuel

storage & filling systems - universal cryogenic fuel station -

Linde AGA





# World Wide Hydrogen Fueling Stations

- ✓ Davis, California
- ✓ El Segundo, California
- ✓ 2X Thousand Palms, California
- ✓ Sacramento, California
- ✓ 2X Torrance, California
- ✓ Oxnard, California
- ✓ Chula Vista, California
- ✓ Richmond, California
- ✓ San Jose, California
- ✓ Chicago, Illinois
- ✓ Dearborn, Michigan
- ✓ Phoenix, Arizona
- ✓ Northern Nevada
- ✓ Torino, Italy
- ✓ 2X Munich, Germany
- ✓ 2X Hamburg, Germany
- ✓ Nabern, Germany
- ✓ Wolfsburg, Germany
- ✓ Russelsheim, Germany
- ✓ Sindelfingen, Germany
- ✓ 2X Berlin, Germany
- ✓ Copenhagen
- ✓ Lisbon
- ✓ Erlangen, Germany
- ✓ Obersdorf Spa, Germany
- ✓ Stuttgart, Germany
- ✓ Stockholm, Sweden
- ✓ London, United Kingdom
- ✓ Amsterdam, The Netherlands
- ✓ City of Luxemburg
- ✓ Oporto, Portugal
- ✓ Madrid, Spain
- ✓ Barcelona, Spain
- ✓ Reykjavik, Iceland
- ✓ Perth, Australia
- ✓ Victoria, Australia
- ✓ South Korea
- ✓ Beijing, China
- ✓ Shanghai, China
- ✓ Cairo, Egypt
- ✓ Mexico City, Mexico
- ✓ New Delhi, India
- ✓ Sao Paulo, Brazil
- ✓ Osaka, Japan
- ✓ Takamatsu, Japan
- ✓ Tsurumi, Japan
- ✓ 2X Yokohama, Japan
- ✓ Tokai, Japan
- ✓ 2X Tokyo, Japan
- ✓ Kawasaki City, Japan
- ✓ Vancouver, Canada
- ✓ Montreal, Canada
- ✓ Surrey, BC Canada
- ✓ Torino, Canada
- ✓ Oostmalle, Belgian
- ✓ Leuven, Belgian



# The Future of Energy is Here

Today these examples are case studies, and are by no means the only examples of fuel cells currently being utilized worldwide

**Grab the Future!**



# Wind Energy



Water pumping,  
agricultural use.



Danish wind mill



Wind turbine, used  
for electricity



Wind Farm

# Who uses them?

## ■ Historically:

- Nile 5000 B.C
- China
- grind grain
- pump water.

## ■ Present day:

- used for electricity
  - Utility power grids for domestic energy
  - Can be combined with photovoltaics
  - Homeowners, farmers, and ranchers

# How wind turbines work

- Kinetic to mechanical to electrical energy
  - Intermittent resource
- They make electricity by orienting the propellers upwind (into the wind).
- “Works opposite of a fan”
- Wind forces the blades to turn---The shaft then spins---The shaft is connected to a generator which makes electricity.
- <http://www.eere.energy.gov/wind/animation.html>

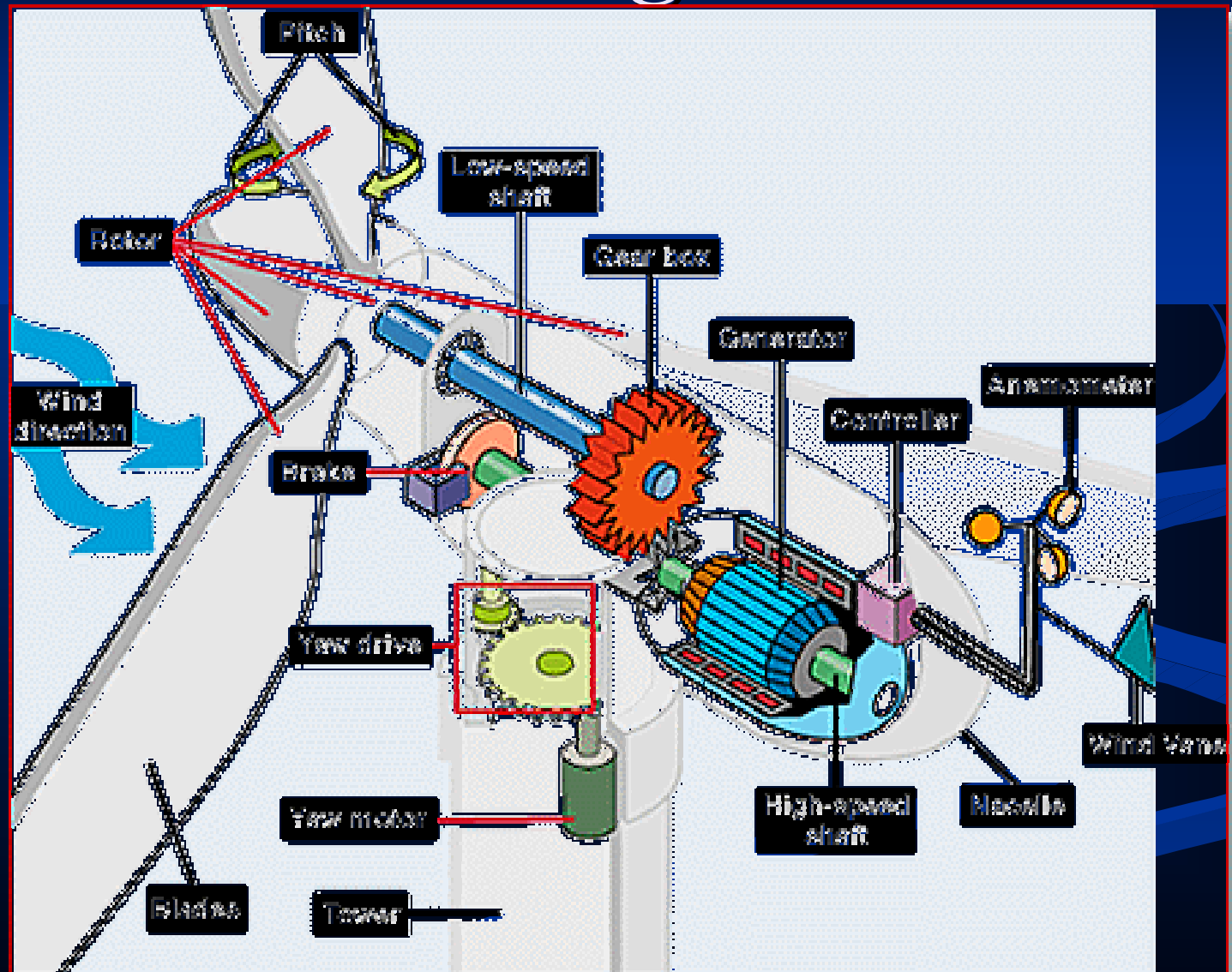
# Common Design

- 3 bladed, 100 feet (30 meters)
- Large: 50 to 750 kilowatts
- Small: < 50 kilowatts
- Hawaii propellers = 100 yards 20 stories high
  - 1400 homes.
- Small = 8-25 feet diameter, 30 ft. tall
  - Home or small business
- Horizontal-axis variety
- Vertical-axis design
  - Darrieus model



# Design

<http://www.eere.energy.gov/wind/feature.html>



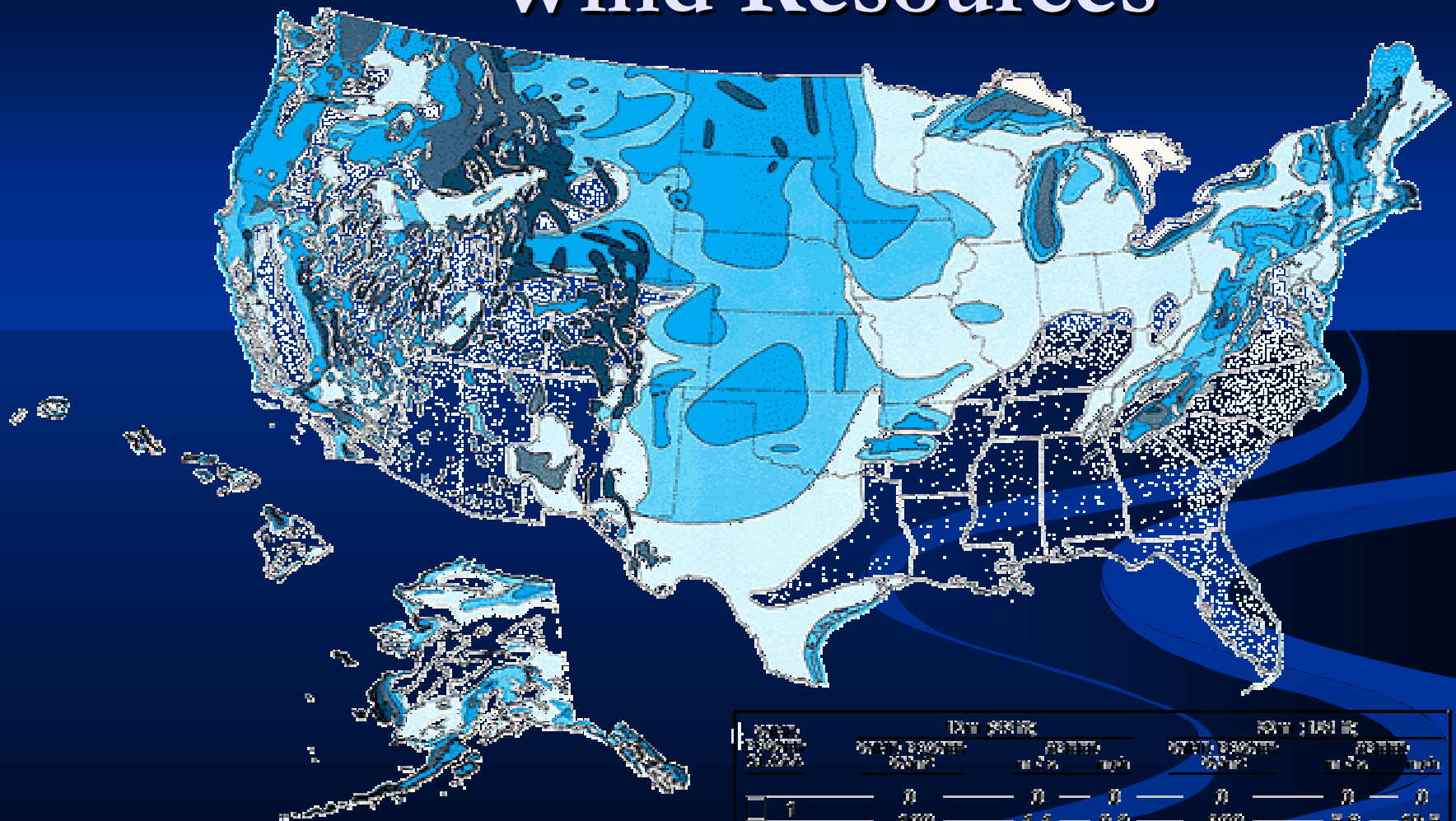
# Energy Capacity

- 6% of the U.S. continental land is viable for wind energy.
- Utility-scale 50 to 750 kilowatts.
- U.S. 4,685 MW capacity
  - 1,822.3 MW in Ca.
  - 2001 installed 1,700 MW worth \$1.7 billion
- capacity of almost 30,000 megawatts world wide
  - 6,500 were installed world wide in 2001
  - \$7 billion in sales
- Small scale single turbines- below 50 kilowatts
  - homes, telecommunications dishes, or water pumping.

# Primary Energy Payback for Various types of Power Plants

- Type of Power Plant Payback (Months)
- Nuclear 0.7
- Coal 0.7
- Wind @ 7 m/s 2.5 - 7.5
- Wind @ 5.5 m/s 3.8 - 11.4
- Wind @ 4 m/s 6.3 - 22.7

# Wind Resources



WIND SPEED 1000 ft	DATA SOURCE		DATA SOURCE		DATA SOURCE		DATA SOURCE	
	WIND SPEED 1000 ft	WIND SPEED 1000 ft	WIND SPEED 1000 ft	WIND SPEED 1000 ft	WIND SPEED 1000 ft	WIND SPEED 1000 ft	WIND SPEED 1000 ft	WIND SPEED 1000 ft
1	0	0	0	0	0	0	0	0
2	1000	4.5	9.3	5000	5.0	12.5	5000	12.5
3	1500	5.4	11.5	5000	5.6	14.5	5000	14.5
4	2000	5.9	13.5	5000	7.0	15.7	5000	15.7
5	2500	6.0	15.5	5000	7.5	17.0	5000	17.0
6	3000	6.5	16.5	5000	8.0	17.0	5000	17.0
7	4000	7.0	15.7	5000	8.5	16.7	5000	16.7
8	10000	8.5	21.1	5000	11.0	20.0	5000	20.0


U.S. DEPARTMENT OF ENERGY, NATIONAL WIND ENERGY PROGRAM, 1990. U.S. DEPARTMENT OF ENERGY, 1990.



# States with the most potential

- Great Plains states
- California has the most installed
- Wind energy and the turbines are expanding rapidly.
  - Iowa, Minnesota, Texas, Wisconsin, and Wyoming
  - Appalachian Mountain region

# Performance Variables

- The power in the wind is proportional to the cube of the wind speed.
  - Probability of direction
    - Wind rose
  - Gustiness
    - Shuts off at 65 mph
- 
- A decorative graphic consisting of several thick, wavy blue lines that flow from the bottom right towards the center of the slide, creating a sense of movement and depth against the dark blue background.

# Economics of Wind Energy

- The cost has dropped 85% in 20 years
  - Looking good for the future
  - \$.35-\$.05-\$.025
  - Current rate is 9 cents per kWh
- Life cycle costs- low
- Buy back rates- not feasible yet
- 30% growth rate capacity of almost 6,000 megawatts.
- High capital cost

# Business

- Wind energy diversifies the nation's energy supply
- Takes advantage of a domestic resources
- Reduces greenhouse gases
- NIMBY
- Pollution-Economy- correlation
- \$1.7 Billion Industry- evidence that the market is working!
- Germany has surpassed the U.S. in installation of wind energy turbines
  - 2,600 MW installed in 2001

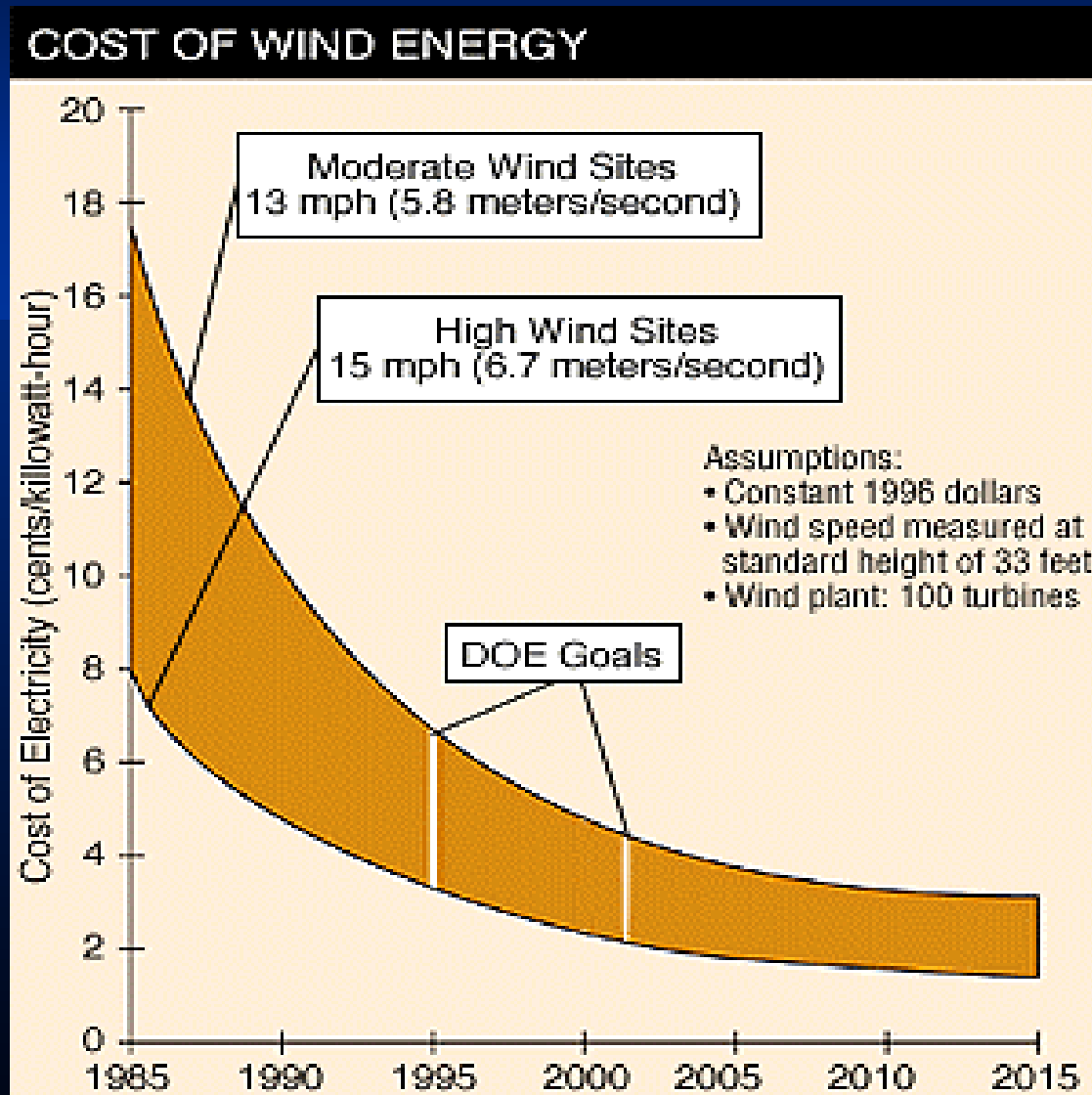
# Policy

- Non-discriminatory transmission rules
  - Renewable Portfolio Standards
  - Fees on emission and pollution from electricity generation
  - Incentives for renewables-
    - could hurt businesses
    - Artificial sense of price
- 
- A decorative graphic consisting of several thick, wavy blue lines that flow from the right side of the slide towards the bottom left, creating a sense of movement and depth against the dark blue background.

# We don't have problems!

- 1-2 Birds are killed a year per turbine
- The noise level is hardly a problem
- Transmission lines will become more viable
- People are not going to oppose them so harshly.
  - Lowers their own energy bill
- The land is not being rendered unusable
  - Agriculture including grain and cattle

# Wind Speeds and Prices




# Wind Power Goals

- Meet 5% of the nation's energy needs with wind energy by 2020 (i.e. 80,000 megawatts installed)
- Double the states that have the capacity to supply more than 20 megawatts of wind power by 2005 and triple it to 24 by 2010
- Keep making wind competitive with conventional sources of energy.
  - Still cheaper than nuclear



# Problems with the Technology

- Aesthetics and visual impacts
  - Birds
  - Noise
  - Lightening
  - TV/Radio interference
- 
- Decorative wavy lines in a lighter shade of blue, flowing from the right side of the slide towards the bottom left.



# Benefits

- ✓ “The electric industry remains the largest, single industrial source of air pollution.”

- ✓ [http://www.eere.energy.gov/state\\_energy/technology\\_overview.cfm?techid=2](http://www.eere.energy.gov/state_energy/technology_overview.cfm?techid=2)

- ✓ 1990, California's wind power
  - offset 2.5 billion pounds of carbon dioxide
  - 15 million pounds of other pollutants that would have otherwise been produced.
  - It would take a forest of 90 million to 175 million trees to provide the same air quality.
  - Therefore, taking advantage of renewables will help us decrease the amount of air pollution.



# EMISSION COMPARISON BETWEEN A WIND TURBINE AND A COAL PLANT OVER 25 YEARS

✓ Plant type   SO<sub>x</sub>(tons)   NO<sub>x</sub> (tons)   CO<sub>2</sub> (tons)

✓ Wind      14              0.3              87

✓ Coal      40              108.0          31,326

✓ The U.S wind industry offset 7.5 million tons of carbon dioxide



# Incentives

- ✓ Pennsylvania's Berks County Community Foundation.
- ✓ The development and use of renewable energy and clean energy technologies;
  - Energy conservation and efficiency;
  - Sustainable energy businesses
  - Projects that improve the environment in the companies' service territories

# Bottom Line

- ✓ Wind Turbines REDUCE (CO2)
- ✓ Scientists have agreed that Global Warming is occurring, so lets start mitigating by using more wind power!
- ✓ 750-kilowatt (kW) (typical for electrical use) produce 2 million kilowatt-hours (kWh) per year.
- ✓ Approximately 1.5 pounds of CO2 are emitted for every kWh generated. An average turbine prevents:
  - *2 million kWh x 1.5 pounds CO2/kWh =*
  - *3 million pounds of CO2 =*
  - *1500 tons of CO2 each year.*
- ✓ “Ecological Footprint”
  - forest absorbs approximately 3 tons of CO2 per acre of trees per year.
- ✓ Thus, a single 750kW wind turbine prevents as much carbon dioxide from being emitted each year as could be absorbed by 500 acres of forest.



# Infrastructure Problems

# Biomass





# Bioenergy

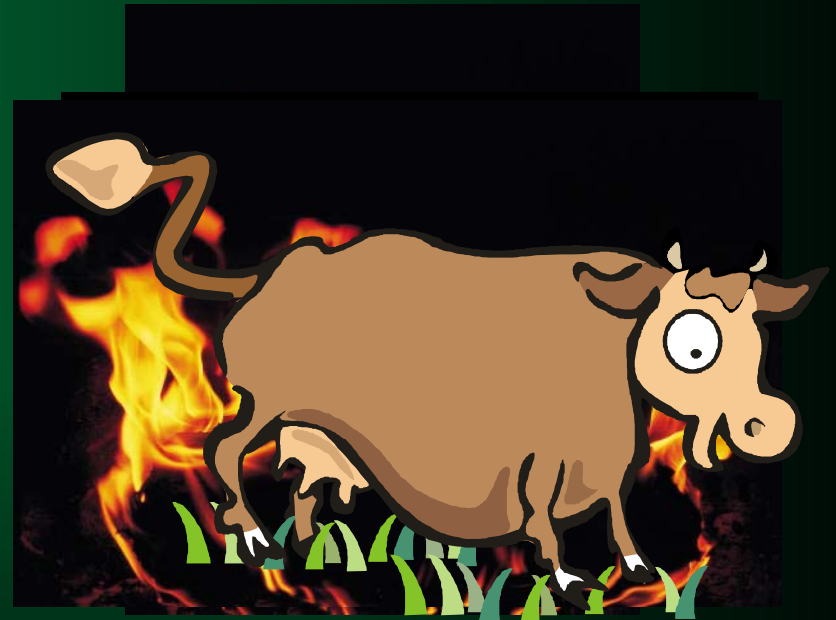
- ✓ Provides about 3% of all energy used in US.
- ✓ In 2001, biomass provided over half of the renewable energy in US
- ✓ Globally, biomass meets about 14% of the world's energy needs





# Biomass

- ✓ organic matter which can be converted to energy or fuels
- ✓ Use of existing resources
  - “Cut it down, process it, then burn it”
- ✓ Active creation of organic material or “energy crops”
  - “Grow it, process it, then burn it”
- ✓ Use of plant and animal byproducts
  - “you get the picture”





# Feedstocks

- ▼ Biomass byproducts used for fueling power plants
  - Wood residue
    - Mill Residues
    - Urban Wood Residues
    - Tree Trimmings
    - Forest Residues
  - Agriculture residue
    - Bagasse
    - Rice husks
  - Energy crops
    - Crops grown specifically for fuel
    - fast-growing trees, shrubs, and grasses, hybrid poplar, willow, switchgrass, and eucalyptus.



# Other sources

- ✓ Municipal Solid Waste (landfills)
- ✓ Animal waste
  - Manure, bedding from swine, cattle, poultry
- ✓ Human Waste (sewage and sludge)





# Combustion

## Direct combustion

- burning of unprocessed material by direct heat to produce heat or steam to generate electric power
- direct combustion is the simplest biomass technology
- wood, garbage, manure, straw, and biogas



# Combustion

## ▼ Residential

- burning wood fireplace or woodstove
- pellets stoves and compacted/ manufactured logs
- space heating, cooking

## ▼ Industry

- Industrial biomass includes:
  - wood
  - agricultural residues
  - wood pulping liquor
  - municipal solid waste
- Furnaces - burns fuel in a combustion chamber to create hot gases
- Boiler - transfers the heat of combustion into steam used for electricity, mechanical energy or heat
  - pile burners
  - stationary or traveling grate combustors
  - fluidized-bed combustors.



# Combustion

## Cogeneration

- combustion facilities that produce electricity from boilers and steam-driven turbine-generators
  - conversion efficiency of 17 to 25 percent (85% improvement of overall system efficiency)
- Bottoming Cycle:
  - steam product used first in an industrial process first and then routed through a turbine to generate electricity
- Topping Cycle:
  - steam passes first through a turbine to produce electric power and then exhaust from the turbine is then used for industrial processes or for space and water heating
  - More common process



# Combustion

## Direct-Fired Gas Turbine

- Pretreated fuel (particle size  $<2\text{mm}$ , moisture content  $<25\%$ )
- fuel burned with compressed air

## Co-Firing with Coal

- secondary fuel ( $\sim 20\%$ ) in a coal-burning power plant using high-sulfur coal
- decreases  $\text{CO}_2$  emissions from the power plant

## Alkali Fouling

- Allows the burning of agriculture products containing alkali compounds (K, Na)
- Special boilers with low exit temperatures to reduce slag



# Gasification

- ✔ Process that converts biomass into a combustible “producer” gas
  - contains carbon monoxide, hydrogen, water vapor, carbon dioxide, tar vapor and ash particles
  - 70 – 80% of potential energy from feedstock
  - gas burned directly for space heat or drying
  - gas can be burned in a boiler to produce steam
- ✔ Gas is cleaned by filters and scrubbers
  - internal combustion engine
  - fuel cells
- ✔ **Pyrolysis** (first stage of gasification) 450° to 600° C
  - Vaporization of volatile components with controlled heat in absence of air
  - carbon monoxide, hydrogen, methane, volatile tars, carbon dioxide, water and charcoal
- ✔ **Char conversion** (last stage of gasification) 700° to 1200° C
  - The charcoal residue + oxygen = carbon monoxide





# Digester Gas

- **Anaerobic digestion**

- Biomass is mixed with water and then put in a digester tank without air.
- converts organic matter to:
  - a mixture of methane and  $\text{CO}_2$
  - syngas, a mixture of carbon monoxide and hydrogen
  - hydrogen
- Sewage, manure, and food processing wastes



# Digester Gas

- **Landfill gas**

- created from anaerobic digestion or decomposition of buried trash and garbage in landfills
- gas generated consists of ~50% methane





# Biodiesel fuel

- ✓ Substitute for petroleum diesel
- ✓ Made by chemical conversion process that converts oilseed crops into biodiesel fuel
  - mechanical press extraction
  - solvent extraction
- ✓ Vegetable oils, such as rapeseed, corn or safflower, can be used as a diesel fuel without further processing
- ✓ Trans-esterification
  - reduces the high viscosity of vegetable oil
  - higher-quality fuel
  - oil reacts with alcohol in the presence of a catalyst to produce glycerol and rapeseed methyl or ethyl ester (RME or REE)
  - used straight or in a blend with petroleum diesel.



# Fuel Alcohol

## Methanol (wood alcohol)

- wood and agricultural residues, but most from natural gas
- ✓ From biomass: made through high temp/pressure gasification
  - carbon monoxide and hydrogen catalyzed to condense into liquid methanol
- ✓ Fuel alternative
  - Methanol is a high-octane fuel that offers excellent acceleration and vehicle power
  - Methanol-fueled trucks and buses emit practically no particulate matter less nitrogen oxides than diesel





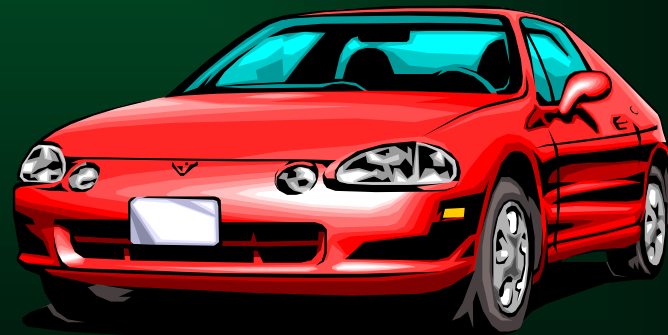
# Fuel Alcohol

- **Ethanol (grain alcohol)**
  - converting starch to sugar → fermenting sugar to alcohol with yeast → distilling alcohol water mixture → **ethanol**
  - wheat, barley, potatoes, waste paper, sawdust, and straw contain either sugar, starch, or cellulose for fermenting
  - alternative fuel for internal combustion engines.



# Ethanol

- ✓ Ethanol is already penetrating the transportation market as gasohol as replacement fuel
- ✓ Higher blends of ethanol, specifically E85, are becoming increasingly available in certain regions of the US
- ✓ Nearly 150 stations in 20 states in the Midwest and Rocky Mountains
- ✓ All major automobile manufacturers have models that can operate on E85, gasoline, or any mixture of the two.





# Hemp

- 10 tons per acre in four months
- contains 77% cellulose
  - compared to wood containing 60% cellulose
- requires no special equipment to plant or harvest
- drought resistant
- removes less nutrients from the soil than any other feedstock
- hemp can yield up to eight times as much methanol per acre as corn
- equals 1,000 gallons of methanol per acre per year
- hemp is perhaps the only plant capable of producing sufficient biomass to provide an alternative to fossil fuels

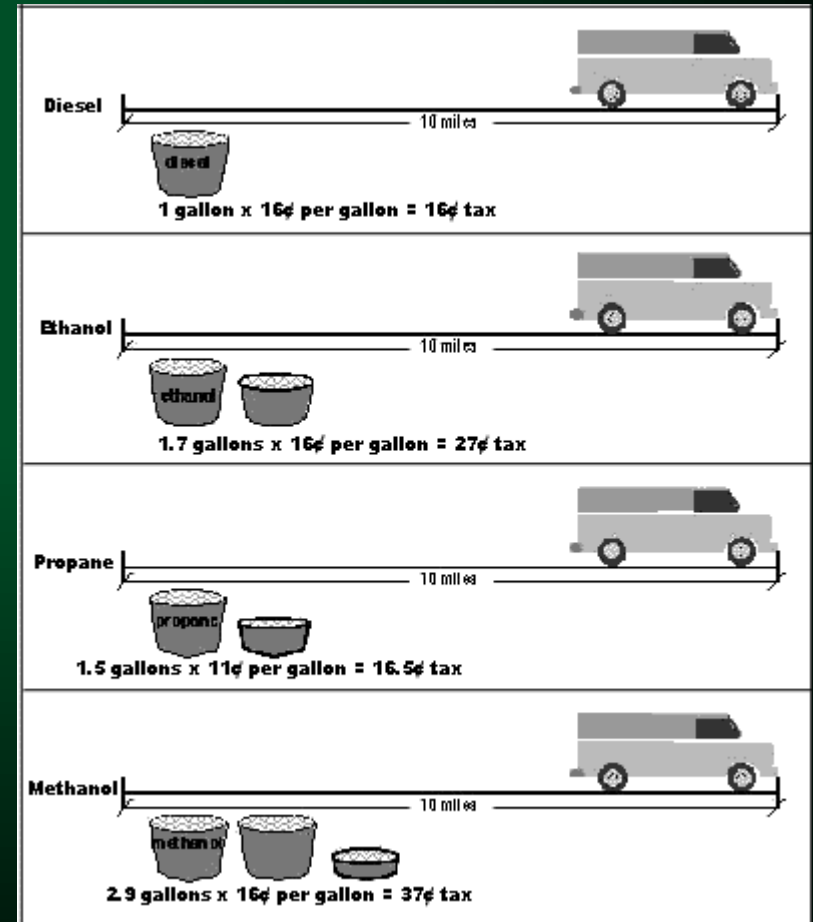




# Tax Incentives ~ Renewable Fuels

## ✓ Case Study: Hawaii

- Act 143 (HB1345, Relating to Energy Content of Fuels)
- encourages use of alternative fuels (less energy per gallon)
- adjusting the fuel tax to reflect the energy content of alternative fuels
- reducing the fuel tax rate of alternative fuels for several years
- Offsets discouragement to use alternative fuels that were once taxed higher



<http://www.hawaii.gov/dbedt/ert/fueltax-act143.html>





# Biomass Methods

Technology	Conversion Process Type	Major Biomass Feedstock	Energy or Fuel Produced
<b>Direct Combustion</b>	Thermochemical	wood agricultural waste municipal solid waste residential fuels	heat steam electricity
<b>Gasification</b>	Thermochemical	wood agricultural waste municipal solid waste	low or medium-Btu producer gas
<b><u>Pyrolysis</u></b>	Thermochemical	wood agricultural waste municipal solid waste	synthetic fuel oil (biocrude) charcoal
<b>Anaerobic Digestion</b>	Biochemical (anaerobic)	animal manure agricultural waste landfills wastewater	medium Btu gas (methane)
<b>Ethanol Production</b>	Biochemical (aerobic)	sugar or starch crops wood waste pulp sludge grass straw	ethanol
<b>Biodiesel Production</b>	Chemical	rapeseed soy beans waste vegetable oil animal fats	biodiesel
<b>Methanol Production</b>	Thermochemical	wood agricultural waste municipal solid waste	methanol



# Environment Benefits

- ✓ Theoretically inexhaustible fuel source
- ✓ Biomass absorbs carbon dioxide during growth
  - Recycling Process
- ✓ Reduce Landfill usage
- ✓ Available to produce everywhere!
- ✓ Low levels of sulfur and ash
  - Does not contribute to acid rain
- ✓ Nitrous oxide emissions can be controlled
- ✓ Co-firing with biomass helps existing power plants comply with clean-air laws

# Biomass Economics



- In 1992, biomass grossed \$1.8 billion in personal and corporate income in US
- 66,000 jobs supported by biomass energy
- economic benefits expected to triple by 2010
- supports agriculture and rural America
- Tax credits
  - 1.5 ¢/kWh relief for electricity generated from "closed-loop biomass"

# Biomass Disadvantages



- If burned directly, contributes  $\text{CO}_2$  and particulates just like coal and petroleum!
- expensive source
  - producing the biomass and converting it to alcohols
- On a small scale there is most likely a net loss of energy
  - energy must be put in to grow the plant mass!

Where are we going?

