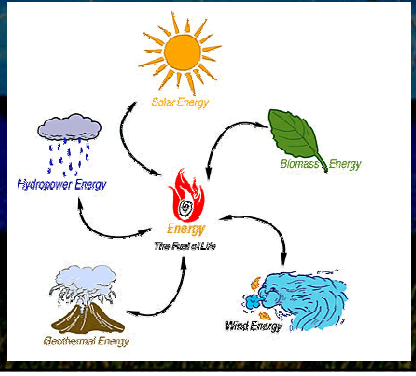
Chapter 15: "Energy Efficiency and Renewable Energy"



Sustainable Energy

NREL, Warren Gretz Staff Photographer

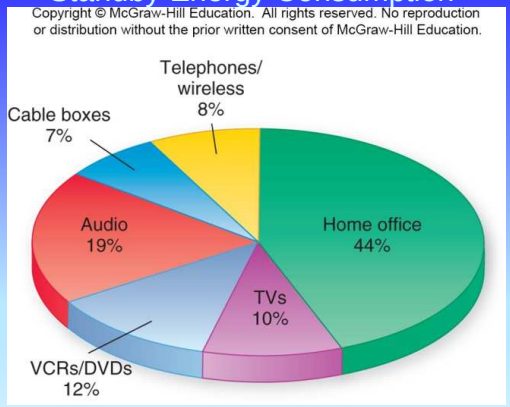
Outline

- Renewable Energy
  - Green Buildings
  - Transportation
  - Cogeneration
- Solar Energy
  - Passive vs. Active
  - High Temperature Solar Energy
  - Photovoltaic Cells
- Wind
- Biomass and Fuel Cells
- Hydropower, Tidal, and Geothermal Energy

Reducing Our Consumption

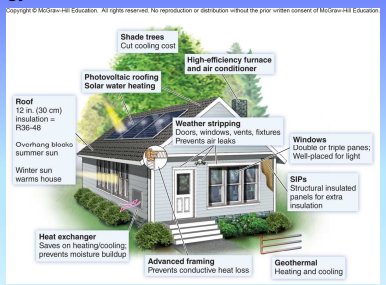
- Utilization Efficiencies
  - Compact Fluorescent light bulbs produce 4x as much light for the same wattage and last 10x as long.
  - LED Bulbs are even more efficient, consuming 90% less energy.
  - One of the easiest ways to save energy is to turn off and unplug appliances (TVs, printers, computers) which are on standby.
    - Appliances on standby represent 25% of the typical monthly electrical bill.
    - Putting a computer to sleep can save 90% energy.

Standby Energy Consumption



Green Buildings Can Cut Energy Costs

- Green Buildings are those that include extra insulation and coated windows.
- Super insulated houses now being built in Sweden use 90% less energy than conventional houses in the U.S.



Transportation Could Be More Efficient

- Automobiles and light trucks account for 40% of U.S. oil consumption and 1/5 of its carbon dioxide emissions.
- Raising average fuel efficiency in U.S. by 3 mpg would save consumers 25 billion dollars a year and save more oil than the maximum expected production from drilling in the Arctic National Wildlife Refuge.
  - In the 1970s, when oil prices rose, U.S. doubled auto fuel efficiency reaching 25.9 mpg in 1988 but by 2004 it was down to 20.7 mpg,..

More Efficient Transport

- You could buy a hybrid gasoline-electric car
- For short trips, you could walk or bicycle

Plug-in Hybrids Are Even More Efficient

- You could buy a plug-in hybrid car which recharges batteries from household electrical outlets at night
  - Electricity costs the equivalent of 50 cents per gallon.
  - We would need to generate more electricity, but we could capture pollutants easier at the plant.
- You could buy a diesel. Honda currently sells a diesel in the US that gets 62.8 mpg.
- A diesel plug-in hybrid could make the U.S. entirely independent from imported oil.

Fuel-cell Vehicles Are Being Developed

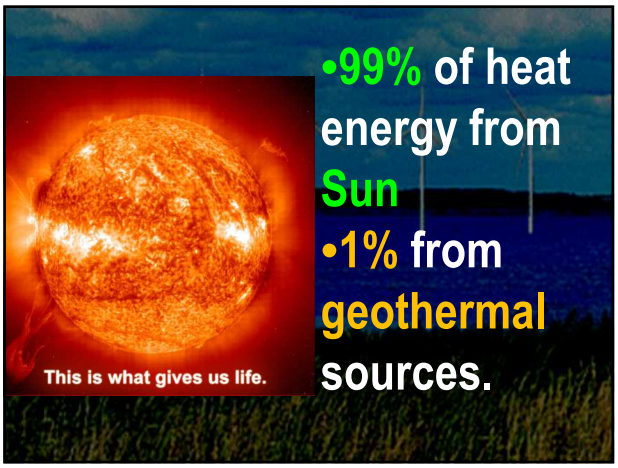
- Vehicles are being developed which use hydrogen gas as fuel.
  - Produce water as their only waste product
  - Will take at least twenty years to come to market
  - Most hydrogen is currently created from natural gas, making it no cleaner or more efficient than burning the gas directly.
- Governments in U.S. and Europe are spending billions on this.

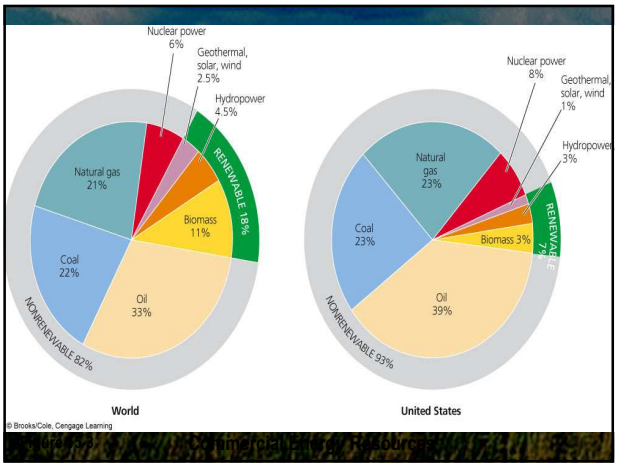
Cogeneration Produces Electricity and Heat

- Cogeneration - simultaneous production of both electricity and steam, or hot water, in the same plant
  - Increases net energy yield from 30-35% to 80-90%.
    - In 1900, half of electricity generated in U.S. came from plants also providing industrial steam or district heating.
      - By 1970s, cogeneration had fallen to less than 5% of power supplies.

Cogeneration Produces Electricity and Heat

- Interest is being renewed
  - District heating systems are being rejuvenated.
  - Plants that burn municipal waste are being studied.
  - Apartment-building-sized power generating units are being built that use methane, diesel, or coal.


This is what gives us life.
•99% of heat energy from Sun
•1% from geothermal sources.


Nuclear power 6%
Geothermal, solar, wind 2.5%
Hydropower 4.5%
RENEWABLE 18%
Natural gas 21%
Biomass 11%
Coal 22%
Oil 33%
NONRENEWABLE 82%
World
Nuclear power 8%
Geothermal, solar, wind 1%
Hydropower 3%
RENEWABLE 7%
Natural gas 23%
Coal 23%
Biomass 3%
Oil 39%
NONRENEWABLE 93%
United States
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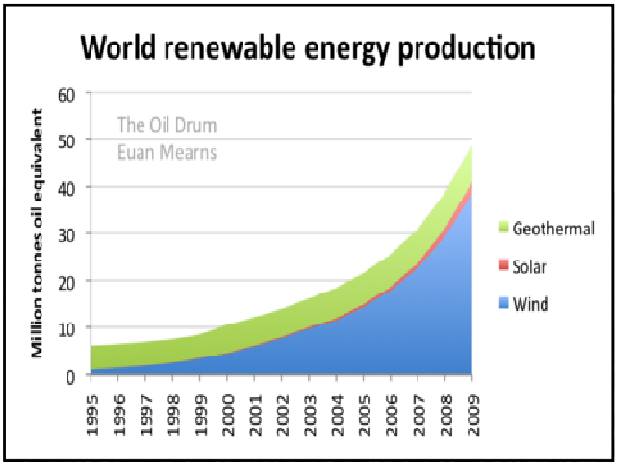

World renewable energy production
The Oil Drum
Euan Mearns
Million tonnes oil equivalent
60
50
40
30
20
10
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Geothermal
Solar
Wind

Solar Energy

- A Vast Resource
  - Average amount of solar energy arriving on top of the atmosphere is 1,330 watts per square meter
    - Amount reaching the earth's surface is 10,000 times more than all commercial energy used annually
      - Until recently, this energy source has been too diffuse and low intensity to capitalize for electricity.

Passive Solar

House is designed to heat cool depending on the season.
Winter: low sun angle = more light in house = warmer
Summer: high sun angle = less light = cooler

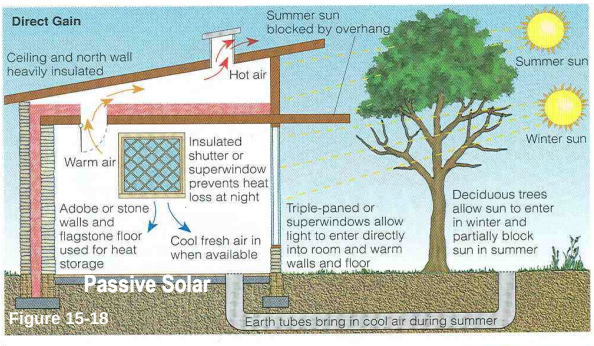
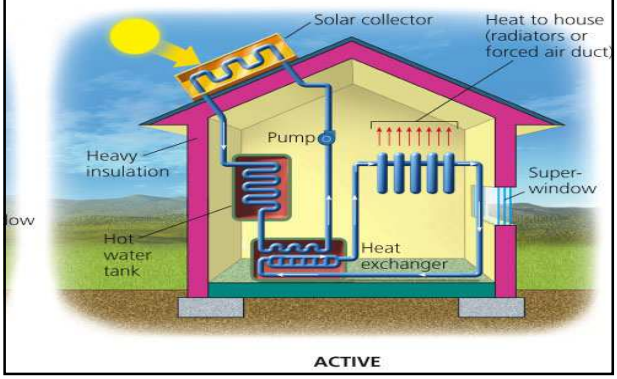


Figure 15-18

Active Solar (Thermal)

Sun heats water pipes in black solar absorbers on the roof . The water is ACTIVELY PUMPED to the house to distribute heat.



Photovoltaic Solar Panels convert sunlight directly into electricity.

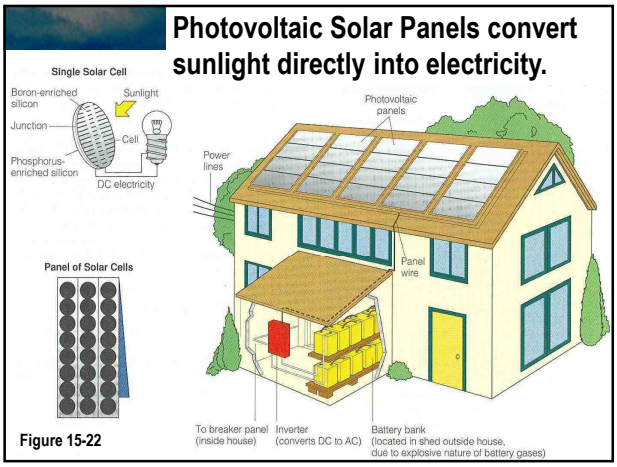
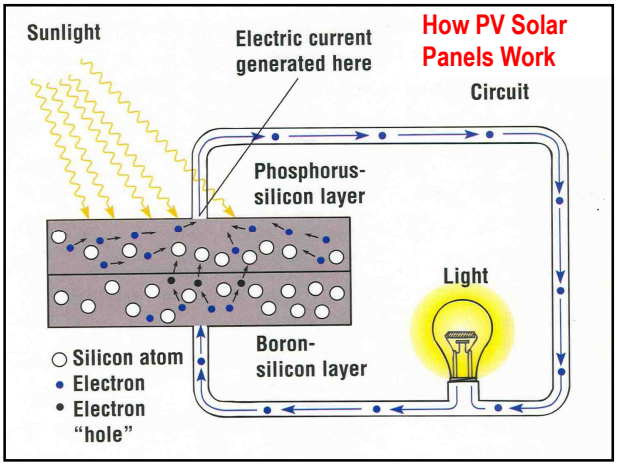


Figure 15-22

How PV Solar Panels Work



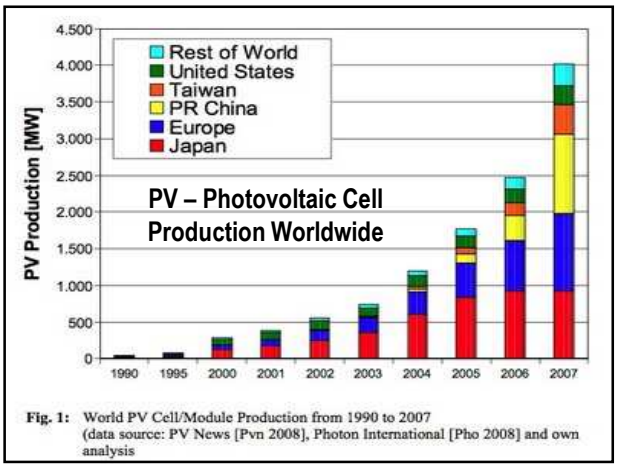
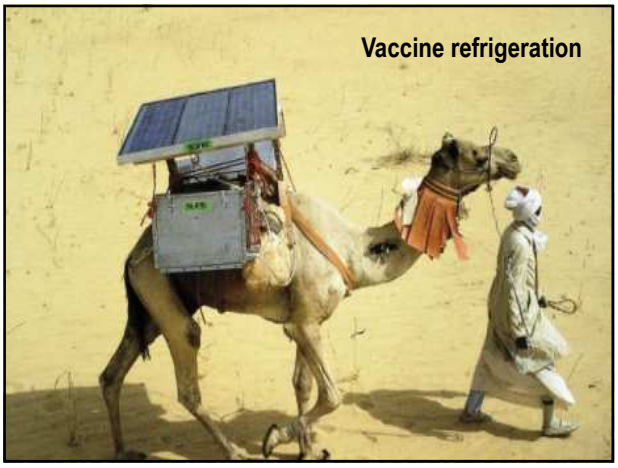
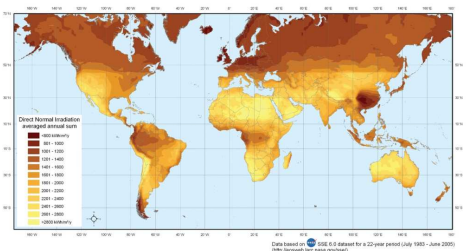


Fig. 1: World PV Cell/Module Production from 1990 to 2007 (data source: PV News [Pvn 2008], Photon International [Pho 2008] and own analysis



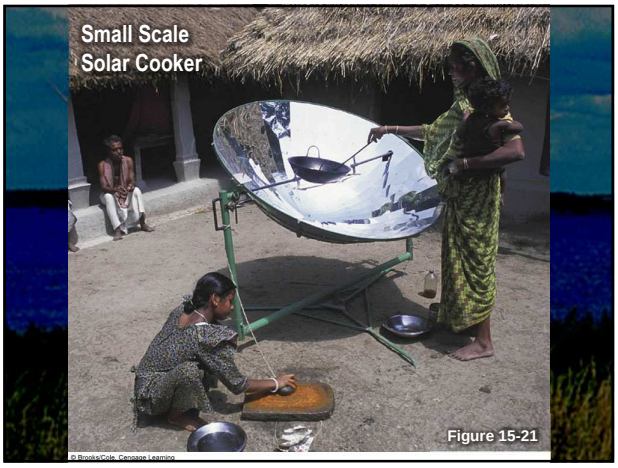
Average Solar Radiation

Direct Normal Irradiation (DNI)



Solar Collectors Can Be Passive or Active

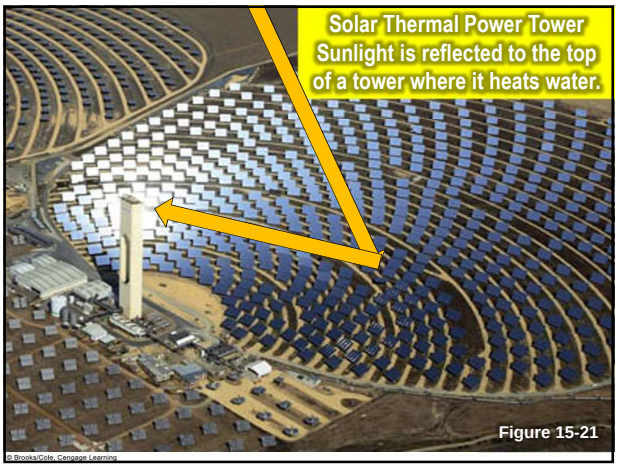
- Passive Solar Heat - using absorptive structures with no moving parts to gather and hold heat
  - Greenhouse Design
- Active Solar Heat - pump heat-absorbing medium through a collector, rather than passively collecting heat in a stationary object
  - Water heating consumes 15% of U.S. domestic energy budget. A flat panel of 5 m^2 can provide hot water for an average family.
  - China produces 80% of the solar water heaters in the world.

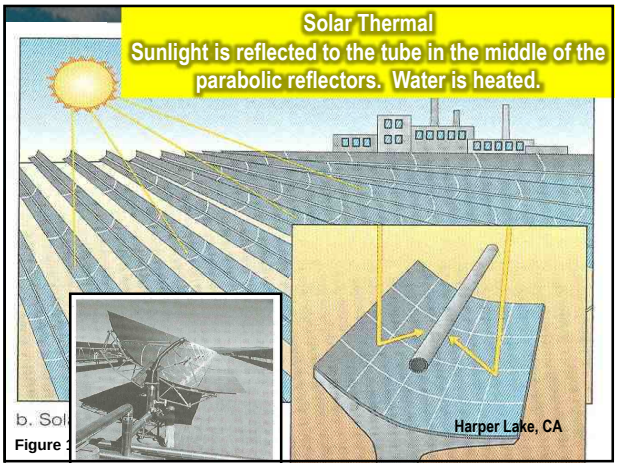


High Temperature Solar Energy

- Parabolic mirrors are curved reflective surfaces that collect light and focus it onto a concentrated point. Two techniques:
  - Long curved mirrors focused on a central tube containing a heat-absorbing fluid.
  - Small mirrors arranged in concentric rings around a tall central tower track the sun and focus light on a heat absorber on top of the tower where molten salt is heated to drive a steam-turbine electric generator.

Solar Thermal Plants





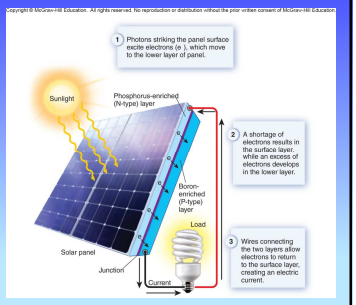
CSP (concentrating solar power) plant
Sunlight is reflected to the top of a tower where it melts salt. The salt can be stored for up to 12 hours. The higher specific of salt is used to store the heat. The extremely hot salt can be used to create steam from water.
Big Benefit? Can make power at night!

Solar Energy

- Only solar power tower in U.S. is in Southern California. It generates enough electricity for 5,000 homes at a cost far below oil or nuclear power.
- Worldwatch Institute estimates that US deserts could produce 7000GW of solar energy, nearly seven times the current US electrical capacity from all sources.

Photovoltaic Cells

- Capture solar energy and convert it directly to electrical current by separating electrons from parent atoms and accelerating them across a one-way electrostatic barrier.



Photovoltaic Cells

- During the past 25 years, efficiency of energy capture by photovoltaic cells has increased from less than 1% of incident light to more than 15% in field conditions and over 75% in the laboratory.
- With further research experts believe the cost by 2020 could be $.10 per kWh, making solar competitive with fossil fuels.
- At least 2 billion people now live without electricity. This could be a solution to their problems.

House With Photovoltaic Roof Tiles

- Invention of amorphous silicon collectors has allowed production of lightweight, cheaper cells.
- Roof tiles with photovoltaic cells can generate enough electricity for a home.

Promoting Renewable Energy Use

- Proposed Energy Conservation Policies:
  - Distributional Surcharges
    - Small fee on utility customers to finance renewable energy R & D
  - Renewable
    - Suppliers must get minimum percentage of power from renewable sources.
  - Green Pricing
    - Allows utilities to profit from conservation programs and charge premium prices for renewable energy

Smart Metering

- The development of plug-in hybrids could serve as an enormous distributed battery system that could store surplus power generated by power plants in the evenings and provide power for transportation during the daytime.
- Can instruct appliances to run when more cost-effective (i.e., at night when consumption is lower)

PROS of Solar

a. Free renewable energy
b. moderate net energy
c. easy installation
d. minimal green house gas (GHG) emissions
e. Minimal pollution
f. minimal maintenance

CONS of Solar

a. Doesn't work when cloudy or at night.
b. initial cost is high.
c. Needs a lot of space.

Hydroelectric Power

Hydropower

- In 1925, falling water generated 40% of world's electric power.
- Hydroelectric production capacity has grown 15-fold but fossil fuel use has risen so rapidly that hydroelectric only supplies 20% of electrical generation.
- Norway uses hydropower for 99% of its electricity supply.
- Untapped resources are abundant for hydropower in Latin and Central America, Africa, India, and China.

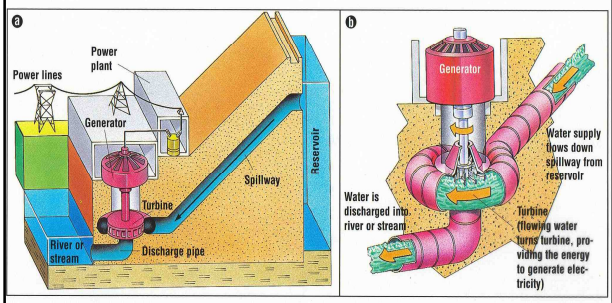
Hydropower Dams Produce Clean Energy

Dams

- Much of hydropower in recent years has been from enormous dams
  - Human Displacement
  - Ecosystem Destruction
  - Wildlife Losses
  - Large-Scale Flooding due to Dam Failures
  - Sedimentation
  - Herbicide Contamination
  - Evaporative Losses
  - Nutrient Flow Retardation

Hydroelectric Power

Gravity pulls water downhill. Water spins a turbine, that turns a generator to make electricity.



Gran Paradiso National Park in Northern Italy

Unwanted Effects of Dams

- Rotting of submerged vegetation kills fish, acidifies water, produces greenhouse gases
- Schistosomiasis - human disease caused by parasitic fluke that lives in snails, which like the slow-moving water behind dams
- Indigenous peoples lose their lands

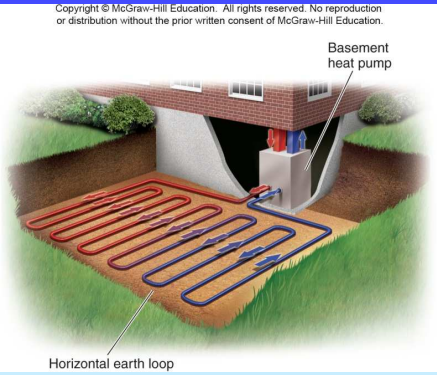
Dam Alternatives

- Low-Head Hydropower - extract energy from small headwater dams
- Run-of-River Flow - submerged directly in stream and usually do not require dam or diversion structure
- Micro-Hydro Generators - small versions designed to supply power to single homes
- Government subsidies for small scale hydropower resulted in abuse of water resources, e.g., diverting small streams

Geothermal Energy

- Geothermal Energy - tap energy from hot springs, geysers
- Few places have geothermal steam, but can use Earth's warmth everywhere by pumping water through buried pipes using heat pumps
- Deep wells for community geothermal systems are being developed.
- Heat from Earth's crust is never exhausted.
- Can reduce heating costs by one-half.

Geothermal Energy



Tidal and Wave Energy

- Ocean tides and waves contain enormous amounts of energy that can be harnessed.
  - Tidal Station - tide flows through turbines, creating electricity
    - Requires a high tide/low-tide differential of several meters
  - Wave energy could meet local needs in coastal areas of Scotland, Canada, South Africa, Australia, and the US (Hawaii).

Pelamis Wave Converter

© Ocean Power Delivery Ltd

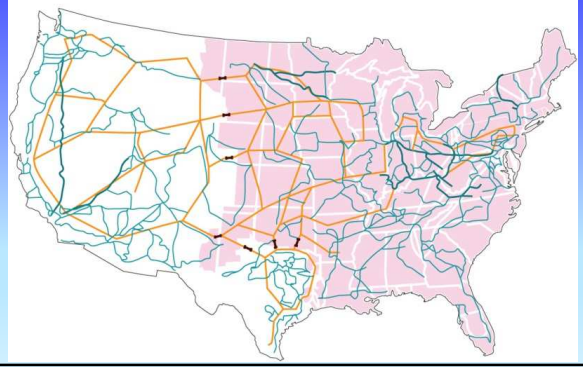
This snakelike machine points into waves and undulates up and down; this action pumps fluid to hydraulic motors that drive electrical generators, and cables carry power to shore.

Ocean Thermal Electric Conversion

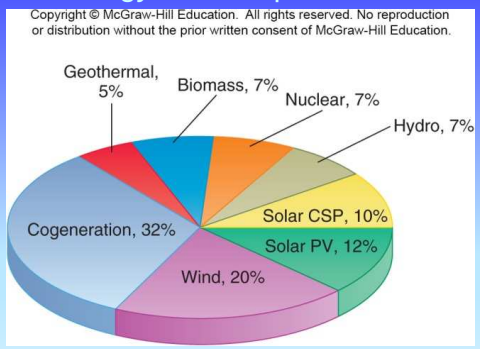
- Heat from sun-warmed upper ocean layers is used to evaporate a working fluid, such as ammonia, which has a low boiling point.
  - Gas pressure spins electrical turbines.
  - Cold water is then pumped from the depths to condense the ammonia again.
  - Need temperature differential of about 20° C between warm upper layers and cooling water.
- An option in western South Africa, the South Pacific Islands, and Hawaii.

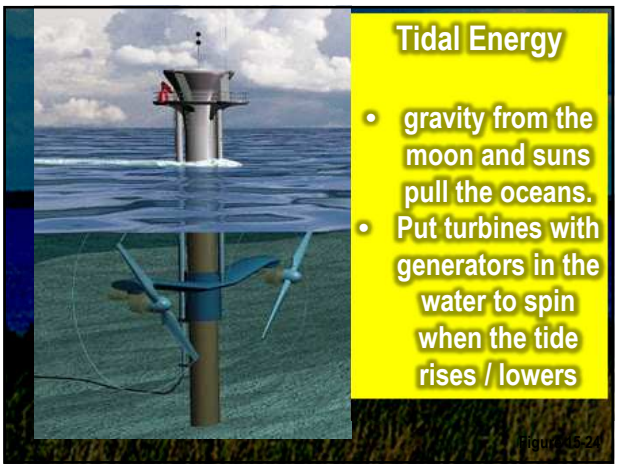
Getting Electrical Power Where It Is Needed

- Many of the places with the greatest potential for solar and wind power are located far from urban centers where the power is needed.
- President Obama is proposing to spend $4.5 billion to expand the power grid to accommodate these new power sources.
- These power lines may not be a welcome sight to people in the rural areas they will pass through.



A Renewable Energy Scenario for World Energy Consumption 2030





Tidal Energy

- gravity from the moon and suns pull the oceans.
- Put turbines with generators in the water to spin when the tide rises / lowers

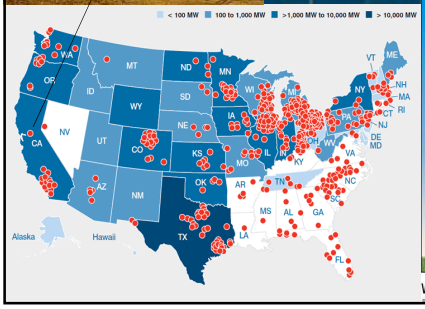
PROS of Hydroelectric Power:

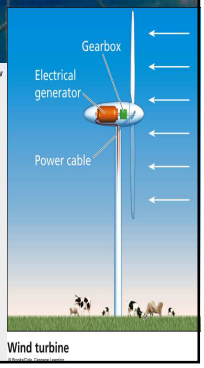
a. net energy high
b. long life span
c. low GHGs
d. flood control / water storage / recreation

CONS:

a. Expensive to build
b. can impede fish migration (salmon)
c. sediment builds up behind dam.

Wind Power





Wind

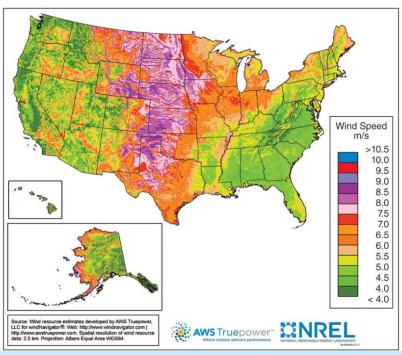
- There are an estimated 80 million megawatts of wind power that could be commercially tapped worldwide.
- This is five times the total current global electrical generating capacity.
- China is now the world leader in wind power turbine production.
- Wind turbines typically operate at 35% efficiency under field conditions.
- When conditions are favorable, electric prices typically run as low as 3 cents / kWh.

Utilizing Wind Resources in the U.S.

Wind Power Pros and Cons

- Pros:
  - no fuel costs or emissions
  - generates income for farmers who rent land for turbines or sell electricity
  - short planning and construction time
- Cons:
  - intermittent source
  - not enough wind everywhere
  - bird mortality
  - power lines needed to transmit the electricity

Wind Resources for the Continental U.S.

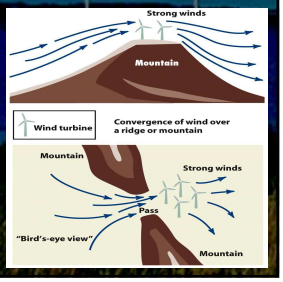


PROS of Wind -

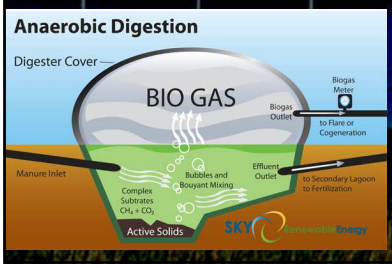
a. net energy moderate → high
b. Low impact
c. no GHG's
d. multiple land use (cows graze at base of windmill)

CONS:

a. Wind is sporadic
b. Needs a large area
c. noisy
d. bird hazard

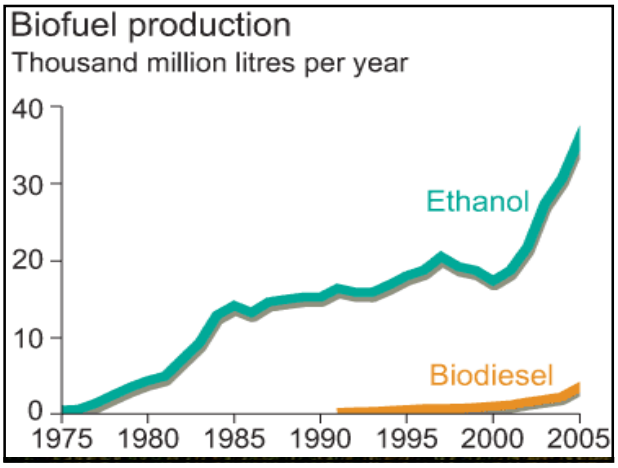


Power from Biomass



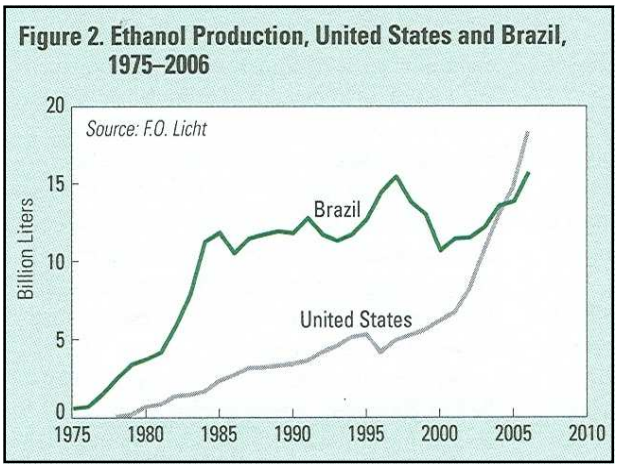
Biomass

- Plants capture about 0.1% of all solar energy that reaches the earth's surface.
  - About half of this energy is used in metabolism and the rest is stored in biomass.
- Useful biomass production estimated at 15-20 times the amount currently obtained from all commercial energy sources.
  - Biomass resources include wood, wood chips, bark, leaves, and starchy roots.



We Can Burn Biomass

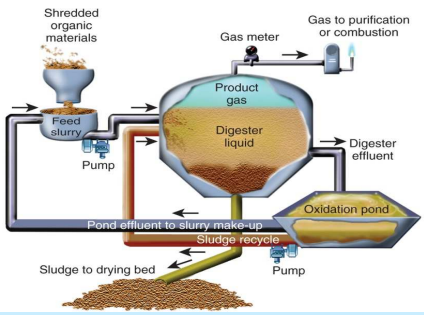
- As recently as 1850, wood supplied 90% of the fuel used in the United States.
- In poor countries it is still a major source of energy and its use can result in habitat destruction.
- Even in rich countries, wood burning stoves are becoming popular in response to rising oil prices.
- The Danish islands of Samsø and Ærø get about ½ of their heating from agricultural wastes and biomass crops.
- Some utilities are installing flex-fuel boilers that burn a mixture of coal and biomass.



Methane From Biomass Is Clean and Efficient

- Methane is the main component of natural gas.
  - Produced by anaerobic decomposition
    - Burning methane produced from manure provides more heat than burning dung itself, and left-over sludge from bacterial digestion is a nutrient-rich fertilizer.
      - Methane is clean, efficient fuel
        - Municipal landfills contribute as much as 20% of annual output of methane to the atmosphere. This could be burned for electricity.

Anaerobic Production of Methane



Methane

- Cattle feedlots and chicken farms are a tremendous potential fuel source since wastes contain more energy than all the nation's farmers use.
  - Haubenschild dairy farm uses manure from 850 cows to generate all their electricity, along with an excess. In January 2001, the farm saved 35 tons of coal, 1,200 gallons of propane, and made $4,380 selling electricity.

Biofuel Use On Campus

- A number of colleges and universities are weaning themselves off fossil fuels:
  - Middlebury College in Vermont uses wood chips in a gasification plant to heat the campus.
  - The University of New Hampshire is working on a plan to heat the campus by burning methane from a nearby landfill.
  - The University of Minnesota is using corn stalks in a gasification plant to heat and cool the campus and a wind turbine to generate most of its electricity.

Ethanol & Biofuels Can Enhance Fuel Supplies

- Brazil is the world's leader in alcohol from biomass, mostly sugarcane waste.
- Currently 1/5 of all corn grown in the U.S. is used for ethanol production.
- Crops with high oil content like soybeans, rape seed, sunflower, and palm oil can be used to produce biodiesel fuel.
- Some countries in Southeast Asia are creating palm oil plantations for biodiesel production, but forests are burned and habitats of endangered animals are destroyed in the process.

Possible New Biofuel Sources

- *Jatropha curcas* is a shrub native to Mexico and the Caribbean which produces nuts high in a non-edible oil.
- *Jatropha* oil is easily converted to biodiesel.
- India has trial plantings of this biofuel crop; yields are 3x greater than palm oil plantations.
- Unfortunately, trials elsewhere have shown *Jatropha* water requirements, sensitivity to pests, and lower-than-expected yield.

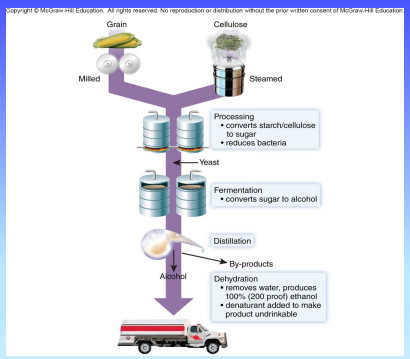
Cellulosic Ethanol May Offer Hope

- Ethanol now made from grains like corn, could be made from cellulosic material such as wood chips, straw.
- This has environmental, social, and economic advantages over using edible grains for fuels.
- Plants put the bulk of the energy they capture from the sun into cellulose and hemicellulose, both of which are made of long chains of simple sugars which could be fermented into ethanol.
- Several pilot plants are currently under construction in the U.S. which will use wheat straw, switchgrass, wood chips, or almond hulls.

Cellulosic Ethanol May Offer Hope (cont.)

- *Miscanthus x giganteus,* called elephant grass, comes from Asia and may be an excellent biofuel crop.
- *Miscanthus* can produce 5x as much biomass per acre as corn.
- Using corn or switchgrass to produce enough ethanol to replace 20% of U.S. gasoline usage would require ¼ of all U.S. cropland.
- *Miscanthus* could produce the same amount of ethanol on one-half that acreage and can be grown on marginal soils with less fertilizer.

Ethanol Production



Could Algae Be A Hope For The Future?

- Algae might be an even better biofuel crop.
- Algae growing in a photobioreactor could theoretically produce more biofuel (30x) than *Miscanthus*.
- They could be grown next to conventional power plants where carbon dioxide from burning fossil fuels could be captured and used for algae growth.
- A coal-fired plant in Brazil has plans to implement this technology in 2011 to reduce their carbon emissions.
- Some algae also produce hydrogen gas which could be used in fuel cells.

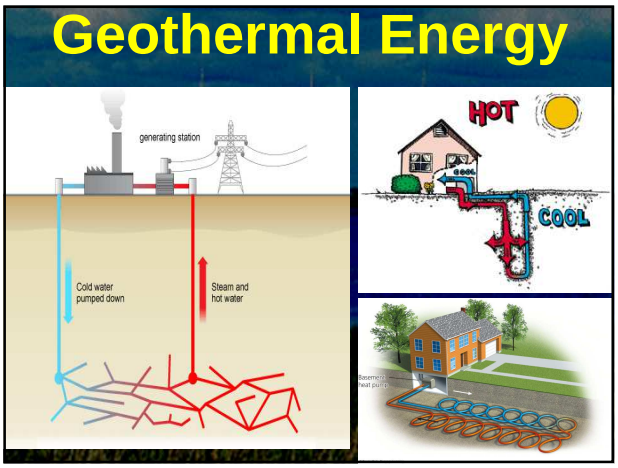
15.7: Biomass

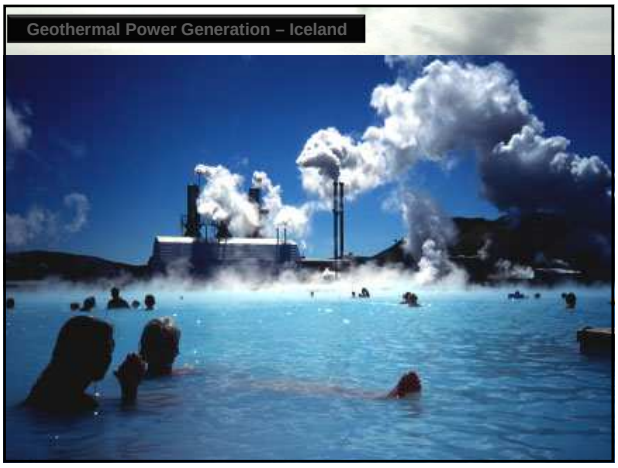
PROS:

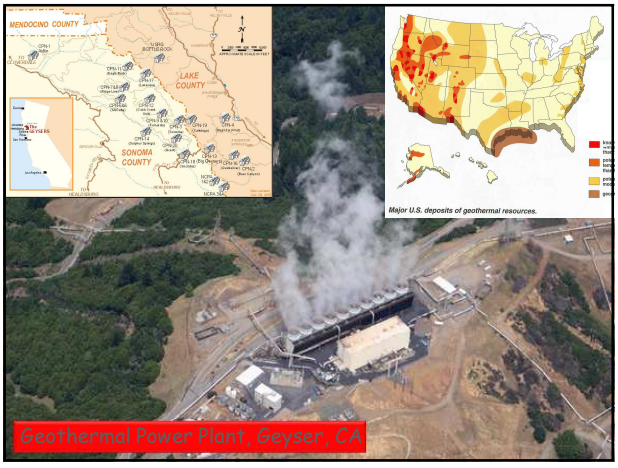
a. large supply / use waste products
b. moderate cost
c. if sustainable, no net CO_2

CONS:

a. potentially nonrenewable
b. environmental impact moderate → high
c. habitat / cropland loss
d. expensive


Geothermal Energy
generating station
Cold water pumped down
Steam and hot water
HOT
COOL


Geothermal Power Generation – Iceland

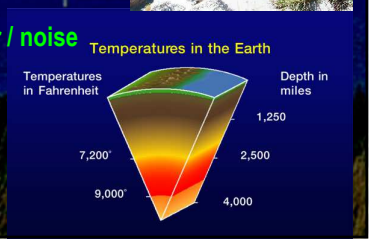

MENDOCINO COUNTY
LAKE COUNTY
SONOMA COUNTY
Major U.S. deposits of geothermal resources.
Geothermal Power Plant, Geyser, CA

PROS of Geothermal Energy

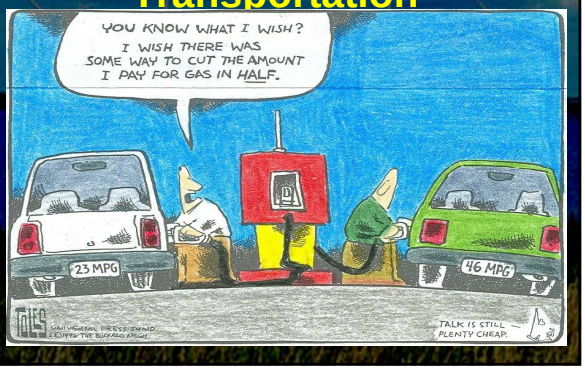
a. efficiency high
b. moderate cost
c. less CO_2 – moderate impact

CONS:

a. few suitable sites
b. air pollution / odor / noise

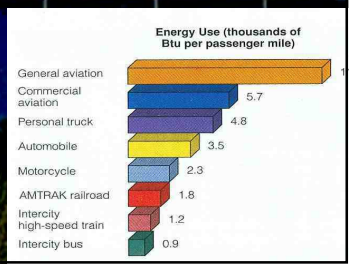


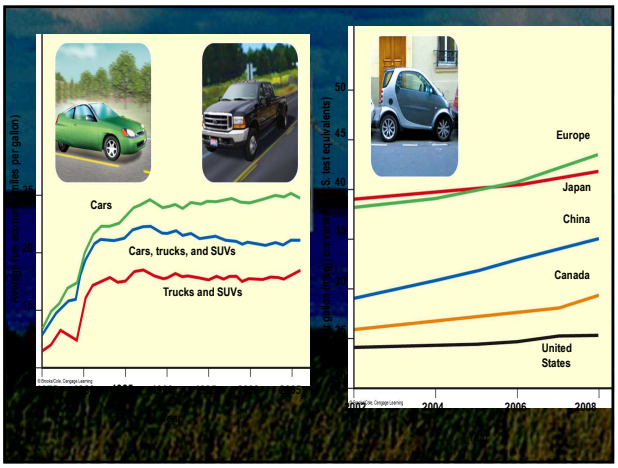
Increasing Efficiency in Transportation



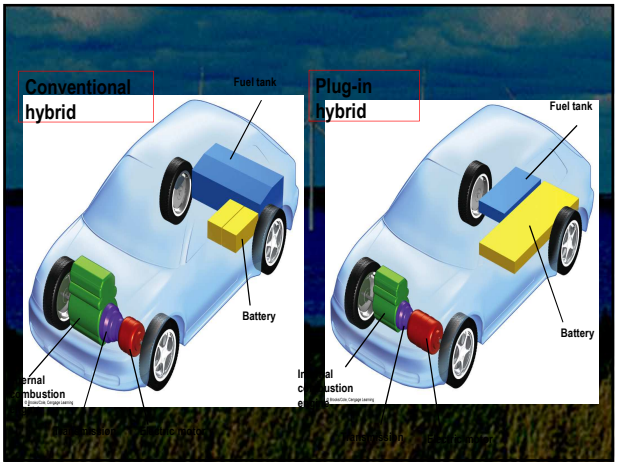
Improving Energy Efficiency in Transportation

a. better fuel economy
b. gas-guzzler tax
c. Use mass transit
d. Tax incentives for hybrids / plug-in hybrids / electric vehicles



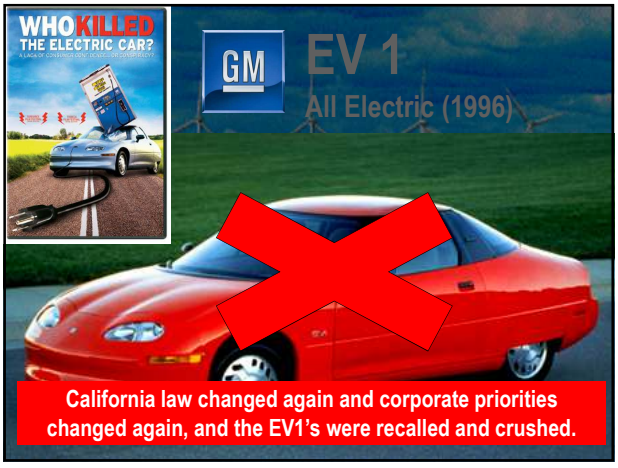

Cars
Cars, trucks, and SUVs
Trucks and SUVs
Europe
Japan
China
Canada
United States

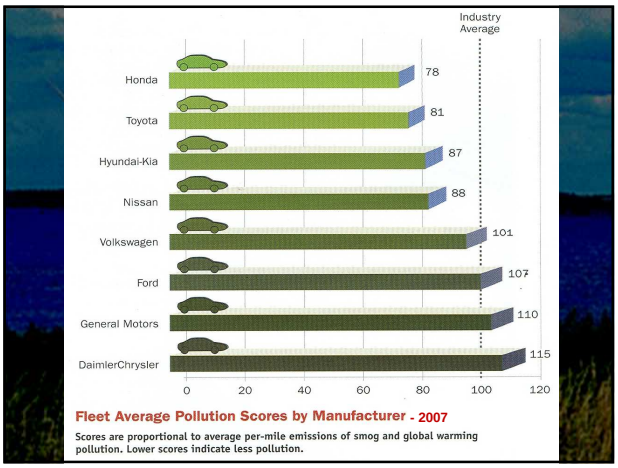

Toyota Prius
Hybrid – runs on both gas and electricity.
Honda Insight


Conventional hybrid
Fuel tank
Battery
Plug-in hybrid
Fuel tank
Battery


VOLT
NISSAN
LEAF
Electric Vehicles – Zero Emissions (with a catch)
TESLA
TESLA MOTORS


Figure 15-9
GM
Ultralite
California law required the building of a zero-emissions vehicle, so corporate priorities changed, the Ultralite concept was shelved


WHO KILLED THE ELECTRIC CAR?
GM
EV 1
All Electric (1996)
California law changed again and corporate priorities changed again, and the EV1's were recalled and crushed.

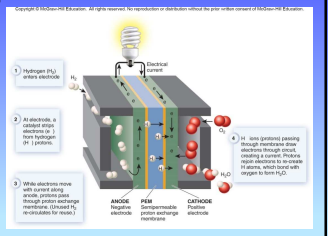


Fuel Cells

- Use ongoing electrochemical reactions to produce electric current.
- Similar to a battery but instead of recharging, add more fuel for the chemical reaction.
- Provides both electricity and water on space shuttle flights.

Fuel Cell

- Cathode (+) and anode (-) separated by electrolyte which allows ions to pass, but is impermeable to electrons.
- Hydrogen passed over anode where a catalyst strips an electron
- Electrons pass through external circuit, and generate electrical current.
- Hydrogen ion passes to cathode where it is united with oxygen to form water.



Fuel Cells

- Fuel cells provide direct-current electricity as long as supplied with hydrogen and oxygen.
  - Hydrogen can be supplied as pure gas, or a reformer can be used for safety (as hydrogen gas is explosive) to strip hydrogen from other fuels. Oxygen comes from air.
  - Fuel cells run on pure oxygen and hydrogen, and produce no waste products except drinkable water and radiant heat.
    - Reformer releases some pollutants, but far below conventional fuel levels.

Fuel Cells

- Typical fuel cell efficiency is 40-45%.
- Current is proportional to the size of the electrodes, while voltage is limited (1.23 volts/cell).
  - Fuel cells can be stacked until the desired power level is achieved. A fuel cell stack that could provide all the electricity for a home would be about the size of a refrigerator.
  - Tiny fuel cells running on methanol could be used in cell phones, toys, etc., instead of batteries.

Stationary Fuel Cell System

Courtesy of Long Island Power Authority

15.8: Hydrogen Fuel Cells

PROS:

a. from water / renewable
b. impact low
c. no GHGs
d. efficiency high

CONS:

a. net energy loss (need energy to split the Hydrogen from oxygen)
b. Needs fossil fuels for energy to split hydrogen.
c. cost high
d. no distribution system
e. long phase-in