PDHonline Course G289W (8 PDH)

Alternative and Renewable Energy Sources (8-Hour Program, Live Webinar)

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G289W
Alternative and Renewable Energy Sources

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INTRODUCTIONS

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Course Outlines

G289W
Energy Basics
Energy Statistics
Fossil Fuels
Solar Energy
Hydro Power
Wind Energy
Biomass Energy
Fuel Cells

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What is energy?

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Energy

- **The ability to do work;**
- **The amount of work that can be performed by a force;**
- **The total amount of work to accomplish a specific task**
- **Energy density varies by fuel type**
- **Energy efficiency is important because it describes how much waste is being generated in relation to the usable work that is being achieved**

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Forms of energy

Potential	Kinetic
Chemical Energy	Radiant Energy
Mechanical Energy	Thermal Energy
Nuclear Energy	Motion Energy
Gravitational Energy	Sound Energy
Electrical Energy	

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Potential Energy

- Stored energy and the energy of position.

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Chemical Energy

- Energy stored in the bonds of atom and molecules.
- Examples
  - Biomass
  - Petroleum
  - Natural gas
  - Coal
- Is converted to thermal energy when burned

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Mechanical Energy

- Energy stored in objects by tension
- Examples
  - Compressed springs
  - Stretched rubber

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Nuclear Energy

- Energy stored in the nucleus of an atom, the energy that holds atoms together
- Very large amounts can be released when atoms are combined or split apart
- Nuclear power plants split atoms – fission
- The sun combines atoms - fusion

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Gravitational Energy

- Energy stored in an object's height
- Higher and heavier an object, the more gravitational energy is stored
- Examples
  - A bike rolling down a hill
  - Hydropower

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Electrical Energy

- Energy stored in a battery and can be used to start something such as a cell phone or car
- Delivered by tiny charged particles called electrons, typically moving through a wire
- Example
  - Lightning

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Kinetic Energy

- Energy that involves motion such as waves, molecules, objects, substances

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Radiant Energy

- Electromagnetic energy that travels in transverse waves
- Examples
  - Visible light
  - X-rays
  - Gamma rays
  - Radio waves
  - Sunshine

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Thermal Energy

- Heat
- Vibration and movement of atoms and molecules within substances
- As an object is heated, its atoms and molecules collide faster
- Example
  - Geothermal energy (thermal energy in the Earth)

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Motion Energy

- Energy stored in the movement of objects
- The faster they move, the more energy is stored
- It takes energy to get an object moving and energy is released when it slows down
- Example
  - Car crash

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Sound Energy

- Movement of energy through substances in longitudinal waves involving compression and refraction
- Sound is produced when a force causes an object or substance to vibrate, energy is transferred in a wave
- Energy in sound is usually less than other forms of energy

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What is Power?

- The speed with which energy is expended to achieve a task;
- More power means the task is accomplished quicker;
- Measured as energy per unit of time

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Key energy principles

- Any form of energy can be transformed into another form
  - Limits to conversion efficiency (2nd law of thermodynamics)

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Laws of thermodynamics

- 1st Law
  - Total energy may not be created nor destroyed. It can only be transformed to another form.
- 2nd Law
  - Every energy conversion produces at least as much waste as it does useable energy (law of entropy)

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1st Law consequences

- All energy goes into heat and is eventually radiated out into space.
- Energy transfer can take many forms
- The total energy into the system must equal the total energy out of the system plus the change in energy contained within the system

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2nd Law Consequences

- There is no process in which the only result is to transfer heat from a cold source to a hot source (Clausius)
- There is no process in which it is possible to produce work using a constant-temperature heat source (Kelvin, Planck)
- Waste is inevitable

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Carnot Principle

- The maximum theoretical yield for producing work in a reversible cycle operating between two heat sources is given as 1- (temperature of the cold source/temperature of the hot source); in other words, the greater the difference between the cold and hot source, the more efficient the system is.

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Examples of Carnot principle

- A steam engine working in a cold climate is more efficient than in a hot climate
- Residential natural gas heaters work better when the gas is burned at a hotter temperature
- A steam engine with a hotter fire is more efficient
- Wood stoves work much better than open pit fireplaces because the burn temperature inside of a stove can be much greater than in an open pit
- The most efficient engine is a jet turbine

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Types of efficiencies

- Energy efficiency
  - The ratio of the useful work obtained from a process by the raw power taken to achieve that process
- Fuel efficiency
  - The amount of miles that can be driven by a gallon of gasoline
- Operating efficiency
  - Efficiency of all the individual parts that comprise a whole
- Cost efficiency
  - Cost of accomplishing a task divided by the amount of work that is done
- Pollution efficiency
  - Amount of work performed by a process divided by the amount of pollution generated by that process

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Energy Efficiency

- The amount of useful energy from any type of system
- Always lose energy when converting from one type to another
- Most energy transformations not very efficient
- Example
  - Human body only convert 5% of the food energy consumed to useful energy (95% is lost as heat)

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Pollution efficiency

- Pollution efficiency of electrical power is terrible
- More compelling than cost efficiency as a reason to support alternative energy sources
- Carbon taxes are a way to converge the cost efficiencies of fossil fuels and alternatives in order to make alternative sources more financially attractive

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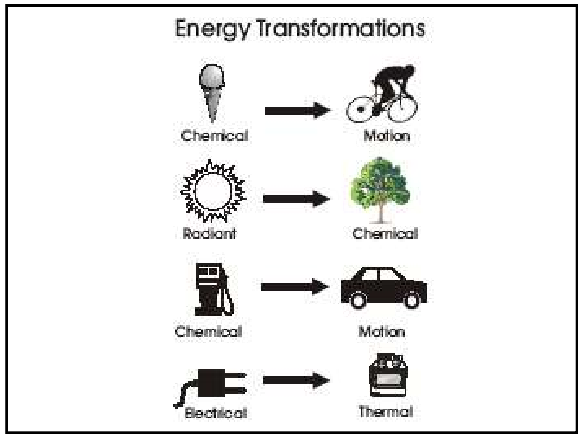

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Internal energy

- Internal energy is the sum of all microscopic forms of energy in a system
- Types of internal energy
  - Sensible energy
  - Latent energy
  - Chemical energy
  - Nuclear energy
  - Energy interactions
  - Thermal energy

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Sensible energy

- The portion of internal energy of a system associated with kinetic energies of the molecules, such as
  - Molecular translation
  - Rotation
  - Vibration
  - Electron translation and spin
  - Nuclear spin

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Latent energy

- The internal energy associated with the phase of a system

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Chemical energy

- The internal energy associated with the different kinds of aggregation of atoms in matter

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Nuclear energy

- The internal energy associated with the strong bonds within the nucleus of the atom itself

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Energy interactions

- The types of energies that are not stored in the system but are recognized at the system boundary as they cross it, representing gains or losses by a system during a process. These include
  - Heat transfer
  - Mass transfer
  - Work

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Thermal energy

- The sum of the sensible and latent forms of internal energy

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Units of measure

- **Joule**: the basic unit of energy measurement in the SI system
- **British Thermal Unit (BTU)**: the amount of heat necessary to raise 1 pound of water 1º F
- **Watt**: Power is energy divided by time
- **Horsepower**: Traditional measure of power
- **Calorie**: The amount of energy required to raise the temperature of one gram of pure liquid water by exactly one degree Celsius
- **Quad**: A large amount of energy equivalent to 10^{15} BTUs
- **Therm**: 10^5 BTUs
- **Kilowatt-Hour (kWh)**: electrical power rating
- TW: terra watt ($1x10^{12}$ watts)

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Equivalencies

1 kWh = 3.6 Megajoules

1 BTU = 1055.06 joules

1 Quad – 10^{15} BTU

1 Therm = 10^5 BTU

1 cal = 4.184 joules

1 Horsepower = 746 watts – 0.746 kW

1 W = 1 joule/second = 3.412 BTU/h

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Degree days

- Unit that compares the outdoor temperature to a standard day of 65°F
- Can evaluate the increase or decrease in the heating and/or air conditioning bills from year to year

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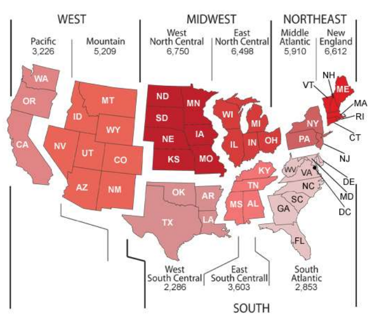
Heating Degree Days by Census Region



Source: Energy Information Administration, *Annual Energy Review*, Table 8.9. (June 2008)

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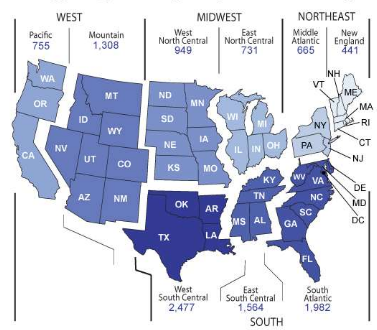
Cooling Degree Days by Census Region



Source: Energy Information Administration, *Annual Energy Review 2008*, Table 1.10

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Energy Statistics

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US Statistics

- In 2000, per capita energy consumption in US was 230 kWh/day
- Current energy demand is 100 quadrillion BTUs
- Energy usage is for
  - Direct heating
  - Turning shafts to make electricity
  - Turning shafts to move automobile
- US oil production is 10 million barrels/day

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Energy densities

Home heating oil	18,921 BTUs/Pound
Natural gas	22,000 BTUs/Pound
Propane	22,584 BTUs/Pound
Gasoline	20,605 BTUs/Pound
Kerosene	20,000 BTUs/Pound
Coal	10, 500 BTUs/Pound
Wood	10,000 BTUs/Pound
Electricity	3,413 BTUs/kWh
Hydrogen	52,000 BTUs/Pound
Enriched uranium	33 billion BTUs/Pound
Battery	60 BTUs/Pound

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Real cost of power

- Americans have spent over $400 billion per year on raw fuel
- Raw costs reflects the cost when delivered
- Actual costs include burning and combusting in order to extract the energy contained in them

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Energy costs ($/ million BTUs)

	Raw	Actual
Electricity	29.30	29.30
LPG	18.54	23.18
Gasoline	15.19	75.96
Kerosene	11.11	13.89
Heating oil	10.82	13.52
Natural gas	10.00	12.05
Coal	9.52	15.87
Wood	7.50	12.50
Uranium	0.00033	0.024

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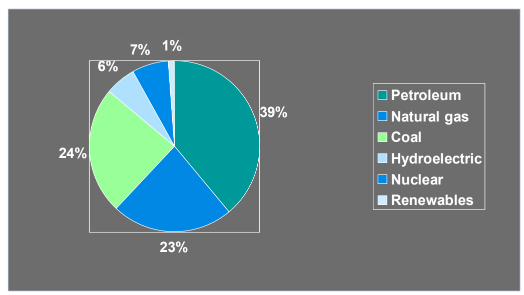
World Power Sources, 2002



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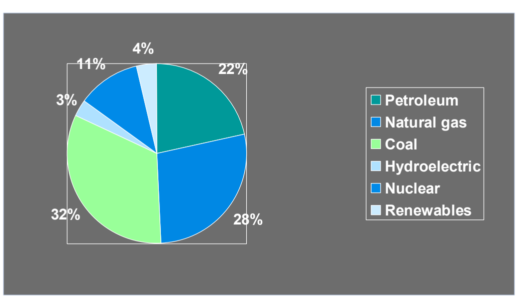
US Power Sources, 2002



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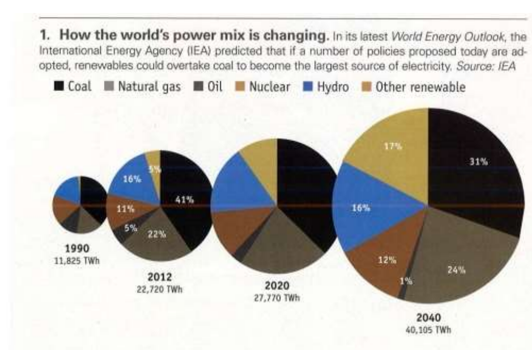

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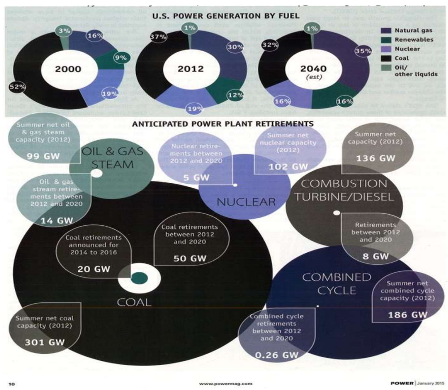

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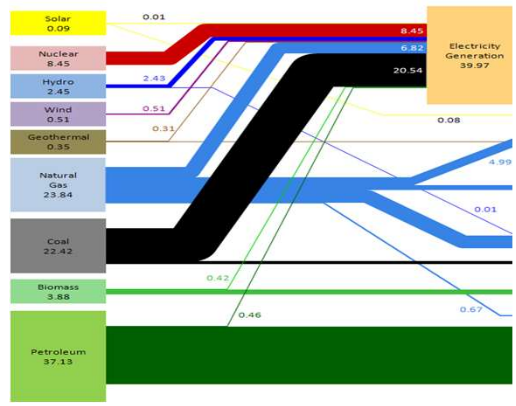

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Energy consumption/per person/yr (MMBTU)

US	339
Canada	418
Mexico	65
Western Europe	149
India	13
China	33
Japan	172

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Global availability of fossil fuels

Coal	39,000
Oil	18,900
Gas	15,700
LPG	2,300
Shale	16,000
Uranium 235	2.800

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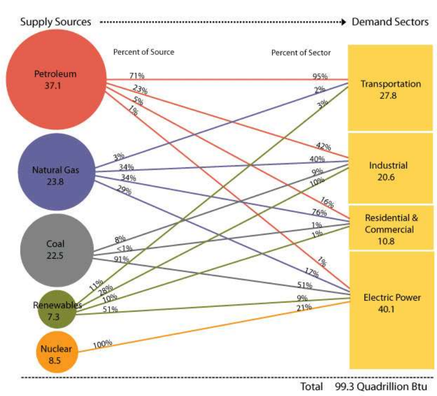

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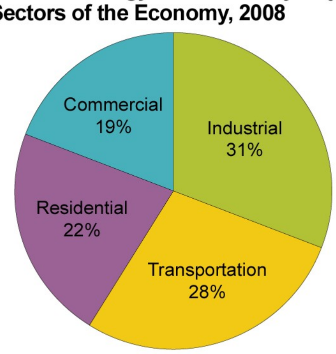
Share of Energy Consumed by Major Sectors of the Economy, 2008



Source: Energy Information Administration, *Annual Energy Review 2008.*

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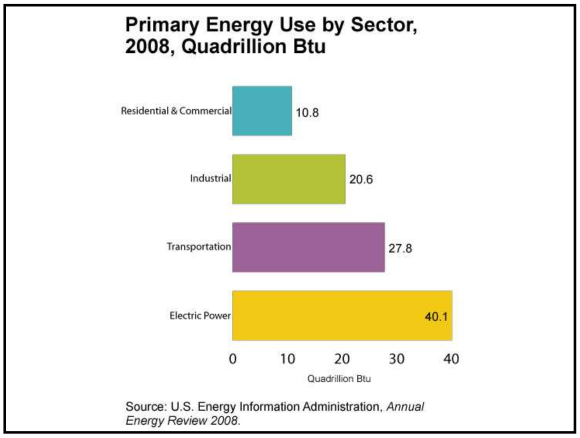

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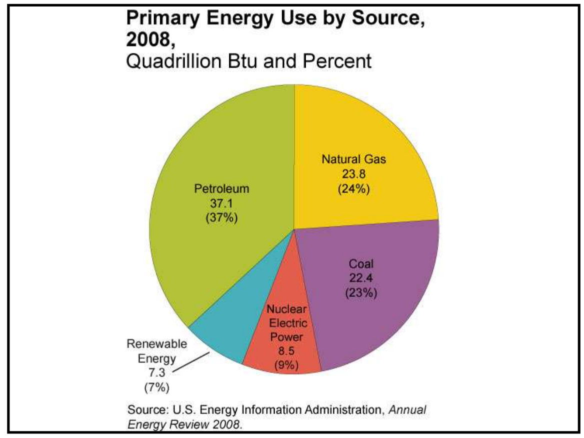

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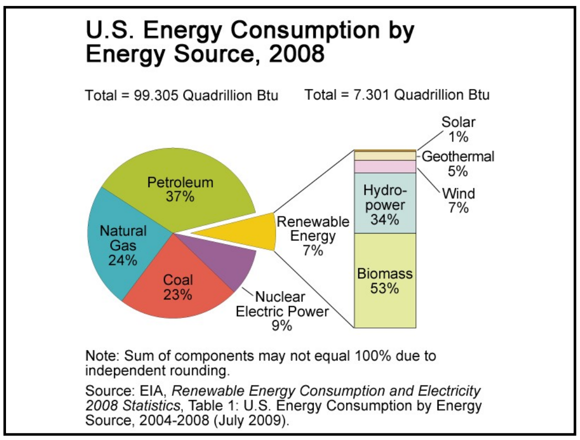

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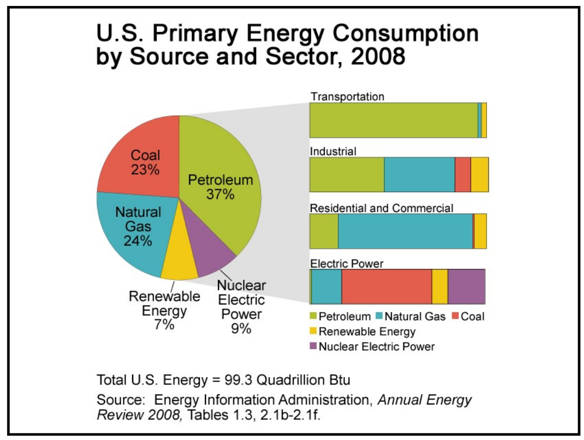

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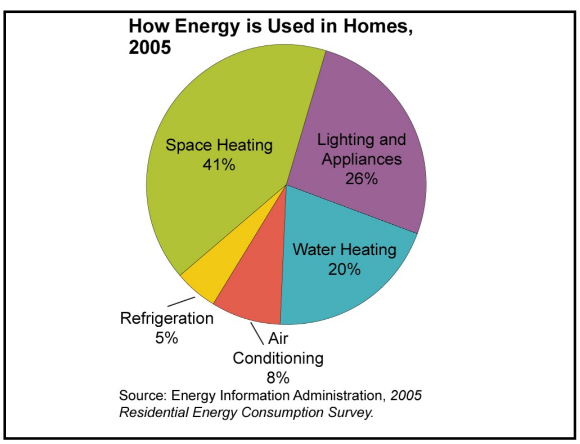

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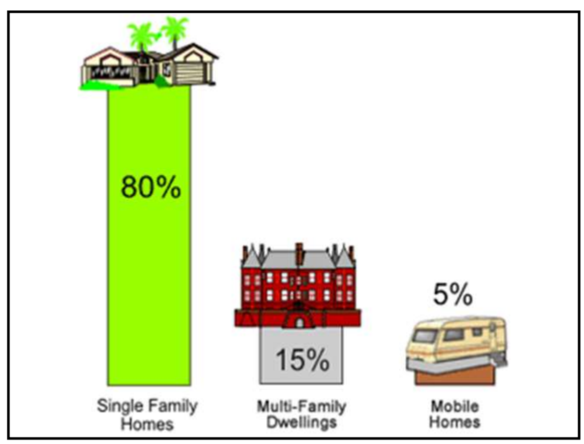

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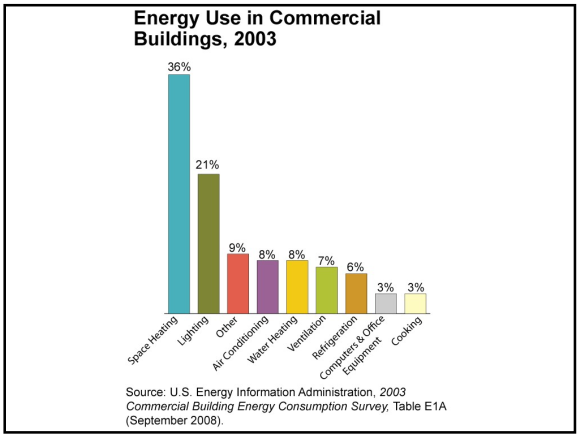

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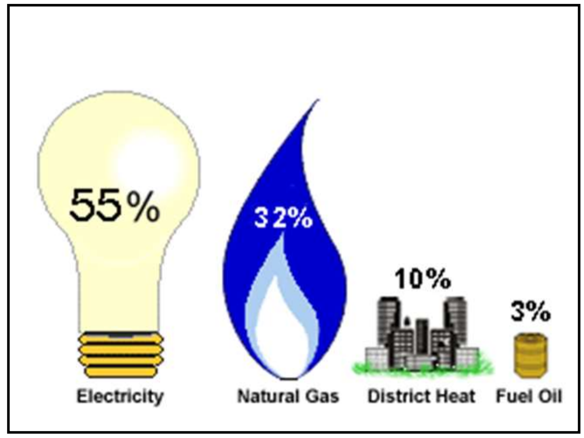

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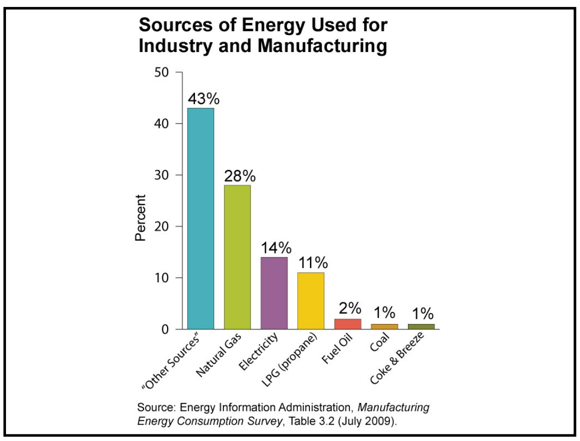

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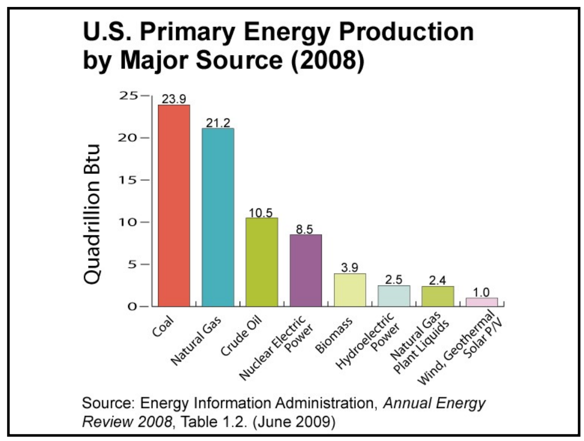

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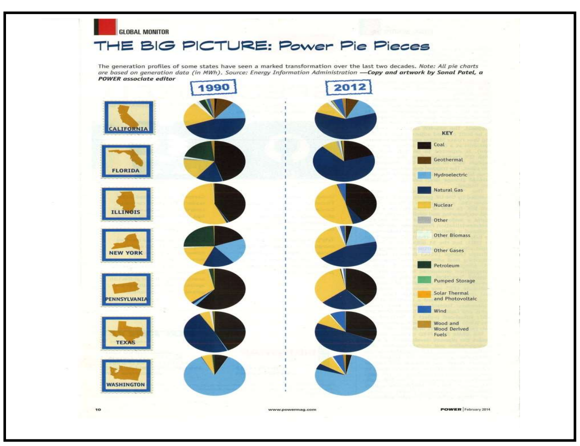

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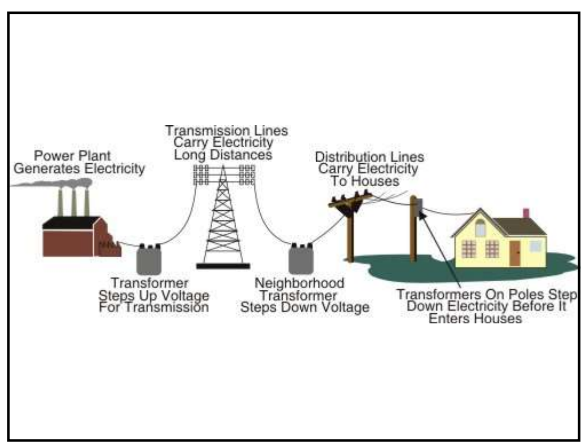

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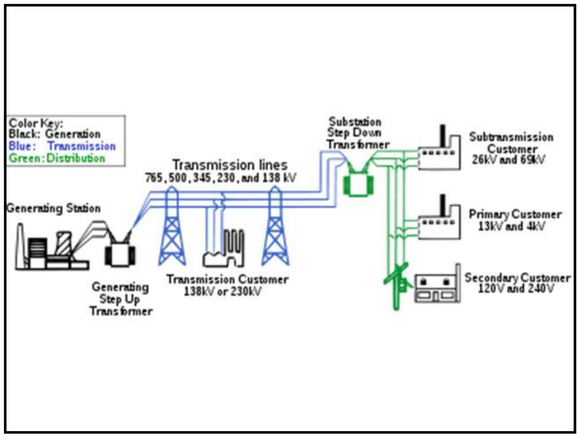

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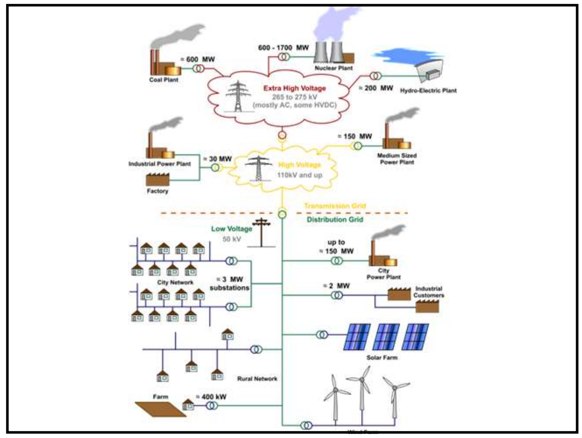

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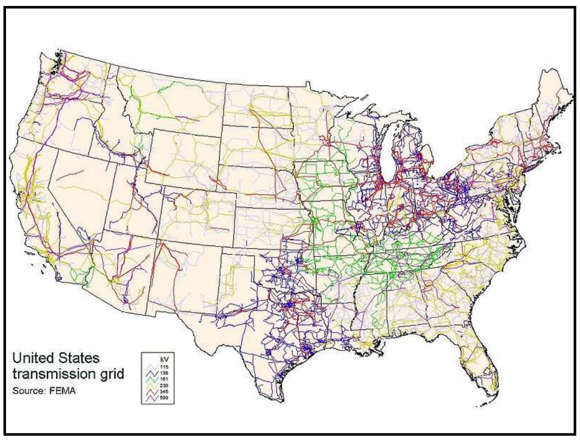

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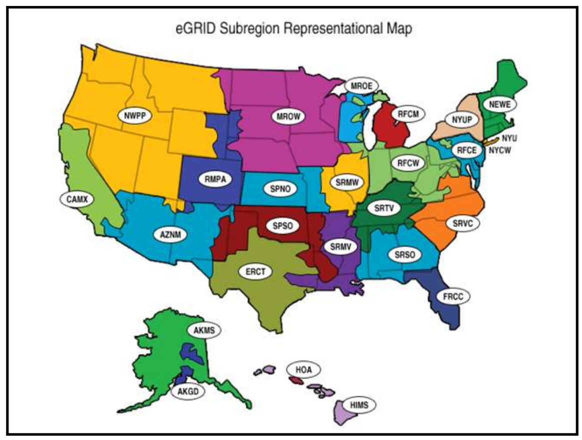

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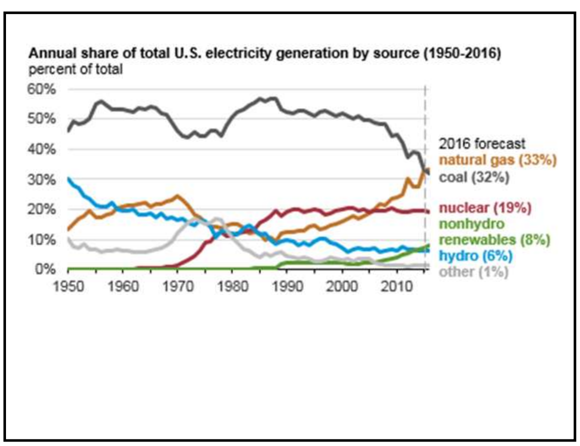

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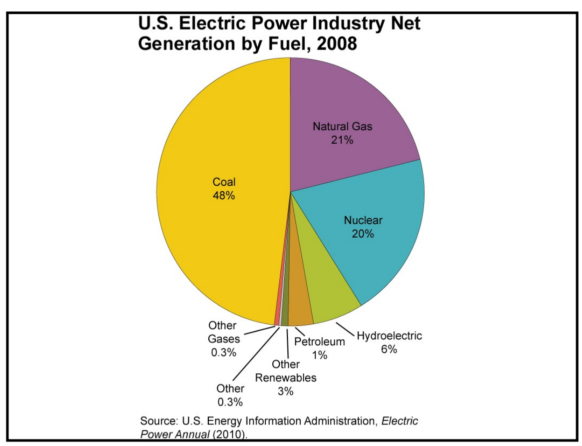

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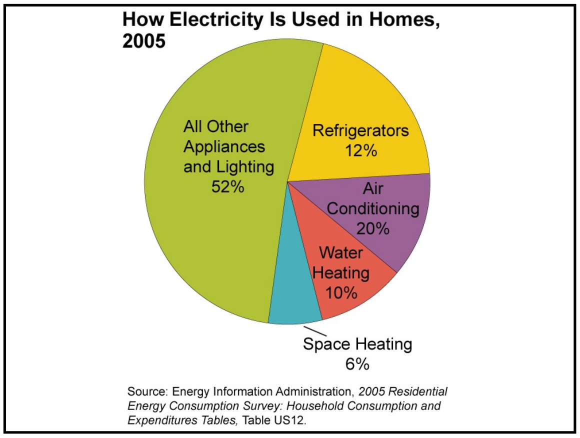

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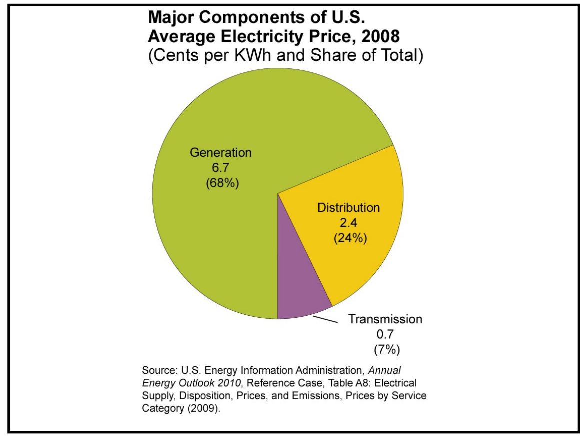

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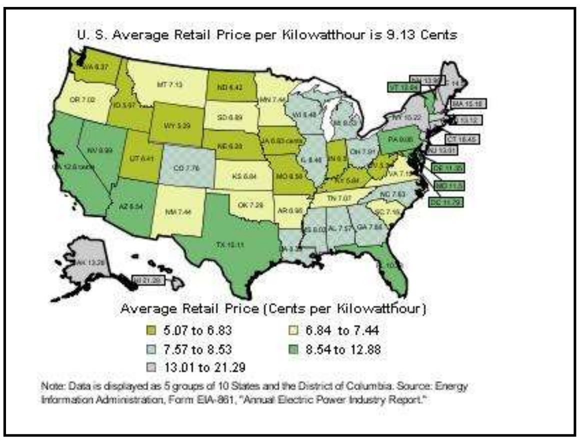

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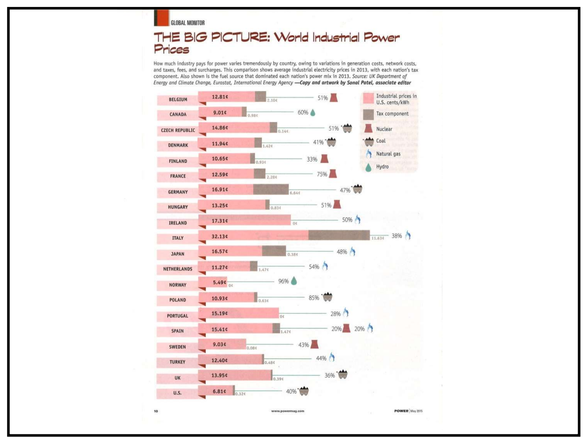

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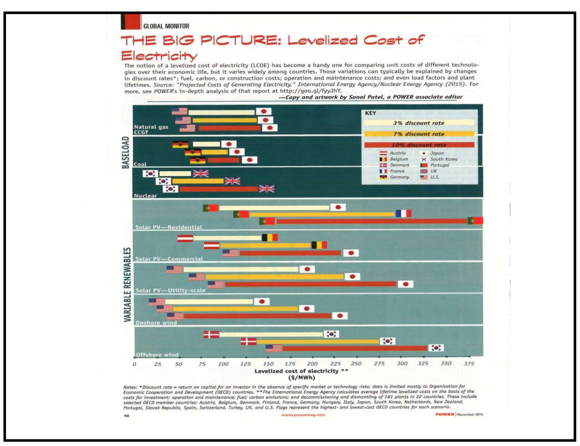

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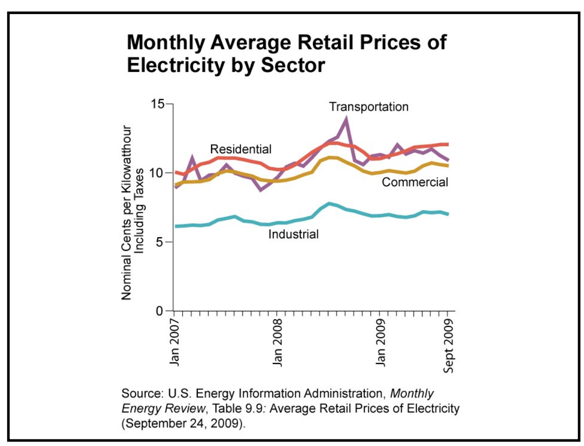

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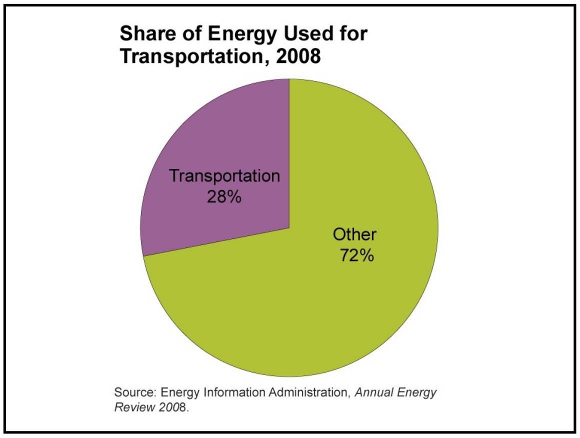

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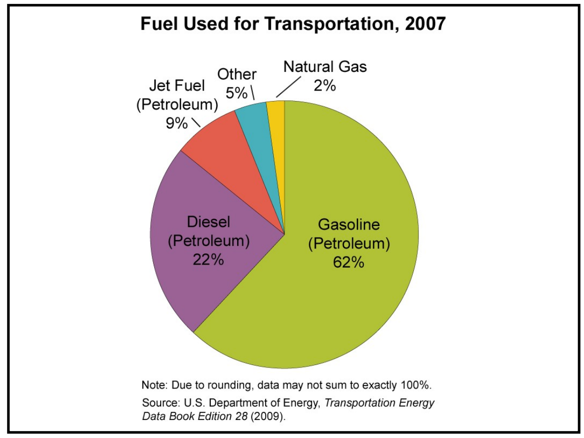

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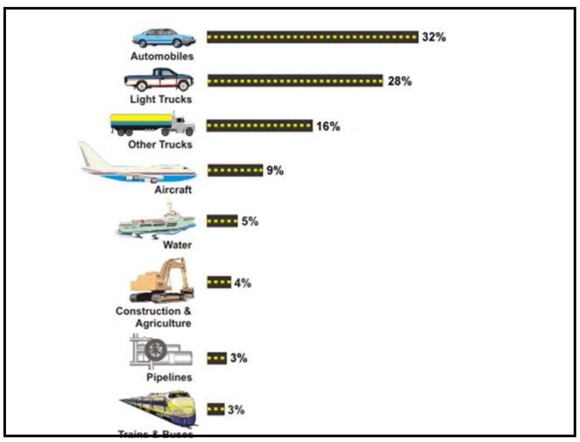

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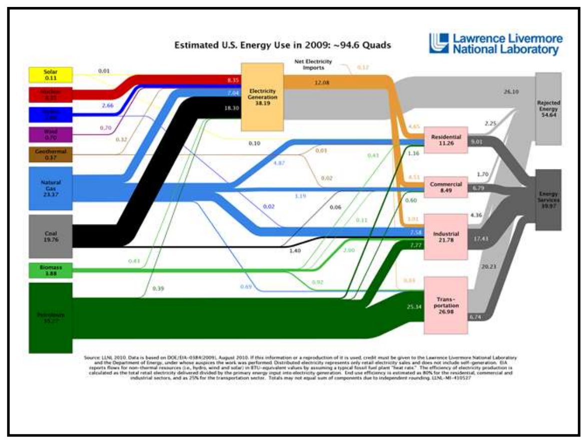

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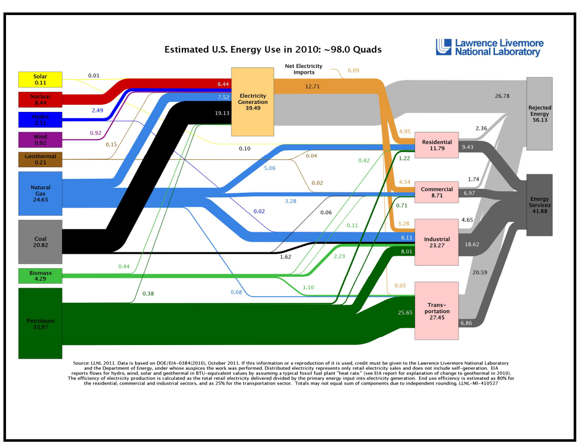

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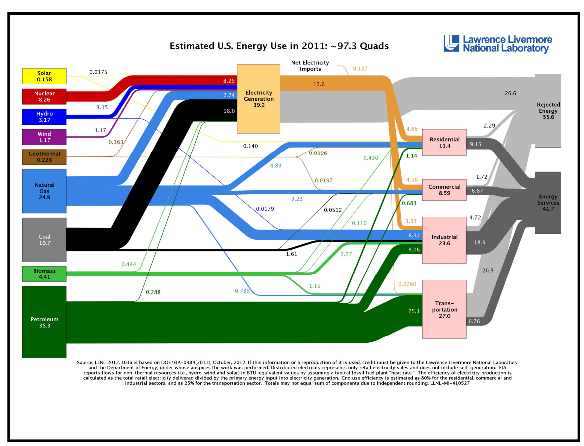

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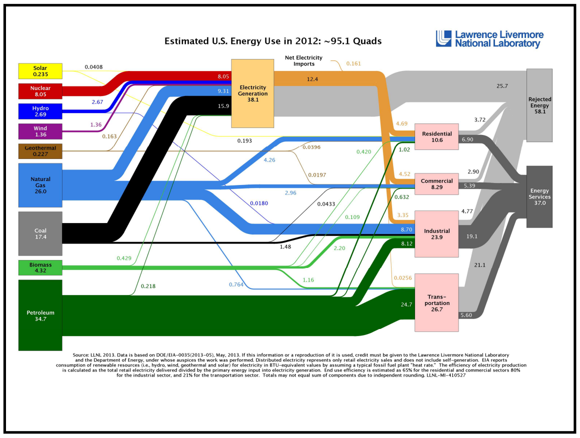

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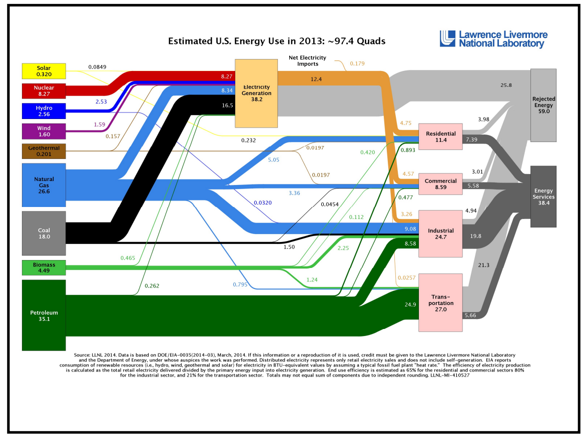

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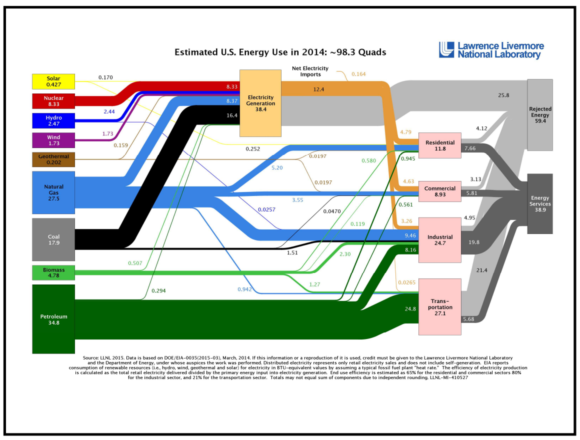

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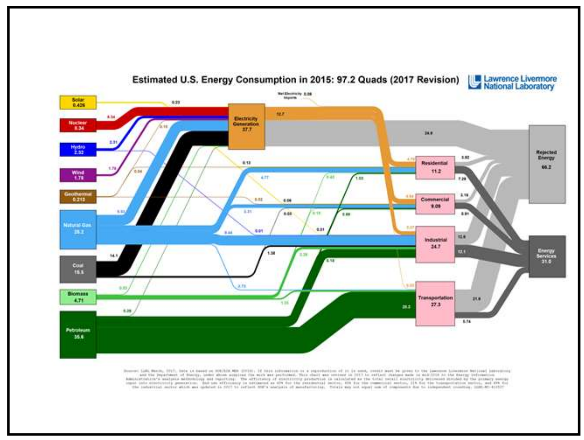

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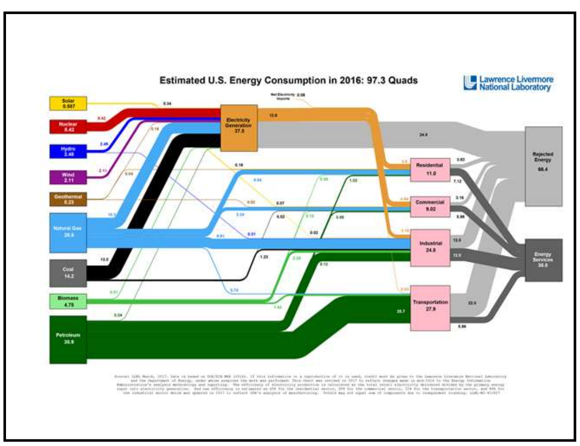

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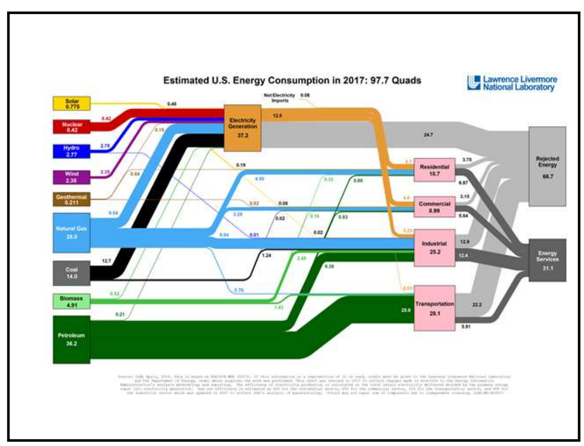

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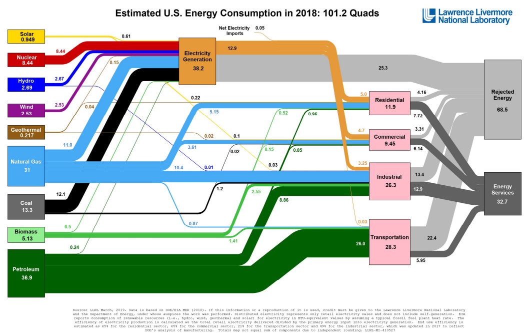

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Total U.S. Energy, 2009-2018 (Quads)

Year	Total Energy (Quads)
2009	94.6
2010	98.0
2011	97.3
2012	95.1
2013	97.4
2014	98.3
2015	97.2
2016	97.3
2017	97.7
2018	101.2

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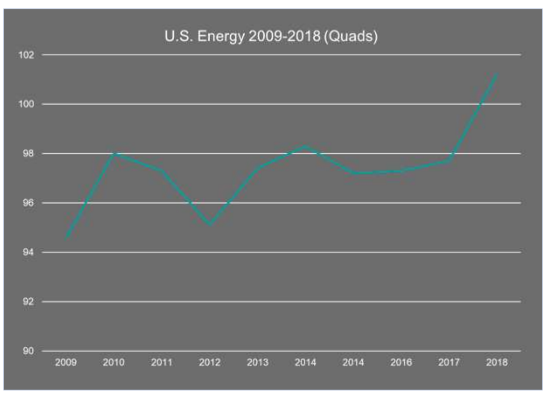

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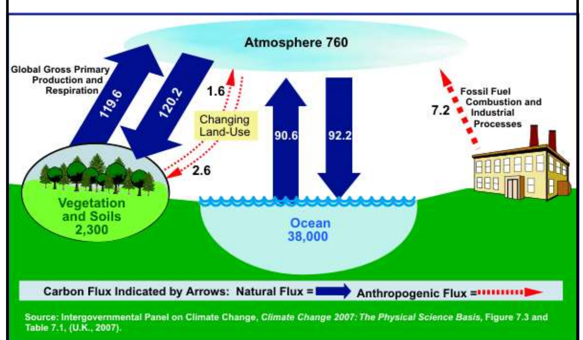

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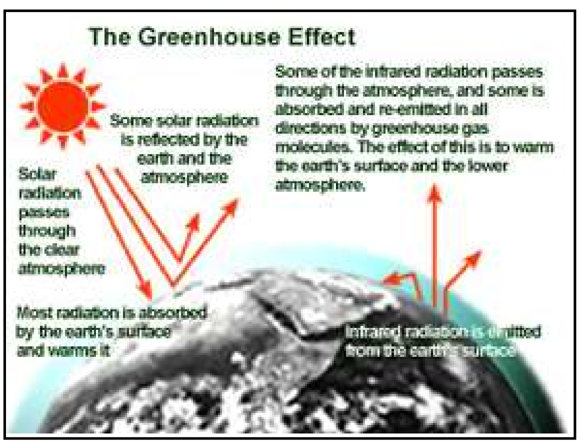


95

Evidence of global warming

- Endangering wildlife
- Shifting agricultural centers
- Melting ice shelves and glaciers
- Mounting violence in weather
- Rising sea levels

96

Greenhouse Gases

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Water vapor (H_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexaflouride (SF_6)

97

Carbon pollution of fuels (pounds CO_2/Unit)

Oil	22.4/gal
Natural gas	12.1/BTU
Propane	12.7/gal
Kerosene	21.5/gal
Gasoline	19.6/gal
Coal	4,166/ton
Electricity	1.75/kWh
Wood	3,814/ton

98

Hydrogen/Carbon

- All fossil fuels contain hydrogen and carbon
- Hydrogen provides the useful energy
- Carbon leads to waste
- When carbon burns completely it forms carbon dioxide (CO_2)
- Gasoline, heating oil and propane are 80% carbon by weight
- Natural gas is 75% carbon
- Hydrogen has little carbon
- Higher the H/C ratio the cleaner burning the fuel is

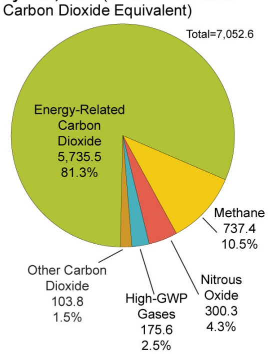
99

Carbon/Hydrogen content

Wood	9.0
Coal	1.63
Oil	0.56
Octane	0.44
Methane	0.25
Hydrogen	0.0

100

U.S. Greenhouse Gas Emissions by Gas, 2008 (Million Metric Tons Carbon Dioxide Equivalent)



Source: EIA estimates, published in *Emissions of Greenhouse Gases in the United States 2008* (December 2009).

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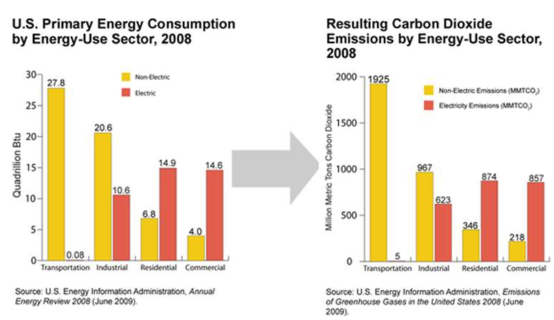

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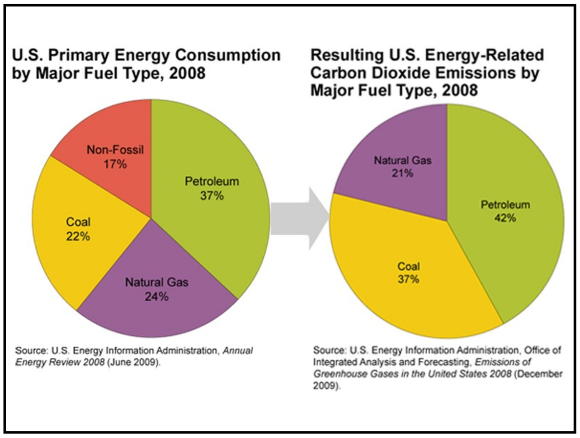

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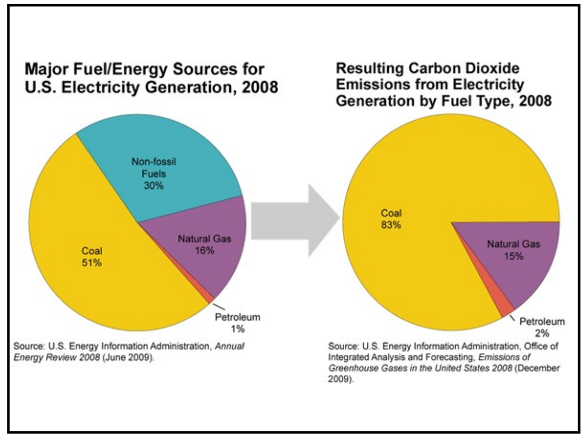

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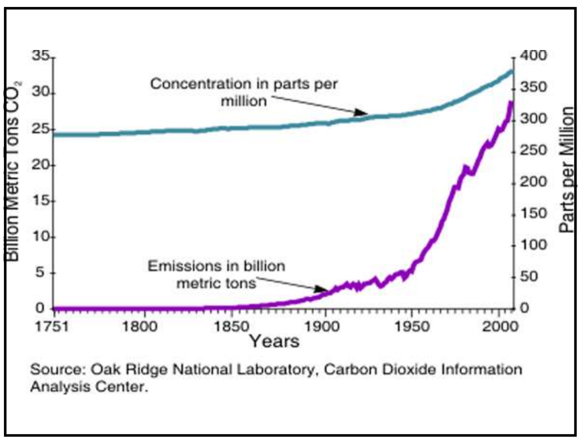

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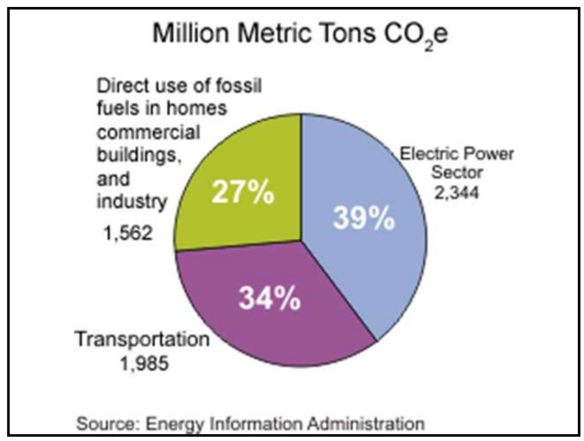

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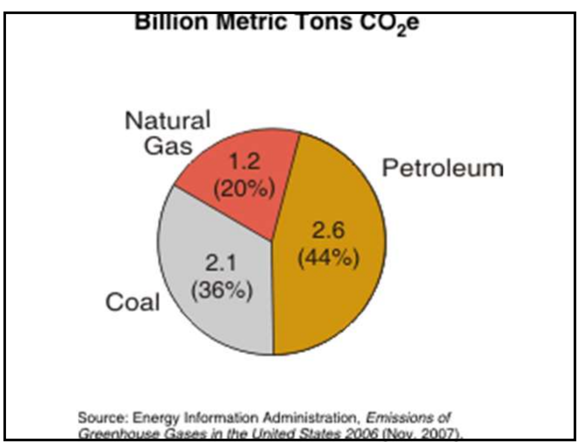

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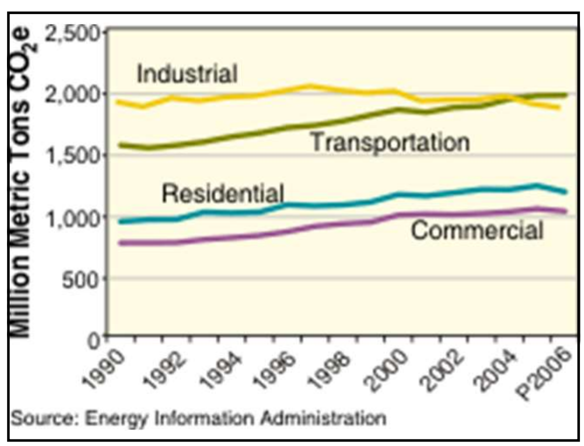

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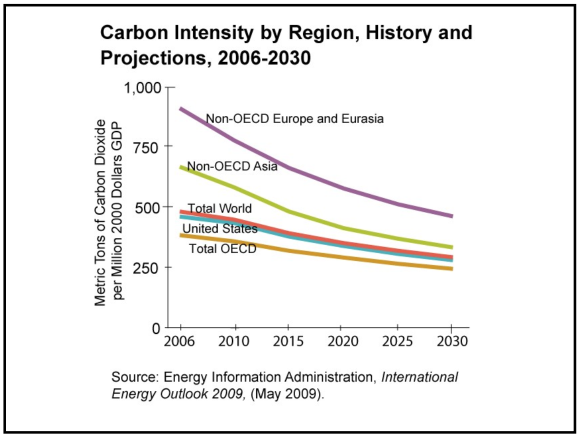

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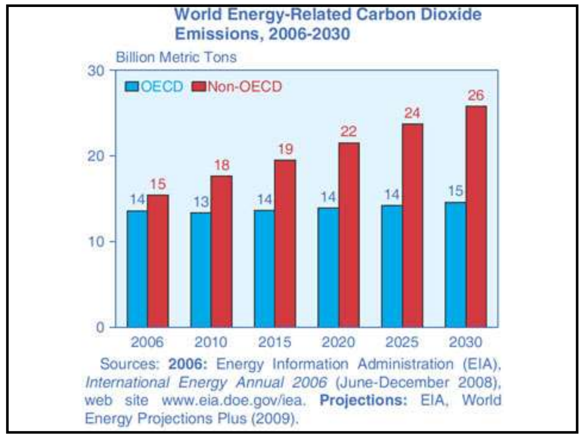

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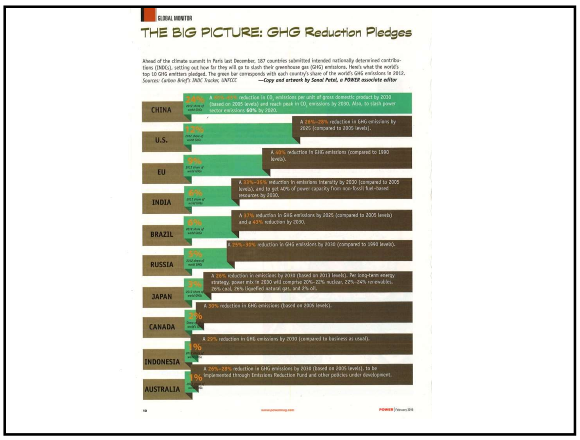

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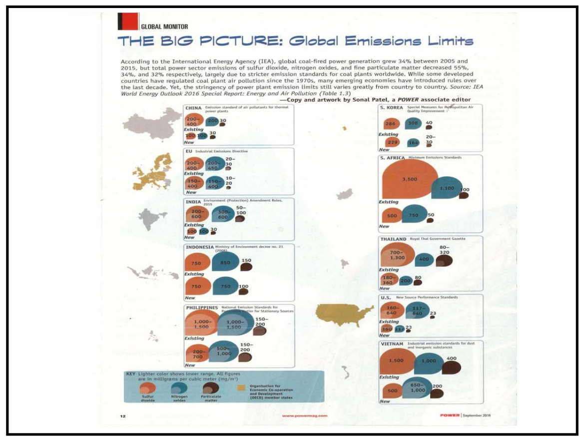

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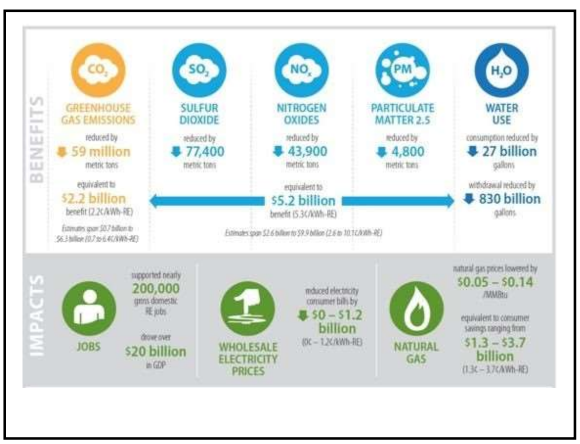

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Energy Sources

- Fossil fuel
- Renewable
- Other
- Almost all derived from solar energy

114

Fossil Fuels

Coal | Petroleum | Natural Gas

Derived from organisms primarily ocean plankton that grew over several hundred million years ago, storing the solar energy that reached the earth's surface.

115

Renewable Sources

Hydro | Solar | Biomass | Wind

Directly or indirectly derived from current solar energy

Note: not all renewable energy is good for the environment

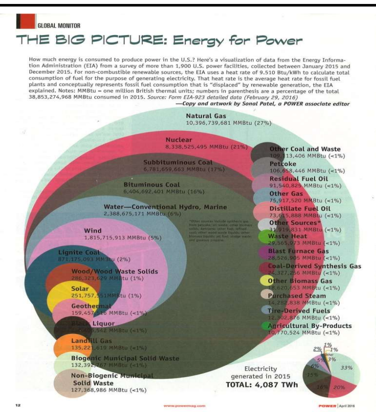
116

Other

Geothermal | Nuclear

Derived from uranium nuclei contained in the earth (nuclear) that existed when the solar system was formed or residual heat created from the nuclear decay of uranium within the earth (geothermal)

117



118

Oil and Natural Gas

- Formed from atoms of carbon and hydrogen
- Produced during a process that lasted several million years
- Derived from ocean biomass mostly plankton that grew due to solar energy
- Produced from deceased sea organisms, such as zooplankton, phytoplankton, shellfish, algae, animals buried in sand and mud

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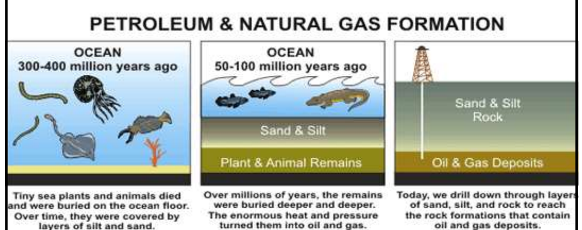

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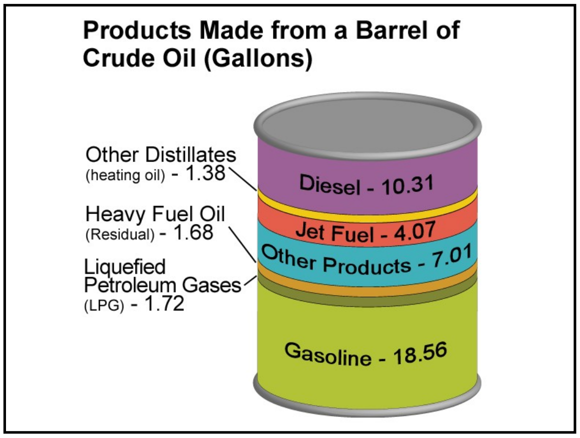

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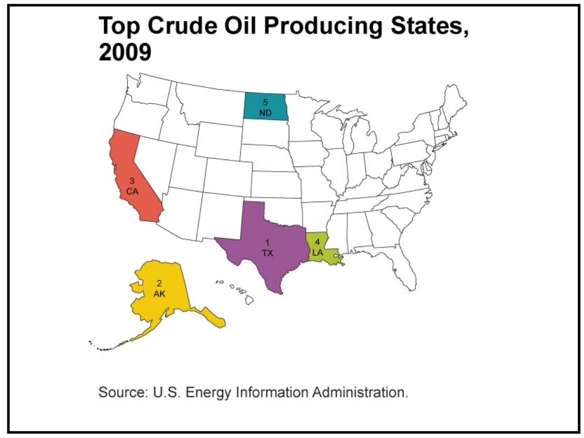

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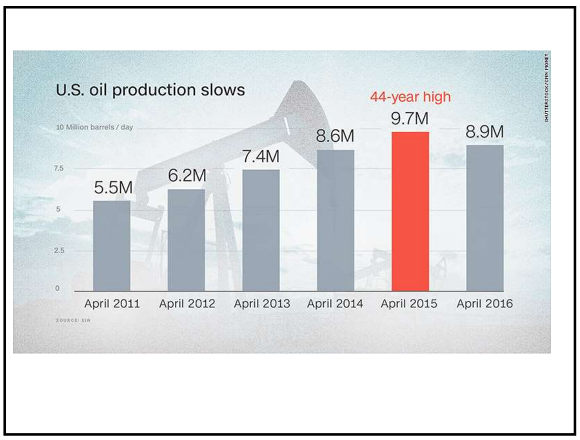

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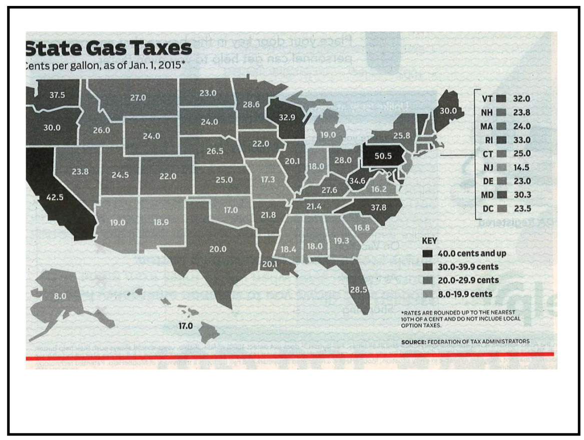

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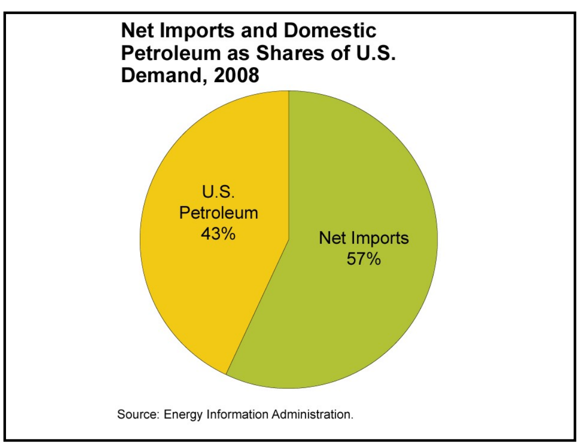

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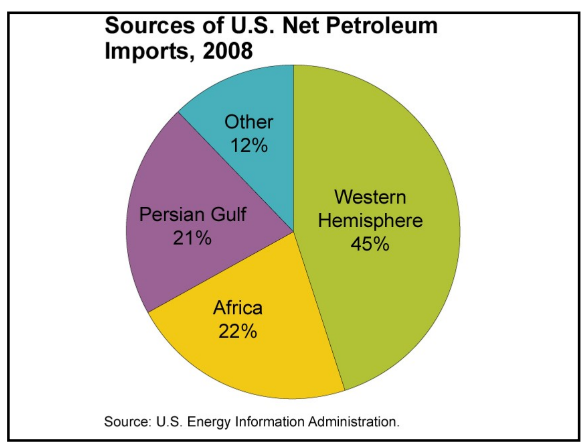

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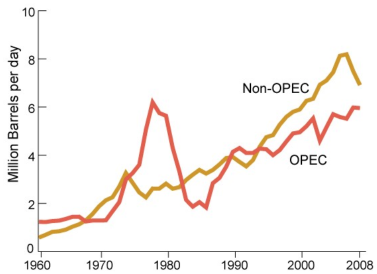
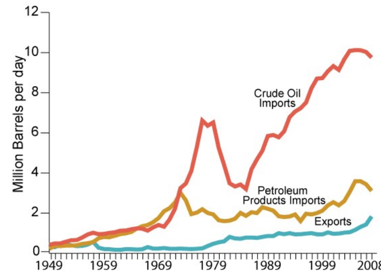
Petroleum Imports from OPEC Are Less than Imports from Non-OPEC Countries



Source: Energy Information Administration, *Annual Energy Review* (June 2009).

127

U.S. Petroleum Trade



Source: Energy Information Administration, *Annual Energy Review* 2008.

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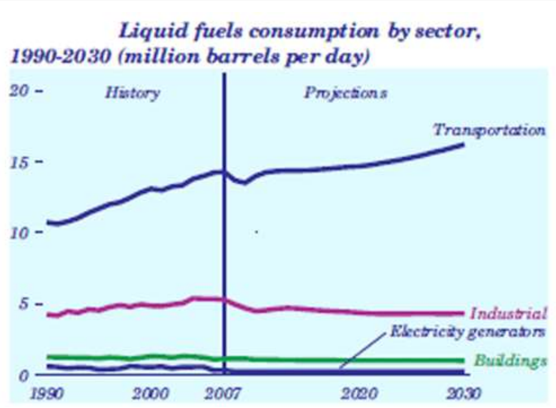
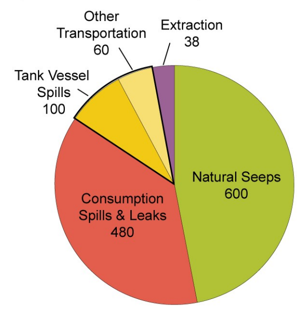


129

Average Annual Contribution from Major Sources of Petroleum in Worldwide Marine Waters, 1990-1999
(thousands of metric tons)



Source: Based on data from *Oil in the Sea III* from the National Research Council (2002).

130

Fuel oil for heating

- Advantages
  - No pipeline required
  - Relatively safe fuel
  - Obvious signs when the system malfunctions
  - High energy density fuel
  - Small systems are practical
  - Heating oil can easily be mixed with biofuels
- Disadvantages
  - When tank goes empty, there is no heat
  - Price is directly related to price of crude
  - Many systems require electricity to operate

131

Gasoline engines

- Advantages
  - Gas has a very high energy density
  - Engines are very powerful given their size and weight
  - Engines can operate over a wide range of temperatures
  - Existing infrastructure supports it
- Disadvantages
  - Combustion produces too much carbon
  - Gas is dangerous
  - Sulfur compounds in gasoline contribute to acid rain
  - Cause noise pollution
  - Gas prices are very volatile
  - Gas additives can cause cancer

132

Diesel engines

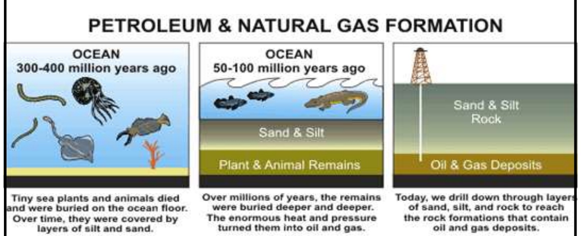
- Advantages
  - More energy dense than gasoline
  - Sometime cheaper than gasoline
  - Diesel can deliver more power than gasoline
  - Combustion is more efficient
  - Combustion produces less CO than gasoline
  - Engines are more reliable than gas engines
- Disadvantages
  - Diesel contains more sulfur than gasoline
  - Exhaust smells
  - Engines are difficult to start
  - Diesel become gelatinous in cold temperatures
  - Diesels fuels are carcinogenic

133

Oil fired power plants

- Advantages
  - Safer than methane plants
  - Oil supply lines are more prevalent
  - Oil is a high energy dense fuel
  - More efficient per unit of weight of fuel
  - Combustion turbines can be modified to accept other fuels such as coal
- Disadvantages
  - Rare to find one of these
  - Pollution levels are high
  - Overall efficiency is less than a combined cycle system

134



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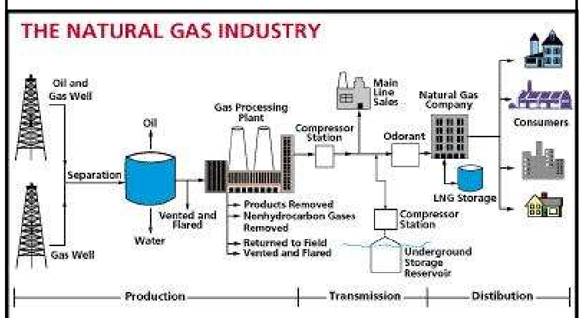

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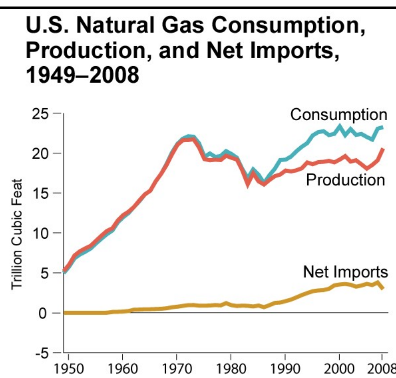

Source: Energy Information Administration, *Annual Energy Review 2008*, Table 6.1 (June 2009).

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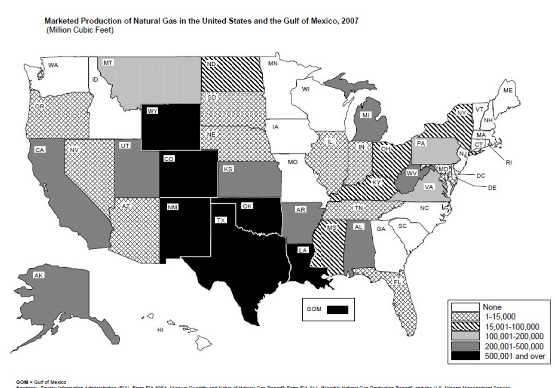

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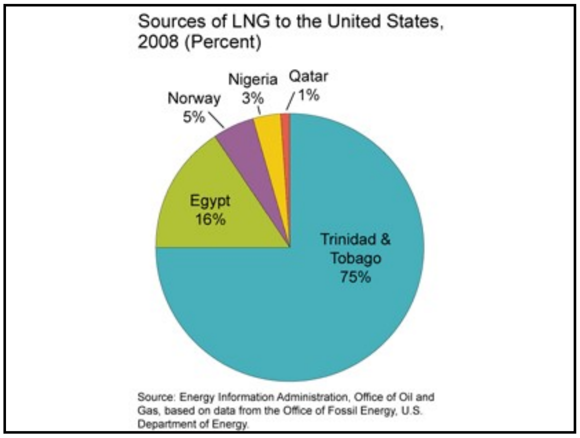

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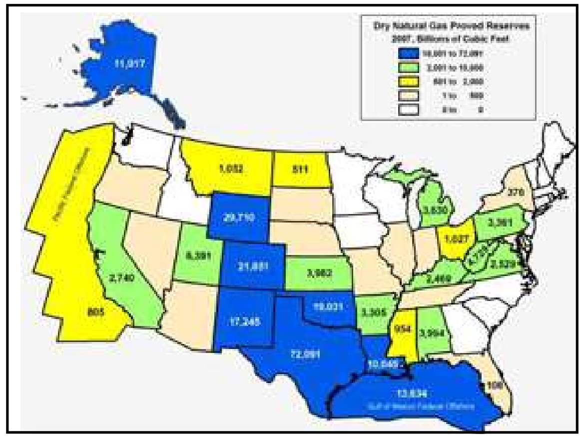

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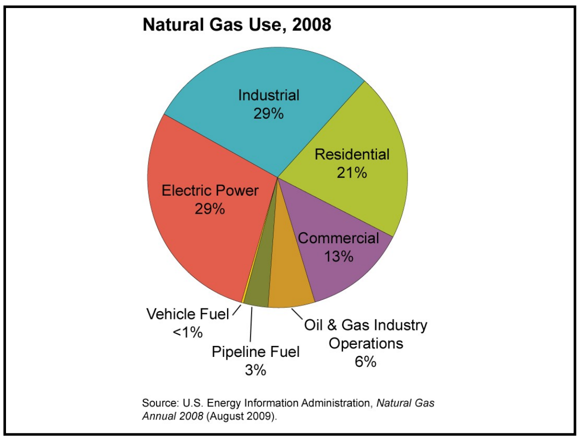

141

International Energy Agency

- Golden Rules for a Golden Age of Gas
  - To be released November 12, 2012
  - Covers unconventional gases such as shale gas, tight gas and coal bed methane
  - If follow rules, demand will rise 50% from 2010 to 2035

142

Golden Rules

- Measure, disclose and engage
- Watch where you drill
- Isolate wells and prevent leaks
- Treat water responsibly
- Eliminate venting, minimize flaring and other emissions
- Be ready to think big
- Ensure a consistently high level of environmental performance

143

Natural gas for heating

- Advantages
  - Very efficient wrt useable heat energy
  - Low in pollution compared to other fossil fuels
  - Exhaust gases are easily vented
  - Readily available in most cities
  - Heaters produce very little smoke and soot
- Disadvantages
  - Methane leaks are dangerous
  - Price volatility is the worst of all fossil fuels
  - Pipelines are not available in rural areas
  - Most systems require electricity to operate

144

Natural gas fired power plants

- Advantages
  - Emits lower CO_2, CO, NOx and SOx than other fossil fuels
  - Very efficient
  - Methane is readily available
  - Pipelines supply the raw fuel
  - Can be modified to burn hydrogen
- Disadvantages
  - Methane is dangerous
  - Price spikes are common
  - Exploration/recovery damages the environment
  - Does produce CO_2

145

Propane for heating

- Advantages
  - Can be used nearly anywhere
  - Supplies are readily available
  - Not water soluble little risk of groundwater contamination
  - Off-grid homes generally use it
- Disadvantages
  - Price/unit of output is generally higher than most other forms
  - Energy density is low
  - Cold temperatures affect the conversion of liquid to gas
  - Interior walls of tanks will corrode and oxidize if allowed to become empty
  - Many require electricity to operate

146

COAL

147

Coal

- Been mined and exploited since 10,000 B.C.
- Coal is a stratified sedimentary rock composed of more than 50% carbon
- Has both organic (70-91%) and inorganic (9-30%) components
- Product of the burial of organic matter in swamps or peat bogs which was formed from the deposition of dead organic material and decomposed in an oxygen poor environment
- Annually US coal fired power plants emit 200,000 pounds of mercury

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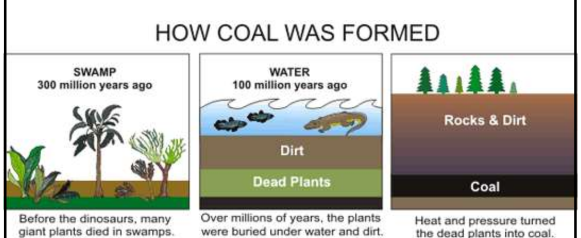

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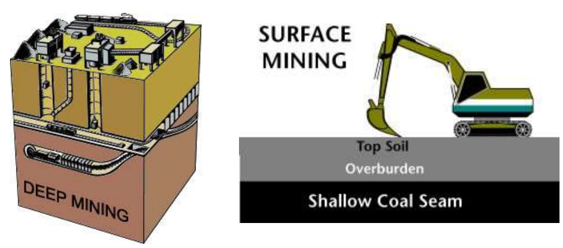

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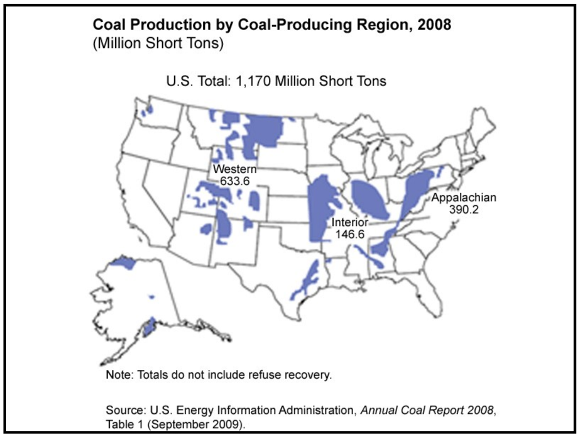

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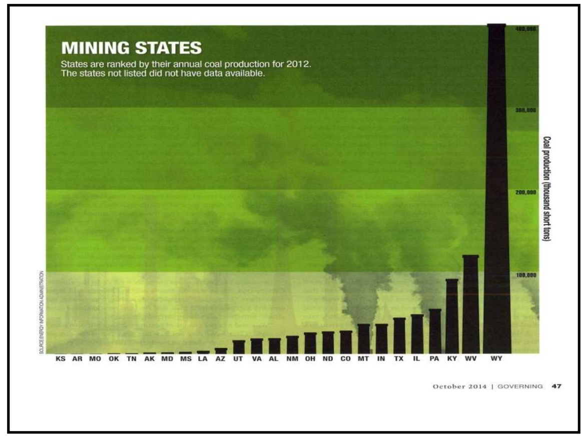

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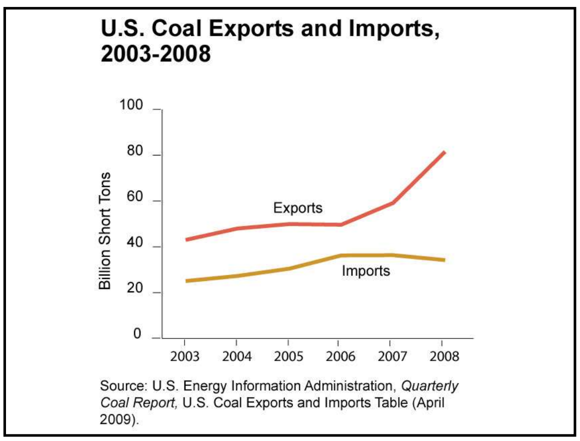

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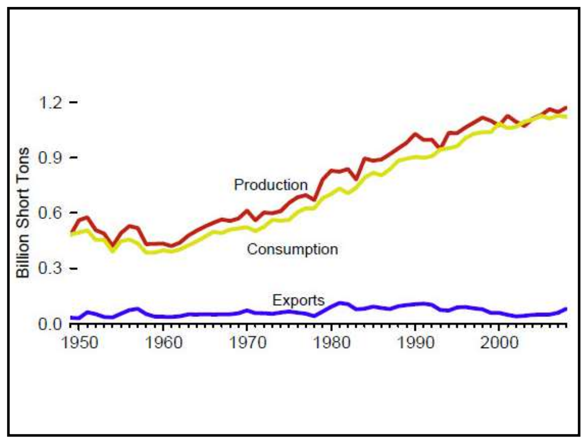

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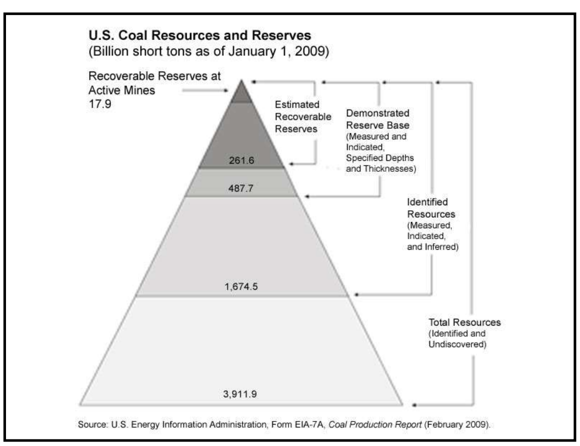

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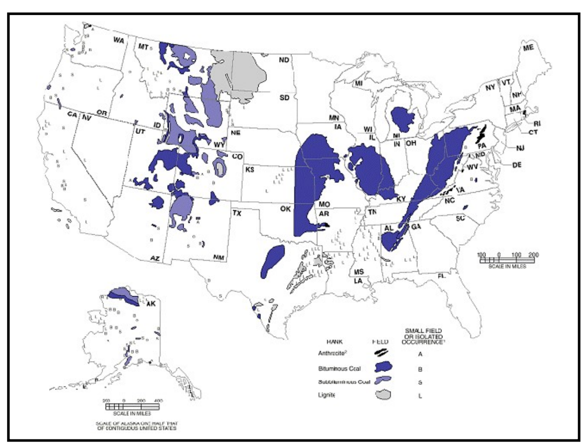

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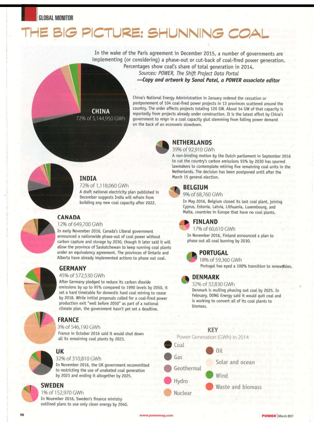

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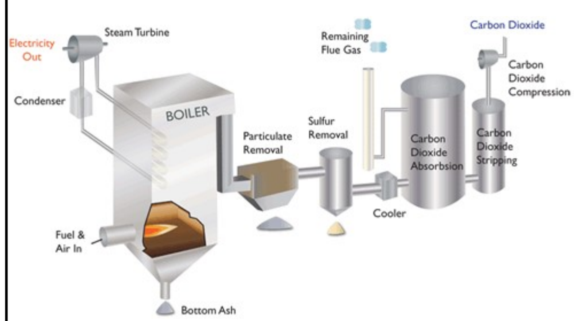

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Coal fired power plants

- Advantages
  - Most abundant energy source
  - Modern plants are very efficient
  - Power plants are common
  - Capital expenditures are smaller
  - Combustion chambers can use a variety of other qualities of coal and other solid fuels
- Disadvantages
  - Combustion is the dirtiest
  - Coal mining is harsh on the environment and dangerous
  - Cost of transporting coal is high
  - Waste problems associated with the ash
  - Water used to make the steam becomes contaminated and is a disposal nightmare

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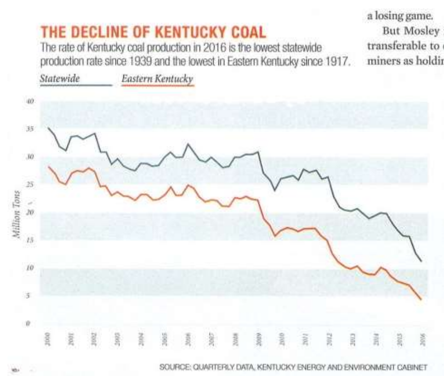

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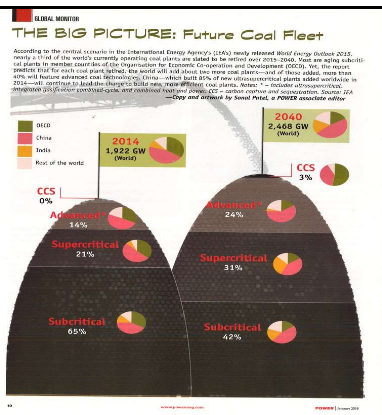

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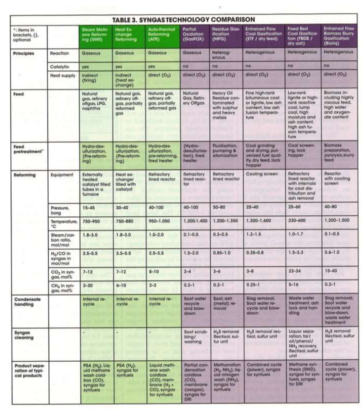

162

Nuclear

- Two types
  - Fission (All plants in world)
  - Fusion (Sun)
- Relatively new source
- Relatively clean of air pollution
- Presents problems with spent materials; however more than 95% of a spent rod can be reprocessed
- Main byproduct of hydrogen fusion is a harmless gas

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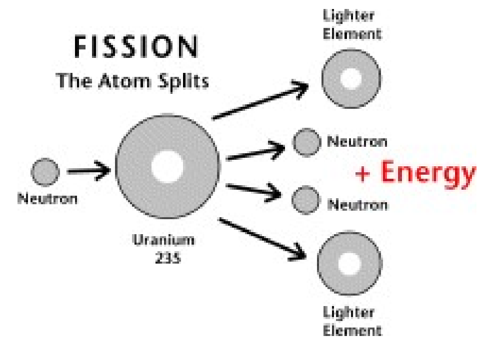

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How fission works

- Atom instantly splits into two separate nuclei, each lighter than the original
- Neutrons are emitted, along with gamma rays, which are extremely energetic photons, and heat is produced
- When one of the emitted neutrons strikes another uranium atom, the new uranium nucleus splits releasing more energy
- A chain reaction occurs when enough neutrons are being emitted by the fission to continue inducing new nucleus decays on a steady basis

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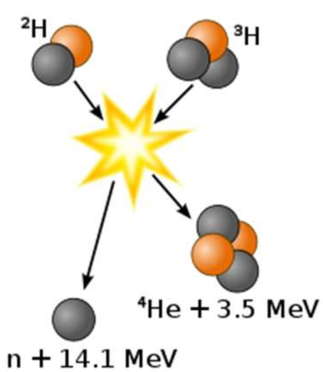

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How fusion works

- Two hydrogen nuclei combine and emit a positron (has the same mass as an electron but a positive charge) and a neutrino
- One of the original protons changes state into a neutron
- The deuterium atom combines with another proton to create helium-3 (H-3), which contains 2 protons and 1 neutron and emits a burst of gamma radiation
- Two separate H-3 nuclei fuse together to form H-4, which has 2 protons and 2 neutrons. In this phase, 2 protons are rejected and these feed further reactions that start the entire process over again

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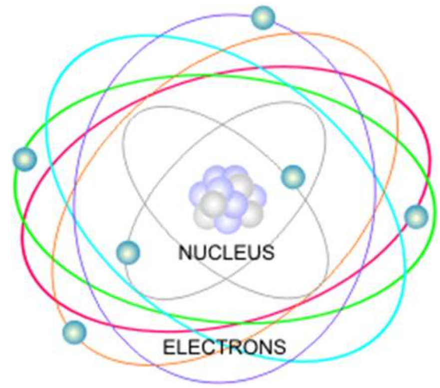

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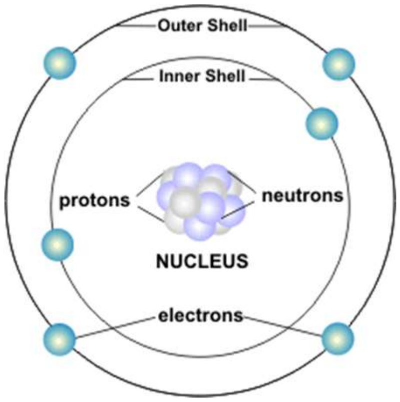

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Nuclear power capacity by country

Country	GW	Share of Electricity (%)	# Reactors
US	98	21	104
France	64	78	59
Japan	45	25	54
Russia	21	17	30
Germany	21	28	18
S. Korea	16	40	19
Canada	12	12.5	17
UK	12	24	27
China	12	unk	15

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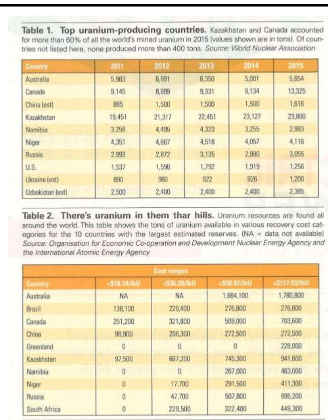

Table 1. Top uranium-producing countries. Kazakhstan and Canada accounted for more than 60% of all the world's mined uranium in 2015 (values shown are in tons). Of countries not listed here, none produced more than 400 tons. *Source: World Nuclear Association*

Country	2011	2012	2013	2014	2015
Australia	5,983	6,991	6,350	5,001	5,654
Canada	9,145	8,999	9,331	9,134	13,325
China (est)	885	1,500	1,500	1,500	1,616
Kazakhstan	19,451	21,317	22,451	23,127	23,800
Namibia	3,258	4,495	4,323	3,255	2,993
Niger	4,351	4,667	4,518	4,057	4,116
Russia	2,993	2,872	3,135	2,990	3,055
U.S.	1,537	1,596	1,792	1,919	1,256
Ukraine (est)	890	960	922	926	1,200
Uzbekistan (est)	2,500	2,400	2,400	2,400	2,385

Table 2. There's uranium in them thar hills. Uranium resources are found all around the world. This table shows the tons of uranium available in various recovery cost categories for the 10 countries with the largest estimated reserves. (NA = data not available) *Source: Organisation for Economic Co-operation and Development Nuclear Energy Agency and the International Atomic Energy Agency*

	Cost ranges			
Country	<$18.14/lbU	<$36.29/lbU	<$56.97/lbU	<$117.93/lbU
Australia	NA	NA	1,664,100	1,780,800
Brazil	138,100	229,400	276,800	276,800
Canada	251,200	321,800	509,000	703,600
China	98,900	206,300	272,500	272,500
Greenland	0	0	0	228,000
Kazakhstan	97,500	667,200	745,300	941,600
Namibia	0	0	267,000	463,000
Niger	0	17,700	291,500	411,300
Russia	0	47,700	507,800	695,200
South Africa	0	229,500	322,400	449,300

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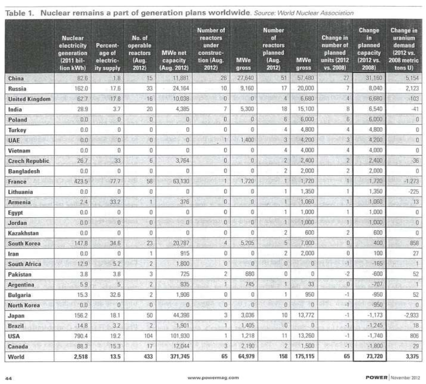

Table 1. Nuclear remains a part of generation plans worldwide. *Source: World Nuclear Association*

	Nuclear electricity generation (2011 billion kWh)	Percentage of electricity supply	No. of operable reactors (Aug. 2012)	MWe net capacity (Aug. 2012)	Number of reactors under construction (Aug. 2012)	MWe gross	Number of reactors planned (Aug. 2012)	MWe gross	Change in number of planned units (2012 vs. 2008)	Change in planned capacity (2012 vs. 2008)	Change in uranium demand (2012 vs. 2008 metric tons U)
China	82.6	1.8	15	11,881	26	27,640	51	57,480	27	31,160	5,154
Russia	162.0	17.6	33	24,164	10	9,160	17	20,000	7	8,040	2,123
United Kingdom	62.7	17.8	16	10,038	0	0	4	6,680	4	6,680	-103
India	28.9	3.7	20	4,385	7	5,300	18	15,100	8	6,540	-41
Poland	0.0	0	0	0	0	0	6	6,000	6	6,000	0
Turkey	0.0	0	0	0	0	0	4	4,800	4	4,800	0
UAE	0.0	0	0	0	1	1,400	3	4,200	3	4,200	0
Vietnam	0.0	0	0	0	0	0	4	4,000	4	4,000	0
Czech Republic	26.7	33	6	3,764	0	0	2	2,400	2	2,400	-36
Bangladesh	0.0	0	0	0	0	0	2	2,000	2	2,000	0
France	423.5	77.7	58	63,130	1	1,720	1	1,720	1	1,720	-1,273
Lithuania	0.0	0	0	0	0	0	1	1,350	1	1,350	-225
Armenia	2.4	33.2	1	376	0	0	1	1,060	1	1,060	13
Egypt	0.0	0	0	0	0	0	1	1,000	1	1,000	0
Jordan	0.0	0	0	0	0	0	1	1,000	1	1,000	0
Kazakhstan	0.0	0	0	0	0	0	2	600	2	600	0
South Korea	147.8	34.6	23	20,787	4	5,205	5	7,000	0	400	858
Iran	0.0	0	1	915	0	0	2	2,000	0	100	27
South Africa	12.9	5.2	2	1,800	0	0	0	0	-1	-165	1
Pakistan	3.8	3.8	3	725	2	680	0	0	-2	-600	52
Argentina	5.9	5	2	935	1	745	1	33	0	-707	1
Bulgaria	15.3	32.6	2	1,906	0	0	1	950	-1	-950	52
North Korea	0.0	0	0	0	0	0	0	0	-1	-950	0
Japan	156.2	18.1	50	44,396	3	3,036	10	13,772	-1	-1,173	-2,933
Brazil	14.8	3.2	2	1,901	1	1,405	0	0	-1	-1,245	18
USA	790.4	19.2	104	101,930	1	1,218	11	13,260	-1	-1,740	806
Canada	88.3	15.3	17	12,044	3	2,190	2	1,500	-1	-1,800	29
World	2,518	13.5	433	371,745	65	64,979	158	175,115	65	73,720	3,375

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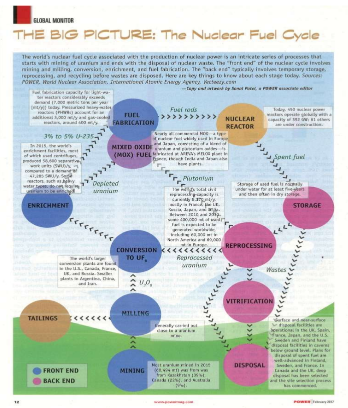

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Types of radiation

- Alpha
- Beta
- Gamma
- Neutron

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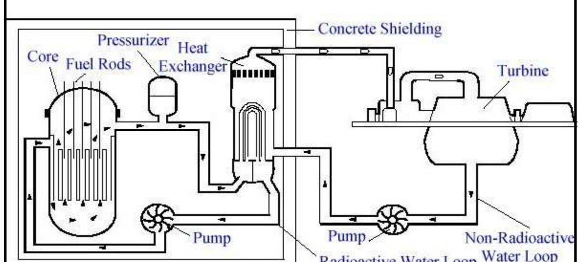

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Nuclear reactor process

- A core of uranium is maintained in the critical state
- Heat from the nuclear reaction is channeled into the boiler
- The heat is converted to steam and the steam powers a huge turbine generator assembly which provides electricity
- A condenser converts the used steam energy back down to a liquid which is then pumped back through the boiler

180

Designed for safety

- The core is housed in a very thick dense structure
- The entire system is housed in a secondary containment structure
- Precise temperatures in the core is maintained by carefully pumping huge amounts of cooling water throughout the system
- Materials used in the reaction must meet predetermined purity and density specifications

181

Fission reactors

- Advantages
  - Uranium is relatively inexpensive
  - Uranium is found in may parts of the world
  - Reprocessing the current stockpile could provide more raw fuel
  - Maintenance is infrequently needed
  - Fission reactors do not need oxygen to operate
  - Reactors can be built underground
  - Do not emit CO_2, and other pollutants
- Disadvantages
  - Reactors can not be easily turned up or down
  - Uranium mining is dangerous
  - Reactors produce a lot of dangerous waste products
  - There is a small risk of a terrorist attack
  - Moving fissionable material is hazardous

182

Fusion reactors

- Advantages
  - Main byproduct is helium-4 which is harmless gas
  - Deuterium can be manufactured from water
  - Deuterium and tritium are the only fuels necessary and both are cheap and abundant
  - No GHG emissions
  - Safer than a fission reactor
  - Fusion cannot sustain itself
- Disadvantages
  - The emitted neutrons eventually cause too much radioactivity in the core
  - Deployment is many years away
  - Public acceptance is a long way off

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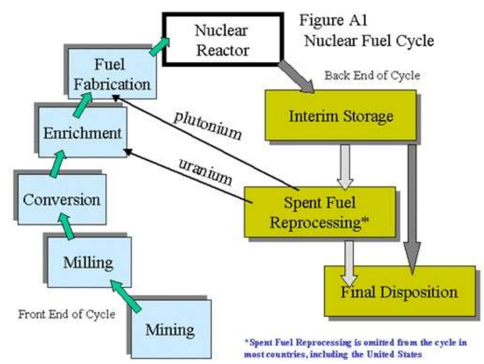

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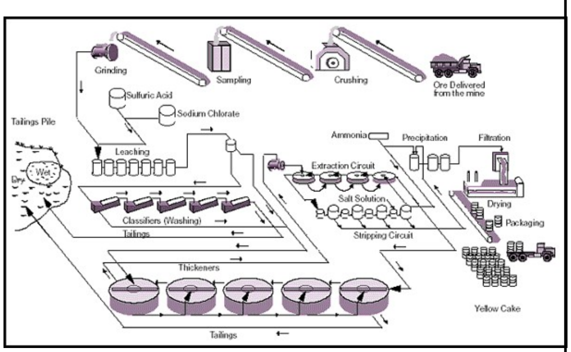

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Mining uranium

- Over half is mined similar to coal
- 27% is obtained from surface mining
- 19% from in situ leaching

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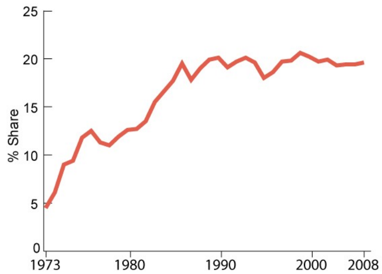
Nuclear Share of Electricity Net Generation, 1973-2008



Source: Energy Information Administration, *Monthly Energy Review.*

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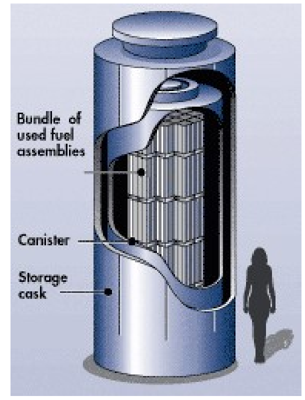

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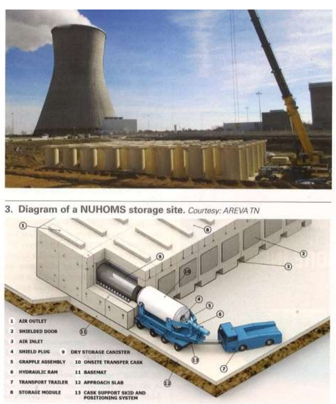

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Nuclear waste options in US

- Keep it in special storage containers at the nuclear reactor sites
  - Creates a local hazard makes security a prime issue
- Store it in temporary disposal sites such as Yucca Mountain
  - Makes the most technical sense, but experiences political opposition
- Reprocess it to extract new, recycled fuels
  - More than 95% of a fuel rod can be recycled for energy and medical isotopes
  - Practiced in most of the world, except US

190

Nuclear fears

- Reactors can explode like an atom bomb
- A massive release of radioactive elements could occur due to an accident
- Meltdowns can occur due to a simple loss of coolants
- There is a continuous release of radioactivity under normal operating use
- Water heating will be ecologically damaging
- An accident can occur during transit of radioactive materials
- Radioactive materials may be used by terrorists
- Disposal of radioactive wastes can never be satisfactorily achieved

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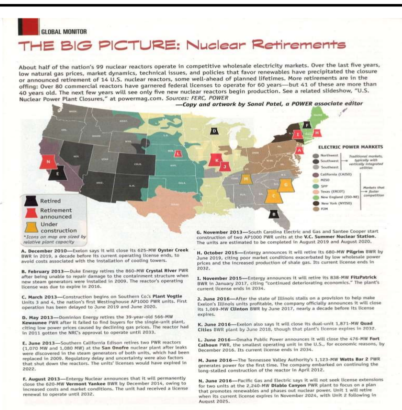

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New concepts

- Small (portable) nuclear plants
  - $500 million to $2 billion vs. $10 billion
  - 3 years construction vs. 5-6 years
  - Similar to ones for submarines
  - About 10% of the power
  - Less danger from terrorists and accidents

193

RENEWABLE ENERGY OPTIONS

194

Reasons to switch

- Pollution mitigation
- Political desirability
- Local jobs
- Sustainable economy
- Keeping money local (not to the Mideast)
- Diversification of the energy supply options
- Security to the US economy
- Increasing the supply of energy options reduces costs
  - Increase competition
  - Making inexpensive energy more available

195

Disadvantages of electrical power generated by alterative means

- Wind generators cover hillsides with noisy, ugly turbines; birds and bats get killed; pristine compared to other alternatives
- Hydroelectric systems dam up rivers and affect wildlife; dams create underwater decay that releases carbon dioxide
- Geothermal wells release arsenic
- Power lines emit radiation, heat the air, buzz and catch birds and planes

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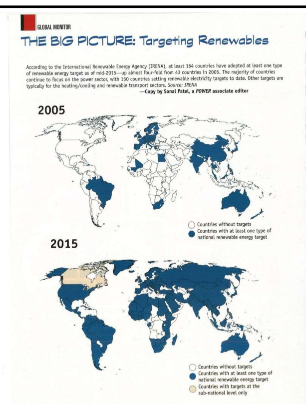

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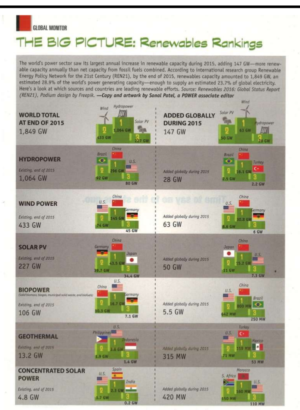

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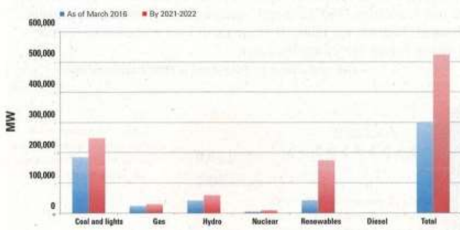
2. A renewables surge. A draft national electricity plan published by the Indian gov-ment in December outlines a capacity expansion from 302 GW in March 2016 to 523 GW by end of 2022. The expansion will be characterized by a surge in renewables capacity. The gov-ment anticipates non-hydro renewables will comprise 33% of installed power capacity by 2 while coal will have a much smaller 47.5% share. *Source: Central Electricity Authority*



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Options

- Solar energy
- Hydropower energy
- Wind energy
- Geothermal energy
- Biomass Energy
- Fuel cells

200

SOLAR POWER

201

Solar power

- Created by energy from the sun
- Can be passive
  - Solar HVAC
  - Solar drying
  - Solar water heating
- Can be active
  - Photovoltaic
- Available only during daylight hours
- Ocean Thermal Energy Conversion (OTEC)

202

Solar energy reaching the earth

- 35% reflected back into space
- 43% absorbed as heat radiation (ground and atmosphere)
- 22% evaporates water, creating rain and water distribution
- 0.2% creates wind energy
- 0.02% is used for photosynthesis by plants

203

Solar use history

- Used for centuries for warmth
- 1839 photovoltaic effects theorized
- 1870 first solar water trough that focused concentrated radiation on a liquid
- 1890 first solar steam engine
- 1905 mathematics of photovoltaic effects theorized
- 1953 first solar cells made (6% efficiency)

204

Challenges with solar

- Technological limitations
  - Semiconductors not very effective
  - Lower efficiencies because of the current power grid
  - PV cannot convert as much light
  - Only certain wavelengths can be used
  - Not all spectrum light can be used
  - Current PV technologies capture only 30 W/m^2

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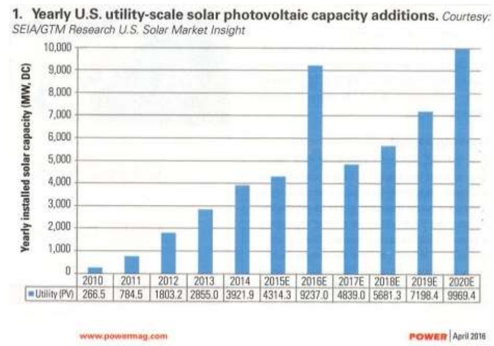

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Weather/temperature effects

- Panels subjected to wind, dust, rain, snow, high/low temperatures, acid rain, birds, etc.
- Panels will see a negative effect due to solar radiation over time (specifically materials of construction)
- Typical lifetimes of panels now exceed 30 years

207

Variability of sunlight

- Cloud cover/smog
  - Sunlight is generally diffused in cloudy areas
  - Air pollution reduces the amount of sunlight
- Position of the sun
  - Varies by latitude
  - Varies by time of day
  - Varies by season
- Sunlight intensity
  - With the sun lower in the sky, solar radiation must pass through more of the atmosphere with a greater chance of being reflected away

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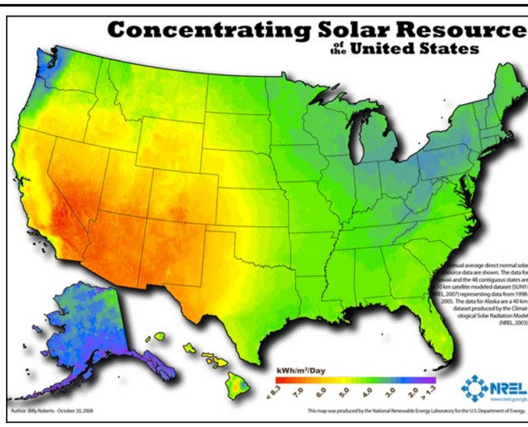

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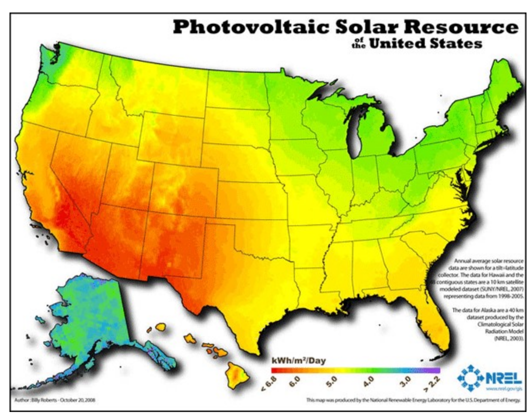

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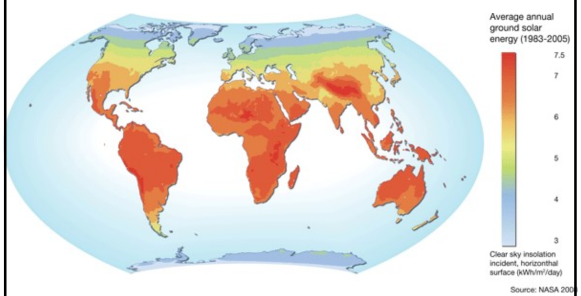

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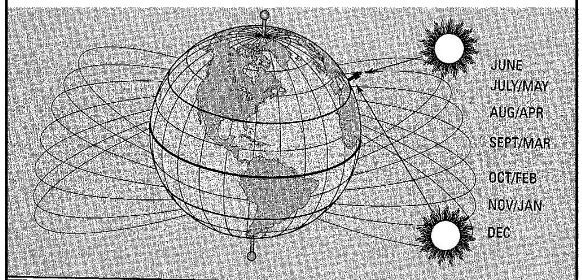

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Economics of solar

- Viable economically mostly in sunshine rich environments: Southwest, Pacific coast
- Solar communities
  - Are cleaner, less air pollution
  - Experience lower carbon dioxide emissions
  - Support recycling programs
  - Much less of community's money goes out of the region
  - Local jobs are created
  - Jobs created are stable and sustainable
  - Jobs created offer high pay and good benefits

213

Solar adoption

- Residential: Currently, 13% of all renewable energy from solar
- Commercial: Currently, 6% of all renewable energy from solar
- Lack of infrastructure
  - More manufacturing plants
  - More contractors to install
  - Price disparities across regions, nations
  - More consistent government subsidies
- Solar typically costs around $.15/kWh (more than fossil fuels)
- Economics could change with cap and trade system and net metering adoption

214

Government incentives

- Federal government favors
  - Solar power is ideal for peak power generating
  - Solar power is cleanest and most efficient source of energy
  - Solar power does not come from one large centralized source
- Federal tax credits
  - Typically 30% of capital cost can be recovered
  - Investment tax credit
  - ARRA (Stimulus)
  - RECs
- State incentives
  - Vary by state

215

Photovoltaic (PV) Solar

- Convert light energy to electrical energy
- Light photons act as both matter and radiation
- Current efficiency is 16%
- A m^2 of PV will output about 0.18 kW with 1kW of sunlight impacting it
- Two current options
  - Monocrystalline silicon
    - Made of one type of crystal only
    - Best material for PV since efficiency is high, but so are costs
  - Polycrystalline silicon
    - Take up more roof space
    - Lower efficiency
    - Lower costs

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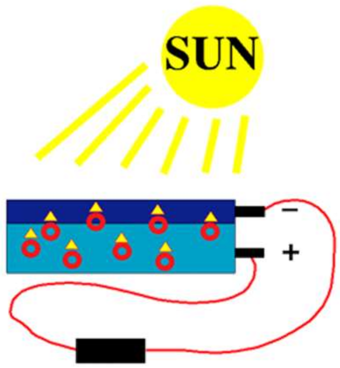

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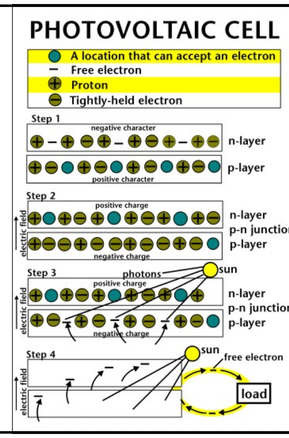

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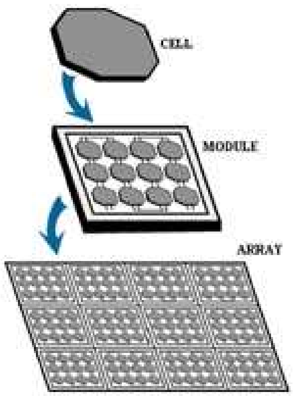

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Typical PV uses

- Remote irrigation pumps
- Remote homes that can't reach the grid
- Power roadway signs, gates, etc.
- Power roadside call boxes, illuminated highway signs, navigation buoys, unmanned installations,
- Directly power DC electrical motors

220

Solar power plants

- Concentrates solar power to create heat
- Heat vaporizes some liquid
- Pressure is used to drive a turbine
- Use mechanical trackers to adjust to sun movement
- Produce majority of the power during the middle of the afternoon when peak demand occurs
- Can be used as a peaking generator
- Generally built in deserts and away from population centers

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Solar Chimney

226

Disadvantages

- Reliability is an issue, especially when tracking the sun; therefore need on site staff
- Need a lot of capital funds
- Randomness due to sun movement
- Need a lot of plants to have a major impact

227

Financing alternatives

- Through utility companies
  - Pay the utility back via the bill
- Via various leasing arrangements
  - Company pays for the installation and customer agrees to a lease amount
- Buying into solar farms
  - Through a utility and designate a portion for use
- Mandating and amortizing
  - Requiring new homes and buildings to have it
- Government incentives

228

Solar Farm at KCRWTF

Between April 2011 and April 2014 generated 4.9 Gwhr about 15%

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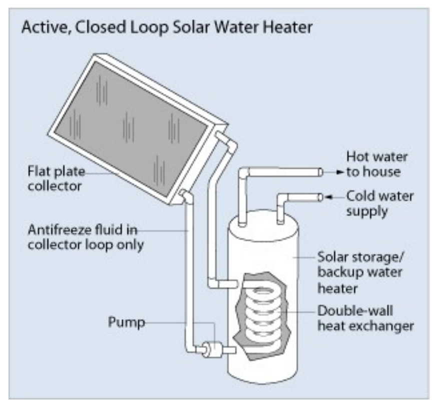

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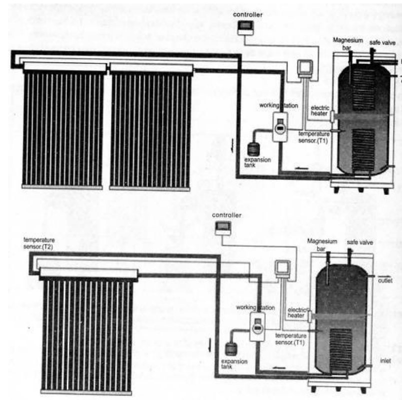

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Passive solar

- Hot water
- Building heating/cooling
- Building lighting
- LEED
- Sludge drying
- Can offer 70% reduction in energy bills

237

Achieving passive

- Proper orientation of the building
  - Longest side should face true south
  - Great rooms, family rooms, living rooms and kitchens should have southern exposure
- Strategic placement of windows, skylights and awnings
- Placement of deciduous trees and trellises outside
  - Can see a reduction of 20% in heating/cooling costs
- Using thermal mass to store heat during the winter
  - Maintains a consistent temperature
  - Concrete floors add to thermal mass
  - Tiles and bricks add to thermal mass
  - Allows heating to be held during winter nights
- Making optimum use of insulation and ventilation
- Using light tubes and skylights to enhance the natural light and reduce the burden on electric lighting
  - Good solar design would not require active lights during the day

238

Solar heating

- Swimming pool heating
- Conservatory
- Trombe wall
- Direct gain

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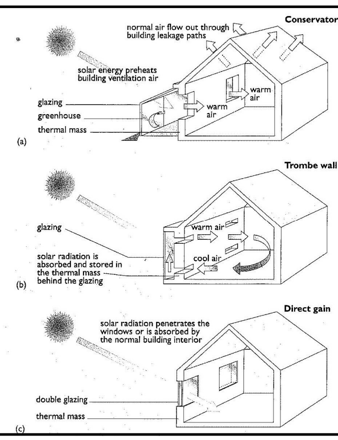

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Window energy balance

- Determining the net energy balance of a window
  - The building's average internal temperature
  - The average external temperature
  - The available solar radiation
  - The transmittance characteristics of the window
  - The U-value of the window

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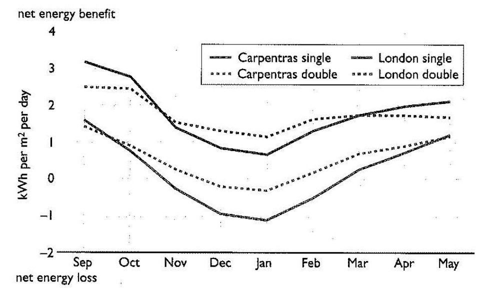

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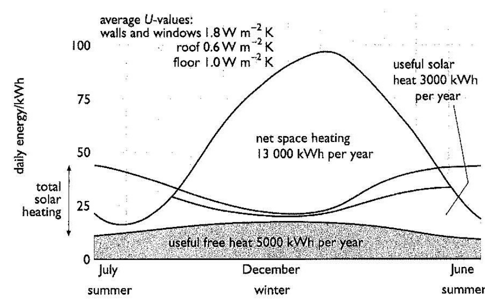
Determine gross heating demand

- Free heat gains
  - Body heat
  - Cooking heat
  - Washing and appliance heating
  - Heating from lighting
  - About 15-20 kW/day
- Passive solar gains through windows
- Fossil fuel energy from the normal heating system

243

Determine net heating demand



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Passive solar heating features

- A large south facing glazing to capture the sun
- Thermally heavyweight construction to store the thermal energy through the day and into the night
- Thick insulation on the outside of the structure to retain the heat

245

General passive solar heating techniques

- They should be well insulated to keep down overall heat losses
- They should have a responsive, efficient heating system
- They should face south (southeast-southwest)
- Glazing should be concentrated on the south side
- Little used rooms to the north (bathrooms)
- They should have overshading by other buildings and deciduous trees
- They should be thermally massive to avoid overheating in the summer

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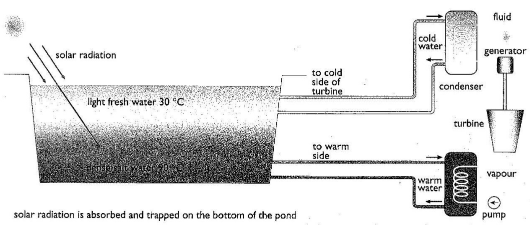

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Passive hot water heaters

- Many used in third world countries
- Uses a black coated collector
- Various types of collectors

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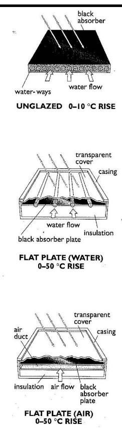

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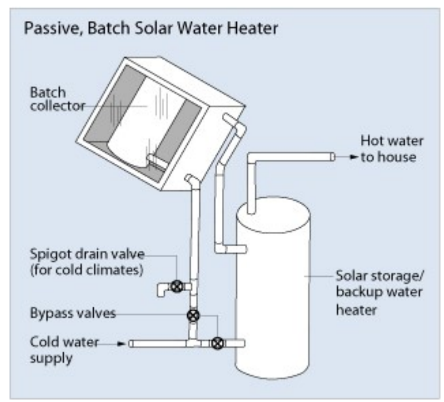

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Saving about $11,000 per week in natural gas costs compared to current system

From 18% solids to 90% solids in 3-6 weeks w/o floor heating

253

Passive sludge drying

- Parkson Thermo-System
- Began operating in August 2011 at Kent County Regional Wastewater Treatment Facility
- Combination of passive solar during the day
- Natural gas/geothermal at night
- Class A achieved
- Can reach 85% solids
  - Substitute for pulverized coal at cement kilns
  - Substitute for wood pellets

254

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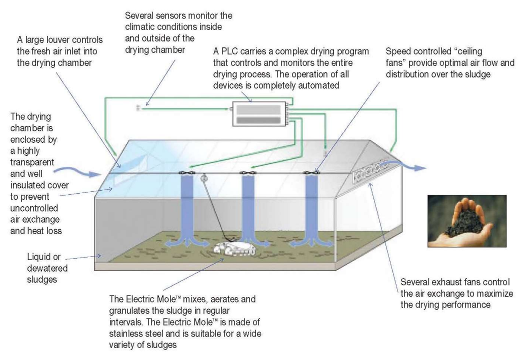
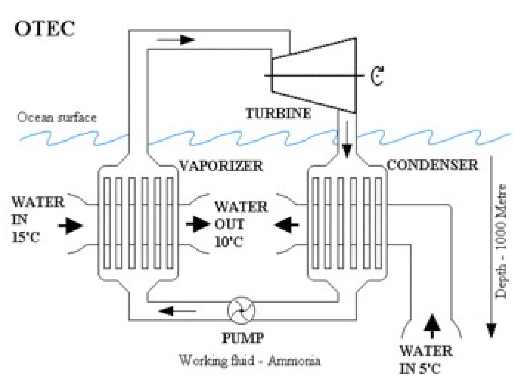


256

Ocean Thermal Energy Conversion (OTEC)

- Takes advantage of thermal changes in ocean water

257



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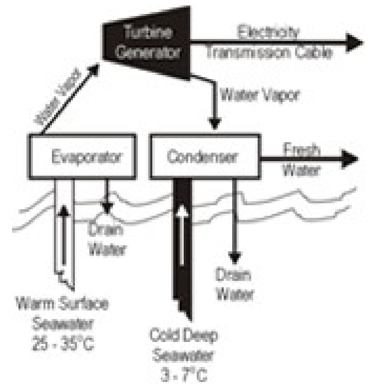

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Review of Quiz

- G289W (first 37 questions)

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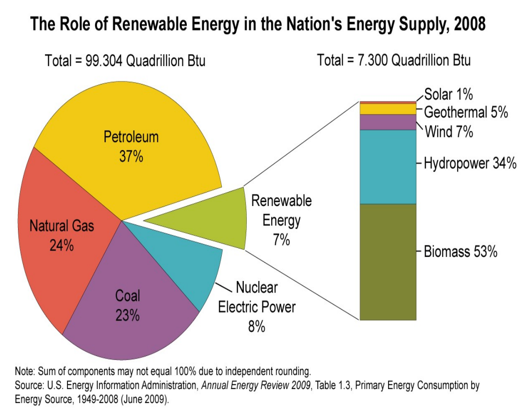
HYDRO POWER

261



262

Hydropower

- Created by moving water
- Can be determined based on height differences or flow
- Includes dammed water plants
- Includes tidal power
- Includes wave power

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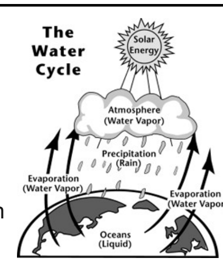
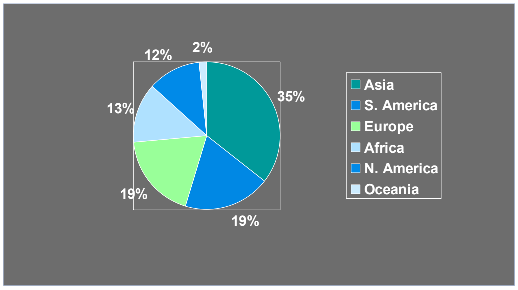
Hydropower



- Solar driven
  - Solar radiation causes evaporation
  - Condensation causes rain
  - Rain falls over the land
  - Streams form into rivers
  - Water flows back to the ocean via gravity
- Combination of solar energy and gravitation potential energy

264

World Technical Water Power Potential (TWh/yr, 1999-2002)



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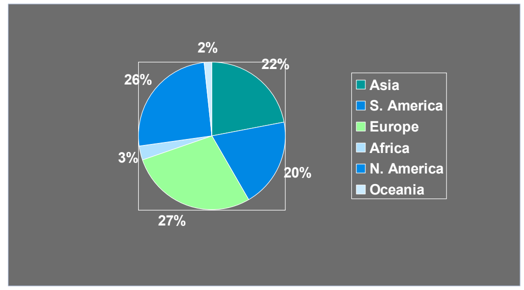
World Annual Output (TWh/yr, 1999-2002)



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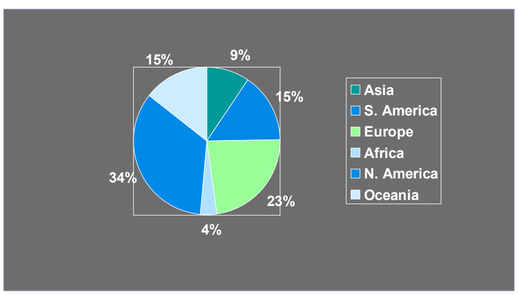
World Annual Output Percent of Potential (%)



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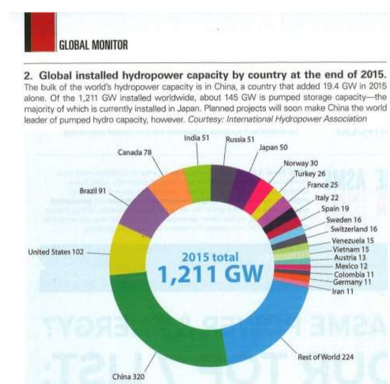

GLOBAL MONITOR

2. Global installed hydropower capacity by country at the end of 2015. The bulk of the world's hydropower capacity is in China, a country that added 19.4 GW in 2015 alone. Of the 1,211 GW installed worldwide, about 145 GW is pumped storage capacity—the majority of which is currently installed in Japan. Planned projects will soon make China the world leader of pumped hydro capacity, however. *Courtesy: International Hydropower Association*

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US Hydropower

- Produces 80,000 MW
- 75,000 dams over 6' high with only 3% used for hydropower
- Many smaller dams don't produce power

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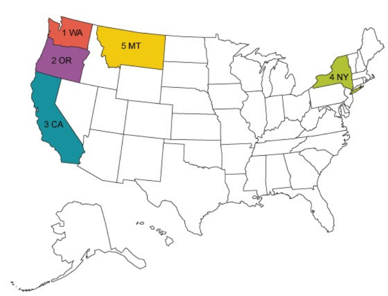
Top Hydropower Producing States, 2007



Source: Energy Information Administration, *Renewable Energy Trends in Consumption and Electricity, 2007 Statistics*, Table 1.18 (April 2009).

270

Stored Potential Energy

PE is the energy stored by water held at a given height

PE = M*g*H

Where M = Mass (kilograms)

g = acceleration of gravity, 9.81m/s^2

H = Height water is raised, aka Head (m)

271

Power, Head and Flow rate

- Power is energy delivered.
- Theoretical Power
  P(W) = 1000 * Q * g * H

Energy losses affect this:
Frictional drag
Turbulence losses

272

Effective head

- Theoretical power – losses
- 75-95%
- Efficiency includes other losses due to the generator and other effects

273

Actual Power

- Actual power

P = 1000 * n * Q * g * H

Where n is the efficiency
H is the effective head

Simplifying:

P (kW) = 10 * n * Q * H

274

Example

Flow: 15 MGD (0.657 m^3/s)
Head loss: 25' (7.62m)
Efficiency: 90%

P (kW) = 10*0.90*0.657*7.62
= 45.1 kW

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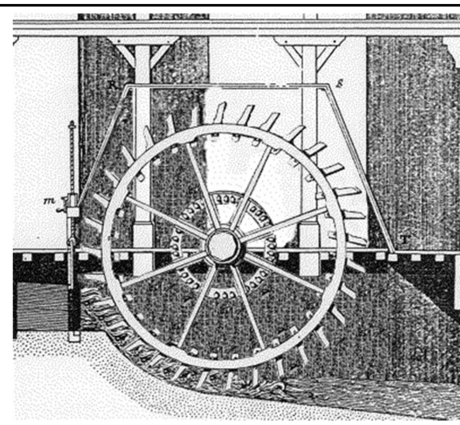

276

History

- Been used for hundreds of years
- Commonly used at the dawn of the industrial revolution (water wheels)
- River systems the most common first types
- Have dammed large rivers worldwide
- Fewer and fewer opportunities in the US
- In 1940, 40% was generated by this method, currently about 8%.
- From 1999-2005, over 200 dams have been torn down in US

277

Types of hydropower

- Impoundment systems
- River systems
- Tidal systems
- Wave energy

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Impoundment systems

- Most common type of system in use
- Use a dam to capture and contain water in a reservoir
- Depth of reservoir creates head pressure
- Deeper the reservoir, greater the potential to generate power

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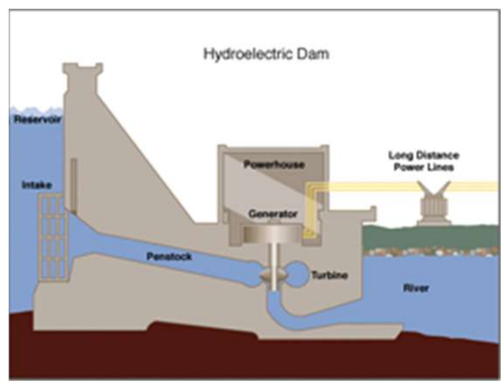

280

Advantages of Impoundment Systems

- Power is cost competitive with other energy sources
- Power can be altered very easily in terms of immediate power
- Storage is safe and clean
- Large reservoirs help ensure consistent energy output
- Power generation produces no toxic wastes, pollutants or carbon dioxide and GHGs

281

Environmental impacts of dams

- Submerges millions of acres
- May foster algae blooms
- Eliminates flooding
- May disrupt the migration patterns of certain species
- Sediment may build up in them
- Aging dams

282

Advantages of dam systems

- Power outputs are much larger
- Power can be provided to larger populations
- Cost per watt is lower than other hydro systems
- Non-impoundment systems are more susceptible to weather conditions
- Very few locations where non-impoundment systems can work

283

Types of River systems

- Diversion systems
  - Same as impoundments, but use only a portion of the river's flow
  - Easier on the environment
  - Much of the water is fed past the generators
- Run of river systems
  - Uses kinetic energy of fast moving water
  - River runs slower after it passes through the generator
  - Head pressure is low, but the flow is strong

284

- Pumped storage systems
  - Generates during peak times and pumps water back into a holding reservoir
  - Very good allowing a utility to met peak energy demand
  - Economics are favorable
- Small scale hydro systems
  - Generate electricity for a single home
  - Alter the environment the least
  - May have a negative effect if aggregated across many homes

285

Small scale systems

- Benefits:
  - Can generate more kilowatt hours per $ than other alternative processes (moving water generator costing $1200 can generate 2.4 kWh in a stream flowing 9 mph)
  - No batteries are required for storage
  - Can install a system of virtually any power output
  - Generate power day or night and in any weather
  - Have long equipment lives

286

- Drawbacks:
  - Complex electrical system designs difficult with constantly moving water
  - Waterways can dry up
  - Upfront costs can be high, particularly for stationary water systems
  - Need to convert raw voltages into standard household voltages

287

Small scale moving water considerations

- Need to measure water flow and speed
- Flow is the amount of water passing a given point
- Speed can be measured by timing a stick in the water over a given distance

288

Small scale stationary water considerations

- Need to devise a pipe system that produces maximum pressure
- May use high head – low volume or high volume – low head systems
- High head system is similar to the impoundment system
- Low head similar to the watermill type of system

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Tidal Power

- Tidal barrages (dams)
- Tidal fences
- Tidal turbines

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Advantages

- Tides are renewable, sustainable and predictable
- Some areas feature very large differentials between high and low tides
- Produce no air pollution
- Barrage can serve as a power generator and a road across an inlet
- Tidal barrage systems are easy to maintain
- Turbines are beneath the surface so they aren't visually polluting

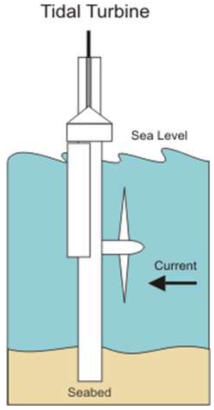
291

Disadvantages

- Capital equipment is expensive
- Technology is relatively new
- Turbines can be difficult to install; setting foundations can be problematic
- Tidal systems can affect the surrounding ecosystem
- Failure of the system can cause flooding in the region around the basin

292

Tidal Turbine



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Wave Power

- 3 main areas of research
  - Floats and bobbing devices used to capture the energy in rising and falling waves
  - Oscillating water columns in a cylindrical shaft that increases and decreases air pressure in the shaft as waves pass by. The pressure differential is used to power a turbine
  - Wave focusing systems constructed near a shoreline that directs waves into an elevated reservoir; when the water flows out towards the ocean, the pressure is used to spin a turbine

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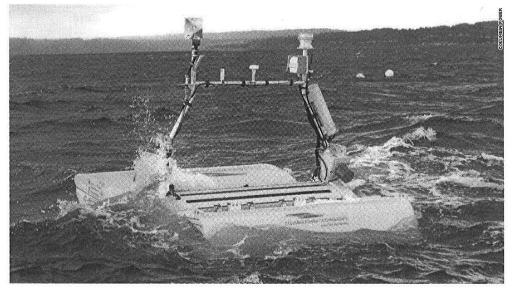

We get power from wind, sun and water.

296

4. Buoyant. About 3.4 meters (m) of the 12.8-m-long PB3 PowerBuoy sits above the waterline. Conversion of wave energy is carried out through a direct-drive generator that continuously charges an onboard battery pack. *Courtesy: OPT*

297

Advantages

- Turbulence of the ocean is a renewable energy source
- No GHG emissions, nor any other air pollution
- Generators are not expensive to install or maintain
- Wave farms can use combined outputs from individual generators
- Wave generators have very low profiles

298

Disadvantages

- When there are no waves, there is no electricity generated
- They make a sucking noise due to air pressure changes
- Big storms can destroy a system
- Boats may inadvertently run into and damage the systems

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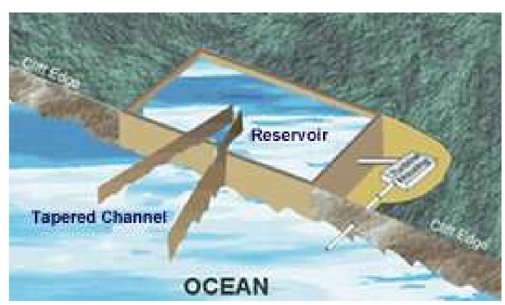

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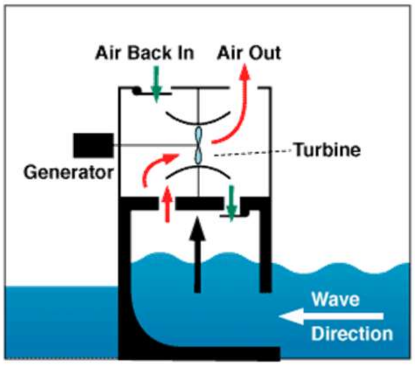

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WIND POWER

303

Wind

- Due to temperature differences between different locations on the surface of the earth and between different altitudes
- Solar heating driven
- Motion of a mass of air

304

History

- Used since around 3500 B.C. to move boats
- Chinese used windmills over 2,000 years ago
- Over 6 million windmills were built in US during the 1800's mostly to pump water for small ranches
- Electricity first generated by wind in 1890
- Windmills fell out of favor to hydropower during the 1940's
- Came back in vogue because of the Arab Oil Embargo in the 1970's

305

Markets

- Small scale production for remote locations
- Hybrid systems combining wind with other alternatives
- Grid connected systems small scale where the output is connected to the utility grid and feeds the grid when more wind power is generated than is used
- Large scale wind power systems on an utility scale, such as wind farms

306

Wind power formula

Power = k* Cp* 1/2 *ρ* A*V³

Where
P = Power output, kilowatts
Cp = Maximum power coefficient, ranging from 0.25 to 0.45,dimension less (theoretical maximum = 0.59)
ρ = Air density, lb/ft³
A = Rotor swept area, ft² or π D²/4 (D is the rotor diameter in ft, π = 3.1416)
V = Wind speed, mph
k = 0.000133 A constant to yield power in kilowatts.

(Multiplying the above kilowatt answer by1.340 converts it to horsepower. [i.e., 1 kW = 1.340 horsepower]).

307

Largest US states generation output, 2006 (MW)

California	2,118
Texas	1,293
Iowa	782
Minnesota	718
Wyoming	285
New Mexico	267
Oregon	263
Washington	240
Colorado	229

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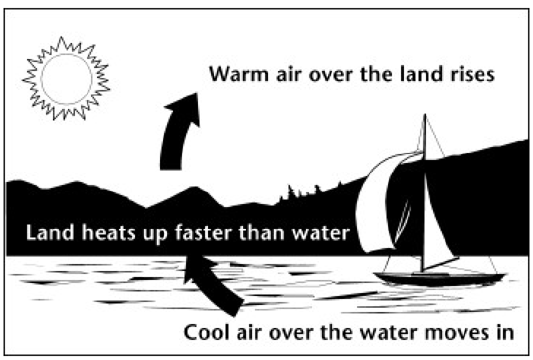

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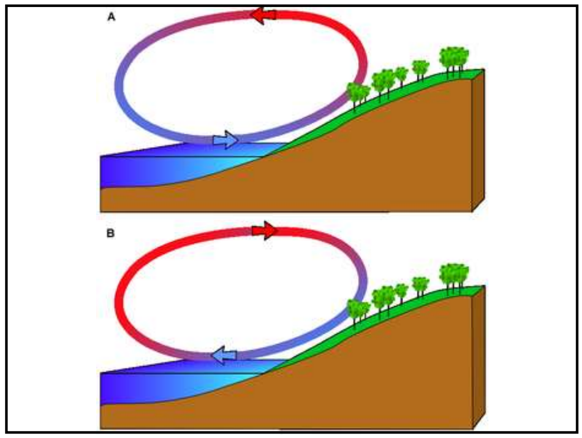

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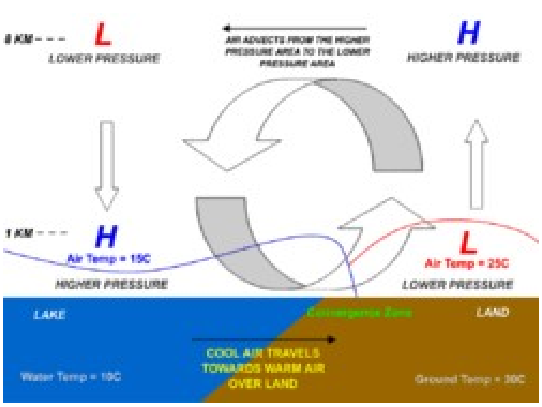

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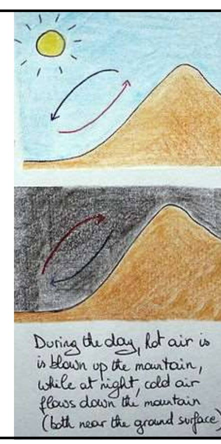

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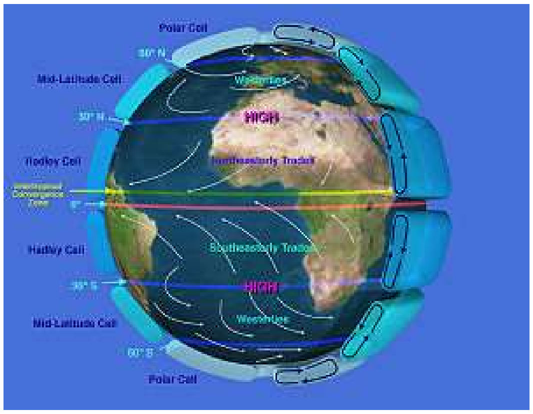

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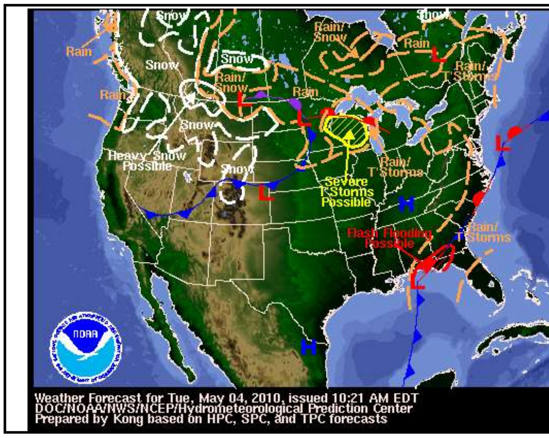

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Estimating wind data

- Wind varies over time and based on terrain
- Use national and state wind maps
- Some places have sufficient wind 24 hours 7 days per week
- Use computer models
  - Example is WinDs, from NREL
  - Need monitoring towers near the planned location
  - Monitor wind speed and direction over time
  - At least a year's worth of data
  - Look at frequency distribution and wind rose
  - Example is Kent County

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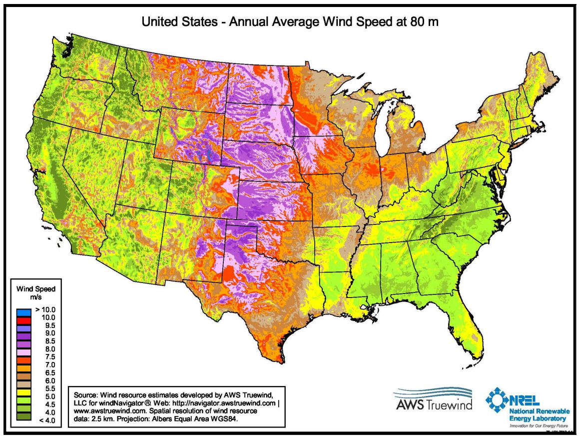

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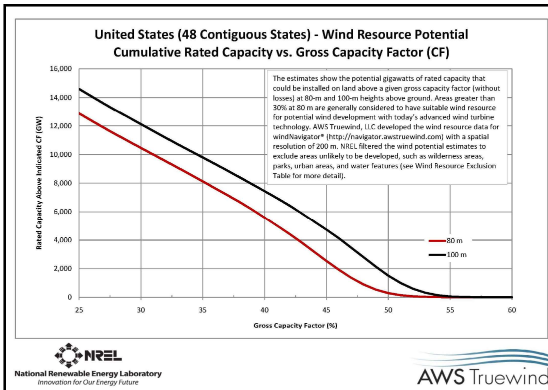

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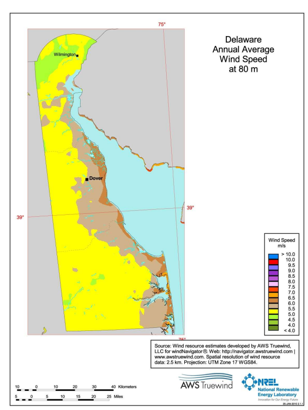

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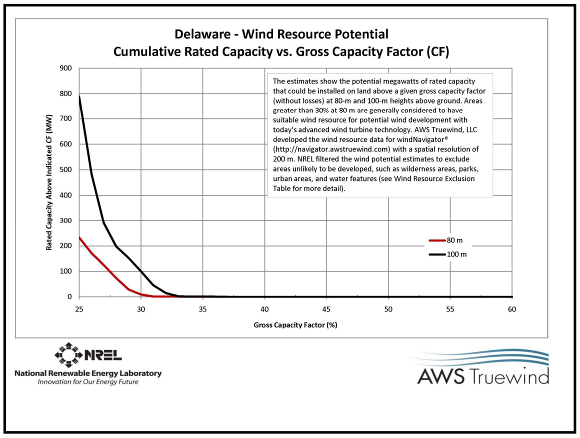

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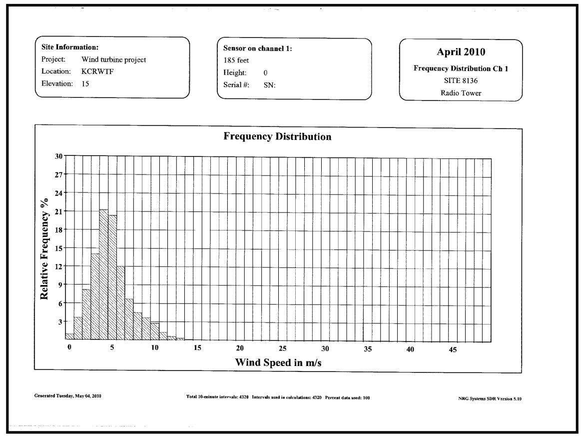

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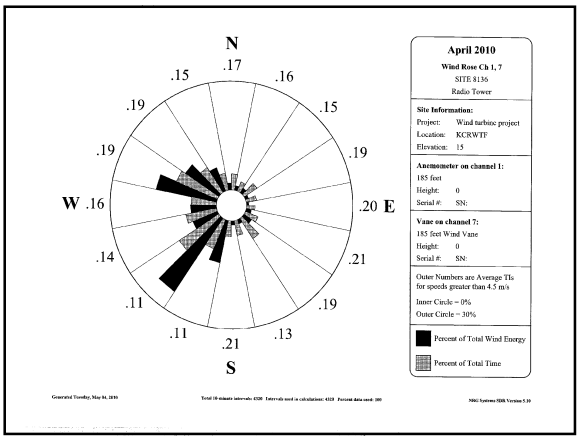

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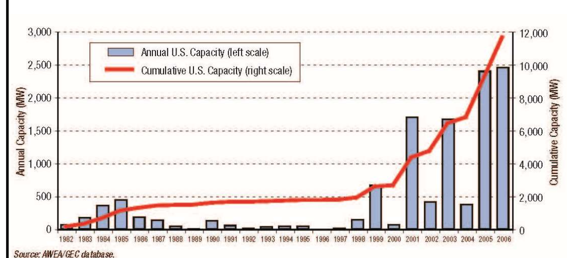

Figure 1. Annual and Cumulative Growth in U.S. Wind Power Capacity

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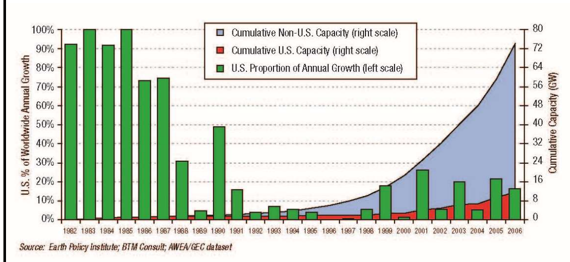

Figure 2. The United States' Contribution to Global Wind Capacity

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Table 2. United States Wind Power Rankings: The Top 20 States

Cumulative Capacity (end of 2006, MW)		Incremental Capacity (2006, MW)		Approximate Percentage of Retail Sales*	
Texas	2,739	Texas	774	New Mexico	7.3%
California	2,376	Washington	428	Iowa	6.0%
Iowa	931	California	212	North Dakota	5.1%
Minnesota	895	New York	185	Wyoming	5.1%
Washington	818	Minnesota	150	Minnesota	3.8%
Oklahoma	535	Oregon	101	Oklahoma	3.5%
New Mexico	496	Kansas	101	Montana	3.3%
Oregon	438	Iowa	99	Kansas	3.1%
New York	370	New Mexico	90	Oregon	2.4%
Kansas	364	North Dakota	80	Texas	2.3%
Colorado	291	Oklahoma	60	Washington	2.3%
Wyoming	288	Colorado	60	California	2.1%
Pennsylvania	179	Pennsylvania	50	Colorado	1.7%
North Dakota	178	Hawaii	41	South Dakota	1.5%
Montana	146	Montana	9	Nebraska	1.0%
Illinois	107	Maine	9	Hawaii	1.0%
Idaho	75	Massachusetts	2	Idaho	0.7%
Nebraska	73	New Hampshire	1	New York	0.6%
West Virginia	66	Rhode Island	0.7	West Virginia	0.6%
Wisconsin	53	Ohio	0.2	Pennsylvania	0.3%
Rest of U.S.	156	Rest of U.S.	0.3	Rest of U.S.	0.02%
TOTAL	**11,575**	**TOTAL**	**2,454**	**TOTAL**	**0.85%**

*Assumes that wind installed in a state serves that state's electrical load; ignores transmission losses.

Source: AWEA/GEC database and Berkeley Lab estimates.

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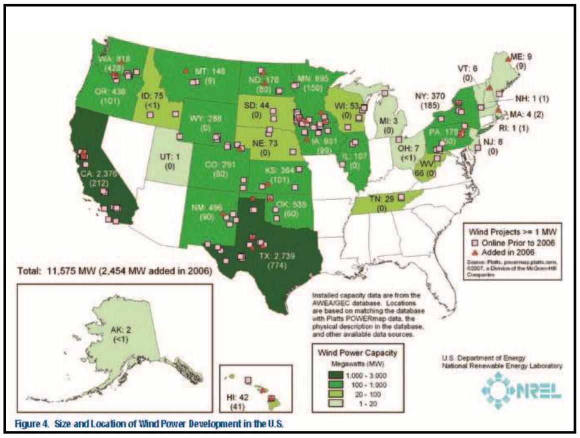

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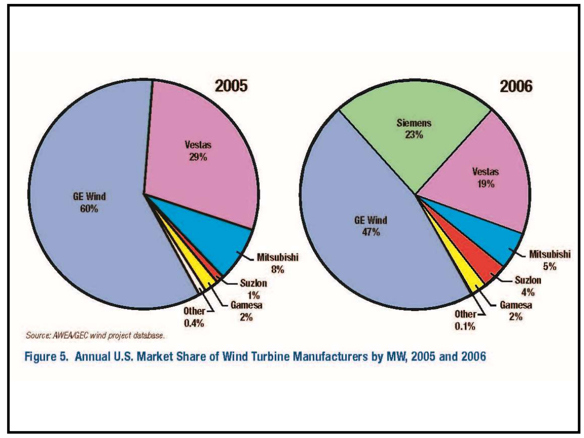

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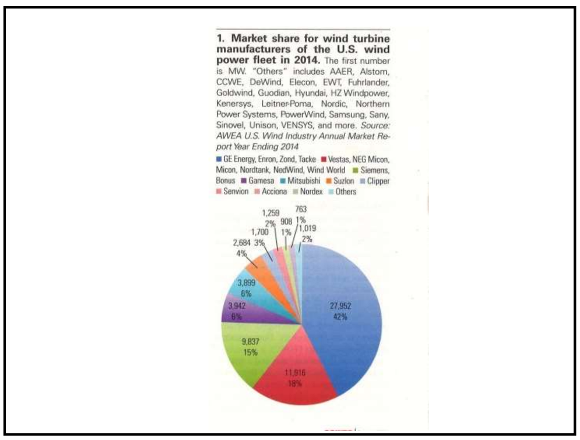

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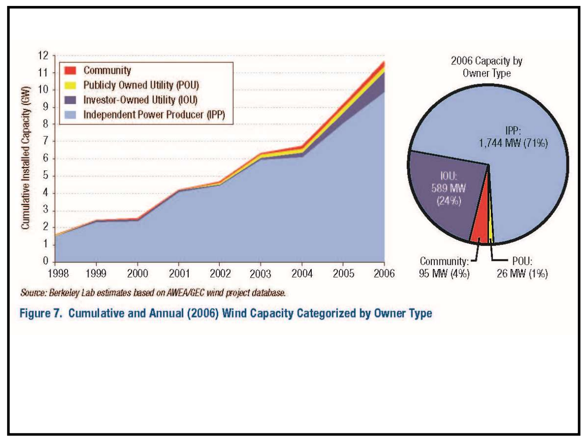

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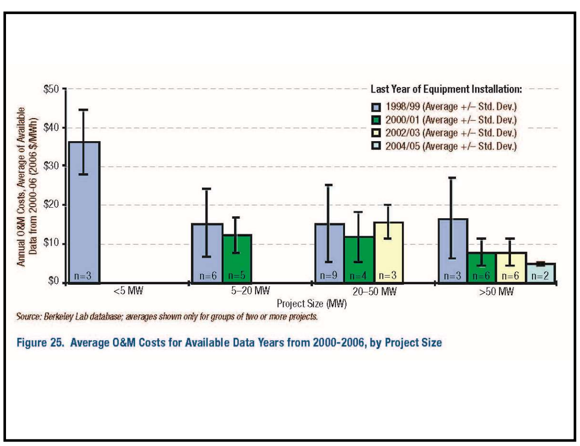

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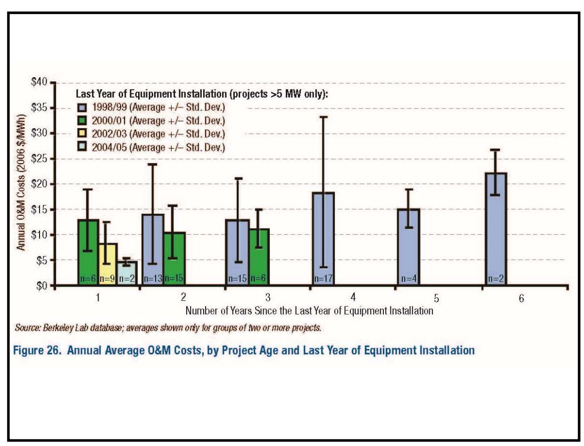

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Planned offshore wind

State	Proposed Offshore Wind Capacity
Massachusetts	735 MW
Texas	650 MW
Delaware	600 MW
New Jersey	300 MW
New York	160 MW
Georgia	10 MW
TOTAL	**2,455 MW**

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Basic technology

- Horizontal axis
  - Most common
  - Axis of rotation parallel to the ground
  - Different airfoil designs provide varying degrees of performance
- Vertical axis
  - Vertical shaft with blades attached at the bottom and top of shaft

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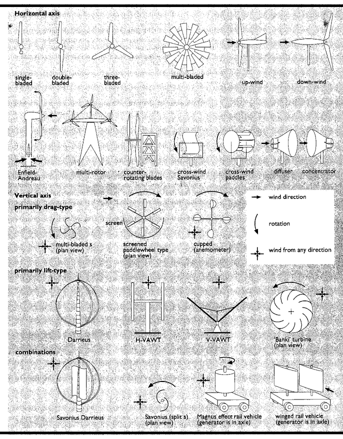

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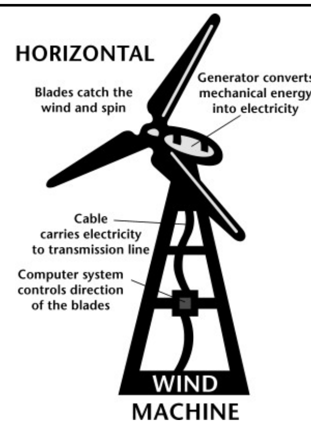

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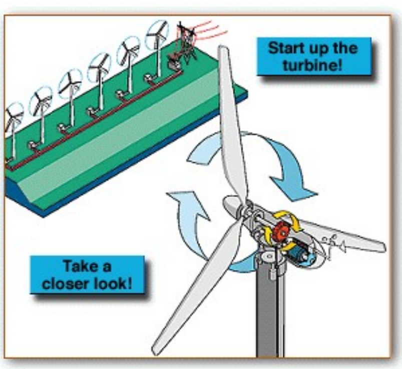

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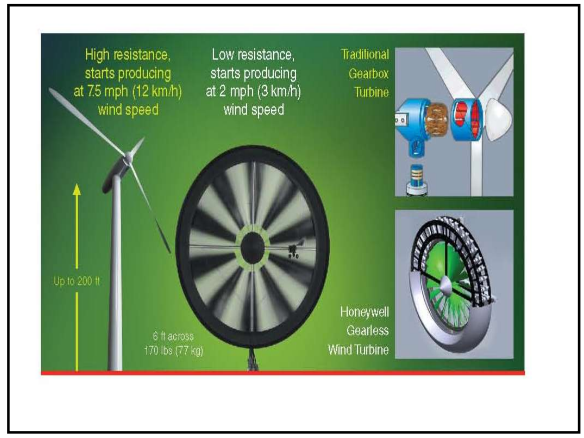

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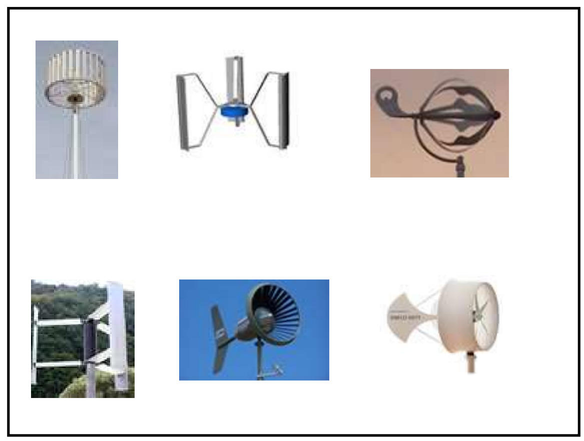

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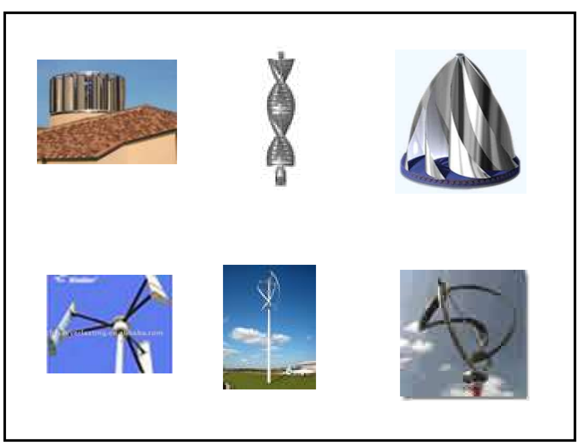

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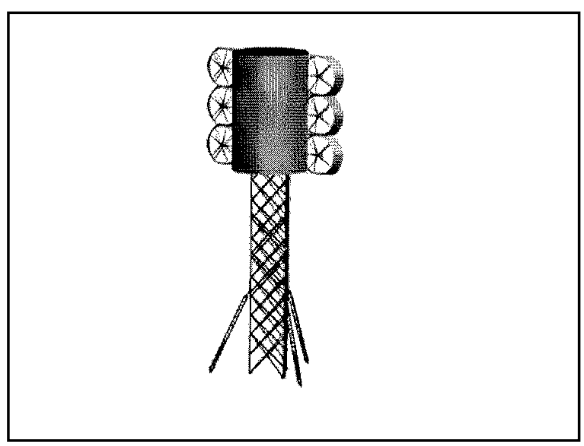

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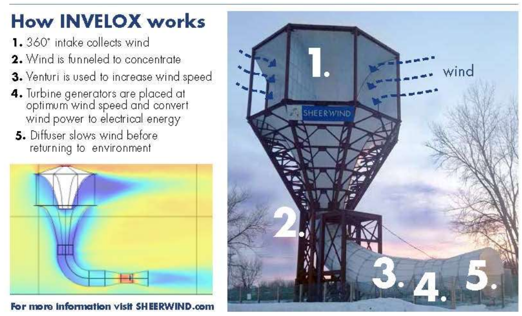


344

Engineering

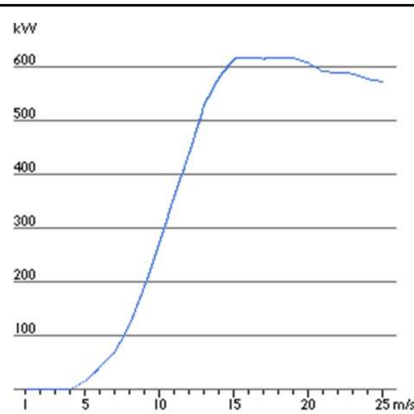
- Wind turbines require the most difficult engineering
- Small changes can result in major changes in performance
- Lot of ongoing R & D
- Results in many different designs

345

Turbine Power Curve

- Graph that indicates power output versus wind speed
- Found by field measurements using an anemometer near the turbine
- Wind data fluctuates considerably therefore must graph of averages
- Does not tell how much power a wind turbine will produce at a certain average wind speed.

346



347

Cut in/Cut out limits

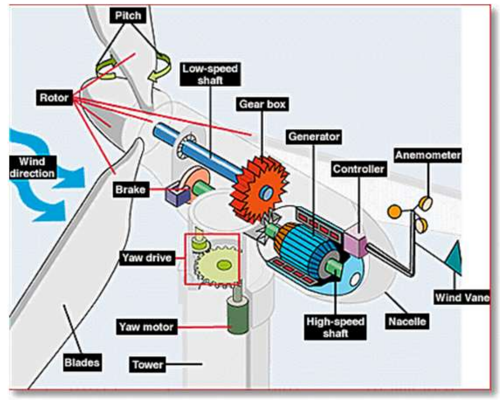
- All wind turbines have these
- Cut in is the minimum amount of wind necessary to enable the turbine to make power (typically 7 mph)
- Cut out is the maximum amount of wind that is safe for operation
  - Many different approaches since the speed is around 65-70 mph

348

Stabilizing the towers

- Heavy torque on the towers
- Often 160-280 feet tall
- Fixed into huge masses of concrete embedded deep into the ground
- Some towers use heavy cable guy wires, but these can impact operation
- Blade bearings, electrical generator and cooling often mounted in a housing located at the top (nacelle)

349



350

Maintaining rotational velocity

- Typically rotates at 20 rpm
- Desired to maintain optimal aerodynamic performance
- As wind velocity varies, the power output varies, but not the blade rotational velocity
- Generator operates at 60 cycles per second

351

Wind direction

- Turbine must be pointed directly into the wind or away from the wind
- Blades and nacelle rotate to accommodate changing wind direction
- Uses an anemometer to measure wind speed and direction
- Motors and gears rotate the nacelle
- In strong winds, blades are locked into place and rotated 90° to the wind

352

Location of the turbines

- Location is critical
- Sites 100 yards apart may have different wind characteristics
- Potential energy increases 8 folds when wind speed is doubled
- Operating range is from 3 meters/sec (7 mph) to 27 meters/sec (65 mph)
- Damage occurs at 50 meters/sec (120 mph)
- Optimum wind speed for a large turbine is 25 meters/sec (60 mph)
- Typical efficiencies of 25-45%
- Best sites are removed from population centers in varying terrain (near mountains or the ocean)

353

Other considerations

- Can enhance efficiency by changing blade pitch
- Total production is related to the surface area of the blades and the torque produced
- Turbines are maintenance free for long lifetimes
- Distances between turbines are not important

354

Environmental impacts

- Can kill birds, bats and insects
- Produce no GHG emissions or other noxious gases
- No need to transport fuel to the site
- No wastes generated
- Wind is intermittent and affected by surrounding terrain
- Turbines are never used to maximum capacity
- Wind farms can take up large tracts of land
- Can create visual and noise issues
- Towers may interfere with TV, microwave or radio signals, air traffic towers, radar etc.

355

Typical noise levels

Activity	Noise level in decibels
Threshold of pain	140
Jet aircraft at 750 feet	105
Pneumatic drill at 20 feet	95
Truck traveling 30 mph at 300 feet	65
Busy office	60
Car at 40 mph	55
Wind farm at 1000 feet	35-45
Quiet bedroom	20
Rural nighttime background	20-40
Threshold of hearing	0

356

GEOTHERMAL POWER

357

Geothermal

- Based on the heat contained within the earth
- About 10% is residual heat from 4.5 billion years ago
- 90% is due to radioactive decay of uranium, thorium and potassium contained within the earth
- Available across the US, but more prevalent in certain locations
- Both electricity generation and heating and cooling options
- High enthalpy (heat content of a substance per unit mass)

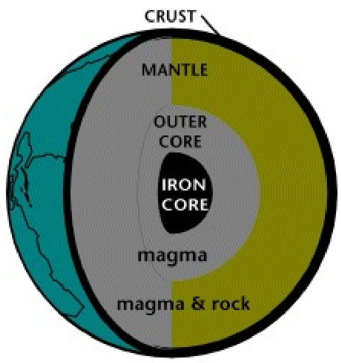
358

359

Geothermal information

- Earth's core estimated at 8,000°F
- Heat radiated outward from core towards the surface
- Each mile of depth, temperature increases about 80°F
- Classifications of geothermal fields
  - High grade sources: 400-1,300°F
  - Medium grade sources: 300-400°F
  - Low grade sources: 212-300°F
  - Different temperatures require different engineering methods to exploit the energy

360



THE EARTH'S INTERIOR

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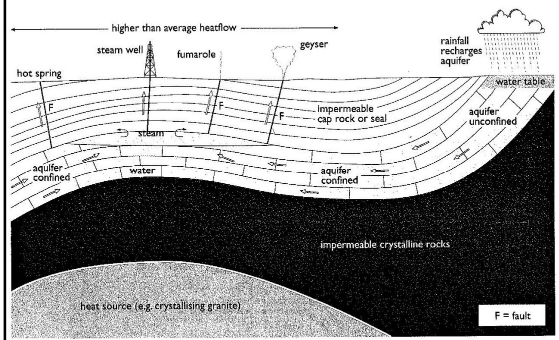

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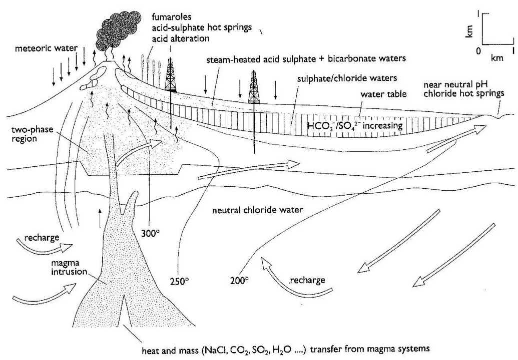


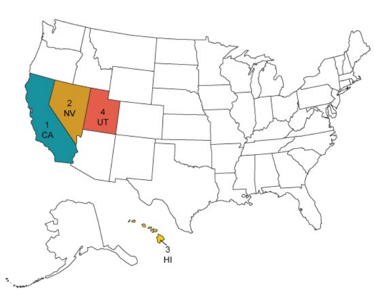
363

Resources

- Beneath rock terrain
  - Difficult to tap
  - Expensive to tap
- Water laden
  - High in sediment
  - Often referred to as brine
  - Difficult to handle
  - Corrode and decay metal equipment
  - Brine content
    - Hydrogen sulfide
    - Ammonia
    - Methane
    - Carbon dioxide
    - Metals (sulfur, vanadium, arsenic, mercury, nickel)

364

Top Geothermal States, 2007



Source: Energy Information Administration, *State Renewable Electricity Profiles 2007* (June 2009).

365

Top 5 geothermal nations(2006)

Country	Output (MW)
US	2,200
Philippines	1,900
Indonesia	800
Italy	780
Japan	570

366

Factors affecting cost

- Flow rate and pressure
  - Impacts the type of piping to be used
- Ease of getting to the source
  - Based on geologic features: Rock, soil, etc.
- Location
  - Some locations more difficult to tap
- Demand level
  - Compared to market price in area
- Capital equipment costs
  - Costs associated with drilling equipment, pumping equipment
- Typical cost is $0.08-1.00/kWh

367

Geothermal Uses

- Produce electricity
  - Dry steam production
  - Flash steam production
  - Binary cycle production
- Directly heat homes and businesses
  - Use a hydrothermal liquid that is piped through a radiator system
  - Use heat pumps

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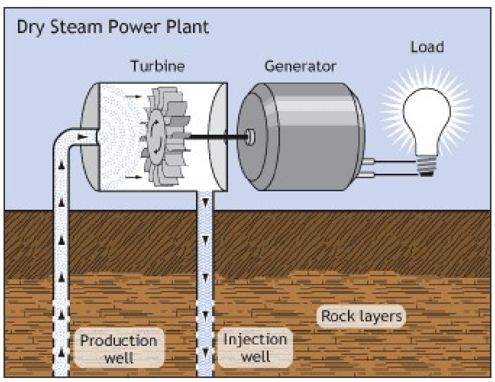

369

Dry steam

- Capital equipment costs lowest
- Must sink a production well into a dry steam reservoir with temps about 212ºF
- Pipe system channels dry steam to the surface
- Steam is fed to a turbine
- Cooled steam is injected back into the earth via a separate well
- Need to keep wells far enough apart so they don't interfere with each other

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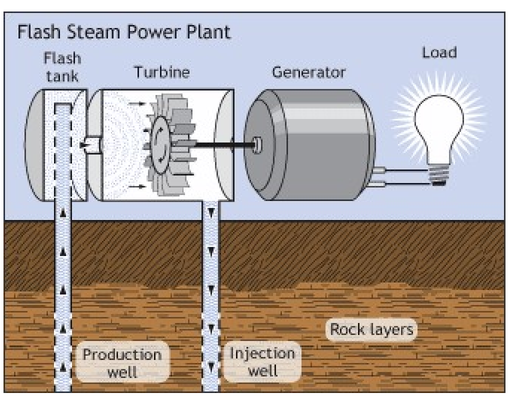

371

Flash steam

- Taps into high pressure areas
- Temperatures above 360ºF
- Production well is used but draws heated liquid instead of steam
- About 40% of the liquid converts to steam immediately
- Require more capital and backup equipment than dry steam systems
- Machinery is more complex
- Maintenance is more expensive
- Can be used to desalinate water supplies if placed near the ocean

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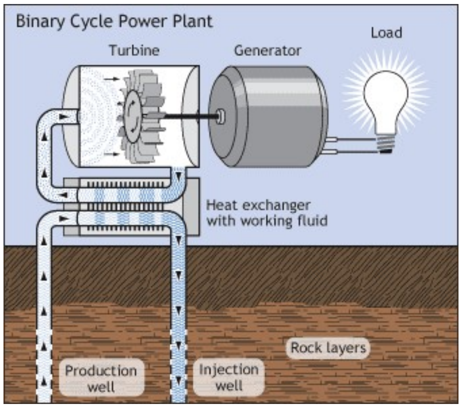

373

Binary cycle

- Used when liquid is below 360^{o}F
- Have two independent closed loops
  - Production/injection wells
  - Generator loop
- Heat exchanger transfers heat from the well loop into the generator loop
- Economical when there is enough hydrofluid
- More risky than other two becomes sometimes wells go dry

374

Geothermal plants

- Supply of energy is virtually limitless
- No toxins or pollutants generated
- No fuel needed to be transported
- No waste materials
- Considered renewable because the resource is so large
- There is a permanent change to the earth in reduced temperature, but change is very minute

375

Factors when designing

- Finding a suitable site
  - Sometimes difficult
  - Permitting issues
- Self-sustaining plants
  - Don't need external sources of energy
  - Operating costs are minimal
  - Requires very little labor
- Plant safety
  - Safer than most fossil fuel plants
  - Almost no risk of explosions
  - Leaks aren't as noxious as fossil fuel plants
  - Can have flammable or explosive gases emerge from the wells
- Can run cold
  - Heat source begins to disappear
  - Natural changes in the earth occur
  - Can see reduced temperatures or pressures

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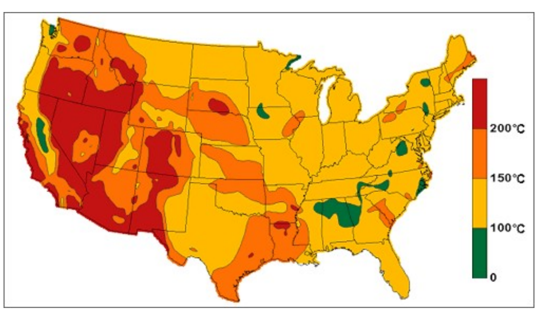

377

Geothermal heat pumps

- Using geothermal directly is very simple
- Direct uses:
  - Heat a home or community
  - Warm water on fish farms
  - Heat greenhouses
  - Pasteurize milk
  - Dehydrate fruits, vegetables and grains
  - Warm underlying soil on farms to increase crop production
  - Sanitize and regulate the temperatures in stables
  - Pump beneath roads and walkways to prevent ice buildup

378

Considerations of heat pumps

- Offer steady, even heating and cooling
- Take up less space than traditional systems
- Safer and cleaner
- Require more maintenance than some systems
- Require electricity

379

Geothermal viability

- A well
  - Used to bring hot water to the surface
  - Must have sufficient pressure and flow
- A mechanical engineering system
  - Used to pump and distribute the water
  - Temperature probes and valves required
  - Piping systems and filters to prevent sediment buildup
- Way to dispose of the water
  - Disposal of used water can be a problem
  - Usually pumped back into the earth
  - Can be surface discharged
    - Could cause environmental damage
    - May need a permit
- Typical capital cost for a small system is around $2500/kW

380

Heat pump operations

- Heating cycle
  - Either ground or air based system
  - Fluid circulates through the loop
  - Extracts heat from the ground
  - Heat is sent to the geothermal unit where it’s compressed and delivered via ductwork or radiators
- Cooling cycle
  - Heating process is reversed
  - Unit removes heat from the home
  - Circulates it through the ground where its cooled by the ground

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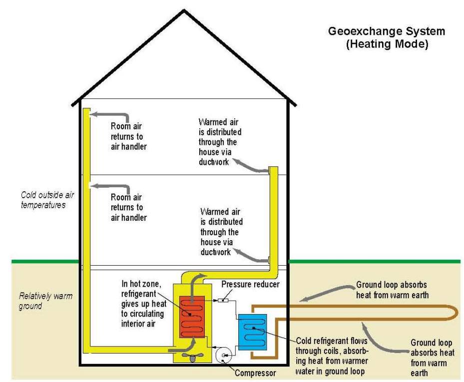

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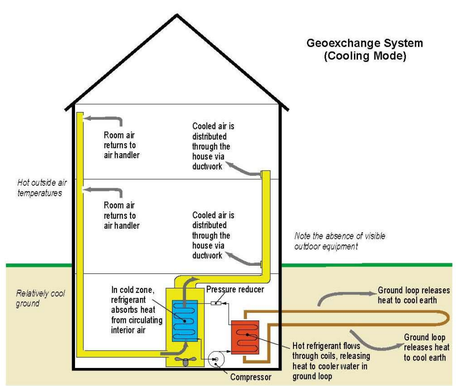

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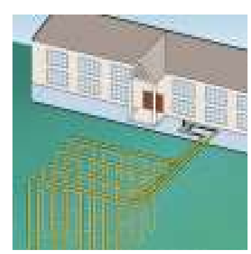

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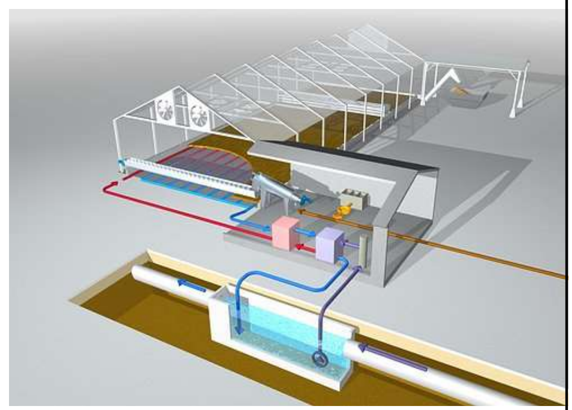

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BIOMASS ENERGY

387

Biomass

- Living or dead biologic material which can serve as a source of energy
- Produced directly or indirectly through photosynthesis
- Been used for over 1.4 million years
- Renewable because the timescale is within that of a human lifetime
- Cellulose based plants are not good for liquid petroleum supplants

Wood and trees	Corn, soy beans
Sewage Sludge	Animal wastes
Microalgae	Landfill gases
Grasses	

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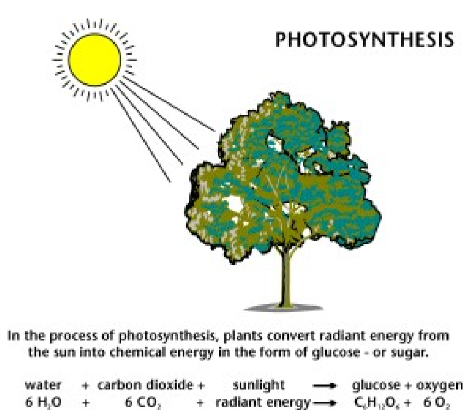

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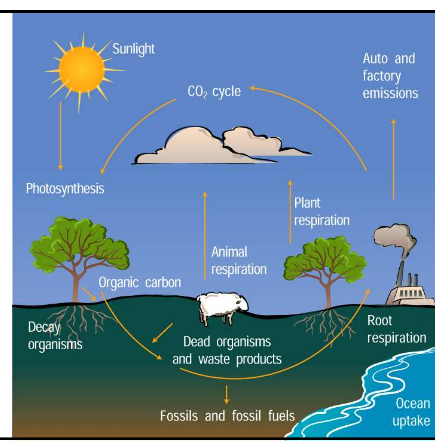

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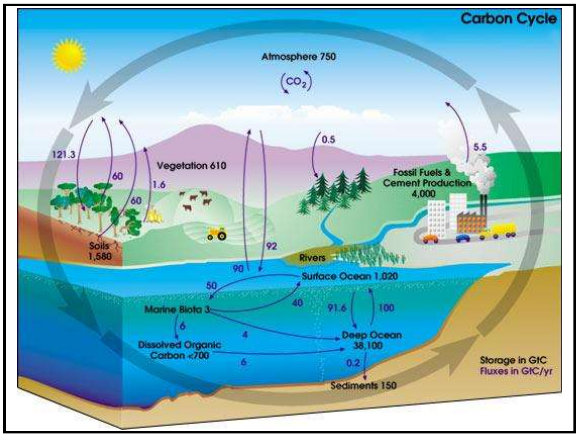

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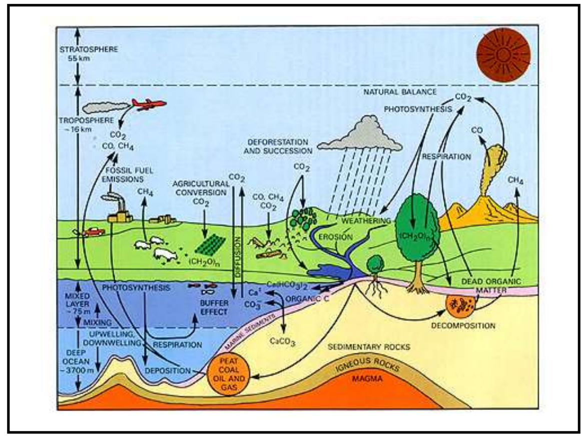

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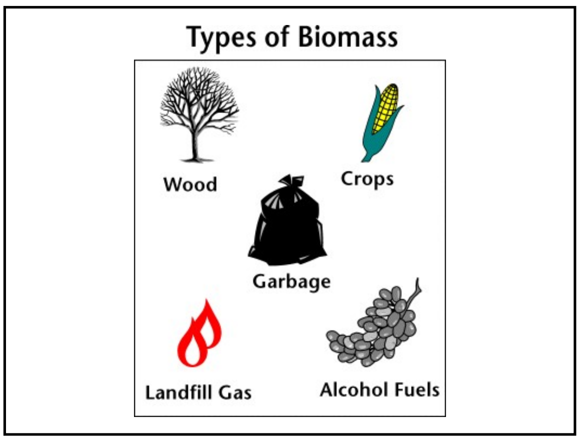

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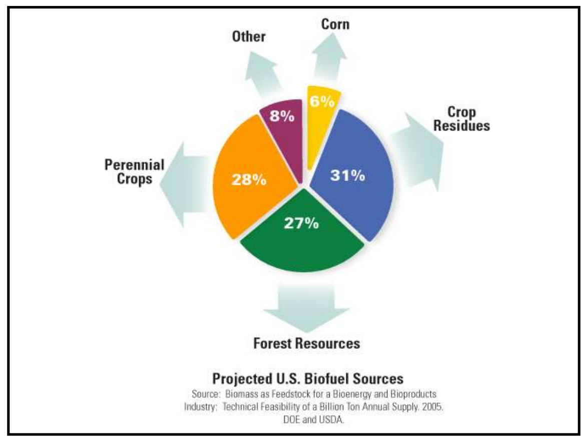

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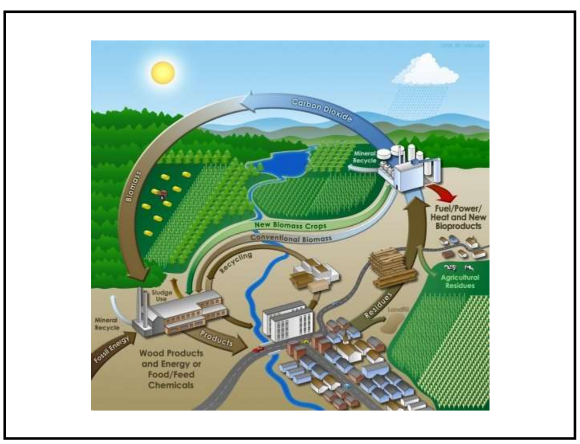

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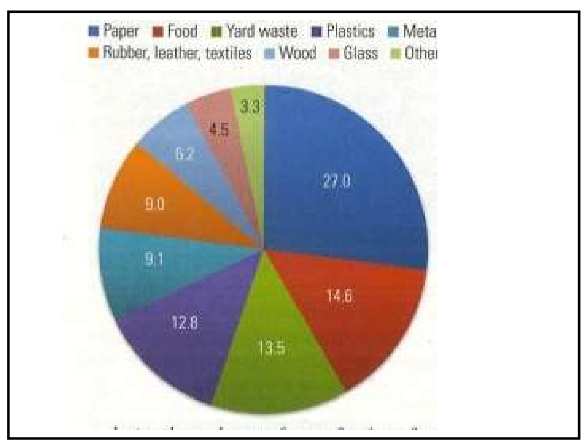

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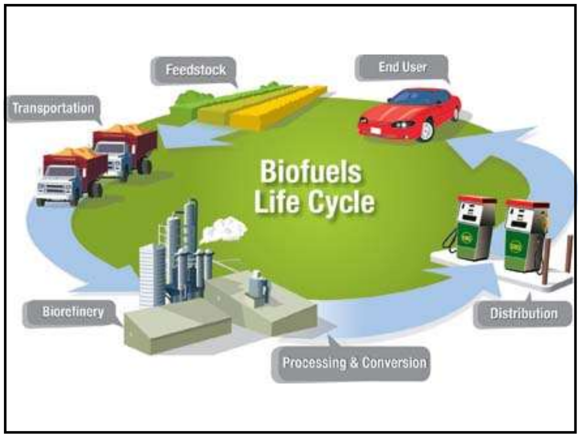

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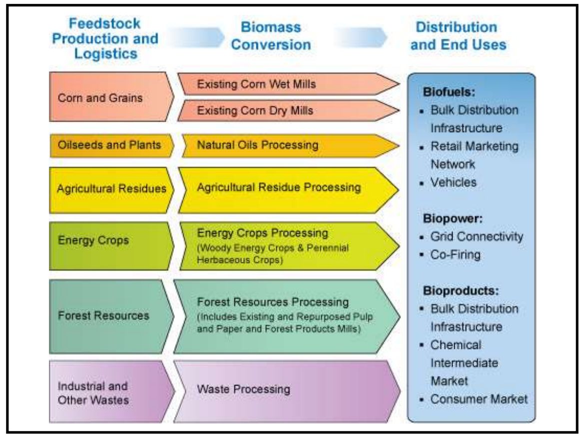

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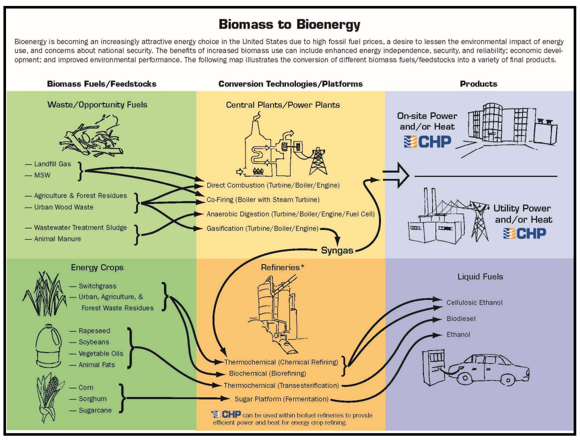

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Benefits

- Combustion does not add to the carbon dioxide buildup since carbon dioxide emitted is collected by the next crop of biomass
- Supports local agriculture and forestry industries
- Supports the development of new domestic industries
- Production can be either local and can occur on a large scale
- Effectively carbon neutral because if emits as much carbon dioxide when burned compared to being decayed

400

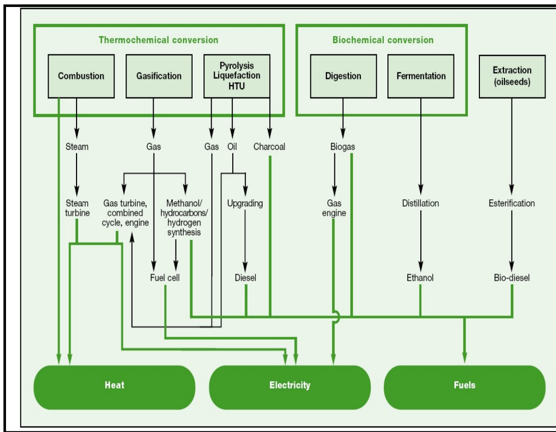
Biomass power plants

- Advantages
  - Biomass fuel is inexpensive
  - Biomass is low in sulfur
  - Biomass plants can operate continuously
  - Methane can be generated

401

- Disadvantages
  - Disposal of waste products
  - Ensuring proper combustion to prevent the release of more harmful products into the air than fossil fuel sources
    - Mercury
    - Lead
    - Dioxin
    - Sulfuric acid
    - Fluorides
    - Cadmium
  - Foul smell

402



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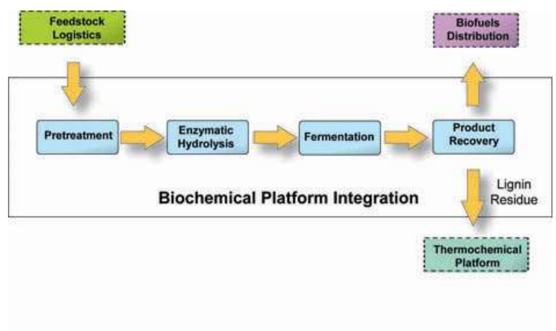

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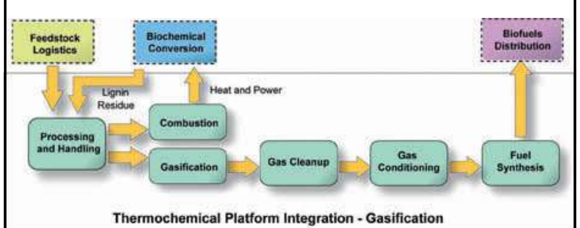

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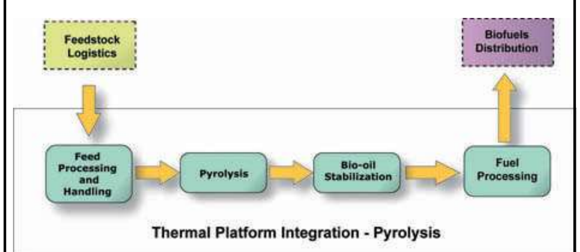

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Biomass fuels

- Ethanol
- Biodiesel

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Ethanol

- Liquid oil
- Conventional vehicles can use up to E25
- More expensive than gasoline
- Conversion efficiency is not great (35% more energy obtained than used to produce)
- Less energy dense than gasoline (kW/pound)

408

Ethanol page 2

- When added to gasoline improves
  - Ethanol contains much oxygen and improves combustion in the engine (flex fuel vehicles)
  - Octane levels are higher than gasoline, engines perform with less knocking
- Its renewable, sustainable and environmentally neutral
- Reduces dependence on foreign oil
- Creates new jobs

409

Ethanol problems

- Produced from corn, in 2006, about 12% of US production went to ethanol, resulting in an increase in world food prices
- Corn production requires a lot of
  - Energy
  - Water
  - Labor
  - Fertilizers
- Modern machine intensive farming techniques degrade the environment
- Options to corn
  - Sugarcane
  - Switch grass
- Produced in only a few states located in the Corn Belt requiring transportation costs to get it to oil using areas such as the coast

410

Ethanol methods

- Pyrolysis
  - Thermochemical process uses high temperature heating to condense carbon compounds
  - Oldest and most widely used method
- Fermentation
  - Biochemical process that uses microorganisms to affect an anaerobic conversion of sugars into alcohol
- Synthesis
  - Converts biomass to gas using a liquefier
  - Holds the most long-term promise

411

Biodiesel

- An organic liquid that can be used as a supplement or in lieu of diesel fuel
- Currently twice as expensive as fossil fuel to make
- Can be conducted on a very small scale
- Mixed with conventional diesel
- B100 (pure biodiesel) solidifies at very cold temperatures
- Most common is B20 (20% biodiesel and 80% diesel)
- Can be made from
  - Waste products such as used cooking oil and animal fats
  - Soybeans

412

Biodiesel fuels

- Reduces dependence on foreign oil
- Can use small or large plants to produce
- Biodiesel plants can be distributed around the country
- Supplies of biodiesel are limited
- Production facilities are few and scattered
- Costs more than regular diesel

413

Burning biomass

- Wood pellets
  - Pellets are renewable and produce the lowest emissions of any solid fuel
  - Pellets can be burned very clean and efficiently
- Corn and other grains such as wheat, barley, rye, sorghum, soybeans
  - Readily available and cheap
  - Must be very dry
  - Consistent heating source
  - Clean burning

414

Corn disadvantages

- Must buy a stove dedicated to burning corn
- Storing corn takes up more room than wood pellets
- Corn can rot and has a limited lifetime of storage
- Home may smell too sweet

415

Anaerobic digestion

- Decomposition of organic matter and inorganic matter in the absence of molecular oxygen
- One of the oldest processes used to stabilize wastewater sludge
- Well understood process
- Process can generate sufficient digester gas to meet most of the energy needs for plant operation

416

Processes

- Hydrolysis
  - Large polymers are broken down by enzymes
- Fermentation (acidogenesis)
  - The formation of soluble organic compounds and short-chain organic acids
  - Volatile acids are produced along with carbon dioxide and hydrogen
- Methanogenesis
  - Bacterial conversion of organic acids into methane and carbon dioxide
  - Acetate, formaldehyde, hydrogen and carbon dioxide are converted to methane and water

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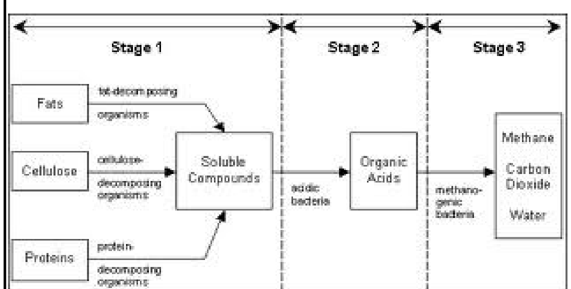


418

Factors to consider

- Solids retention time
- Hydraulic retention time
- Temperature
- Alkalinity
- pH
- Presence of inhibitory substances
- Bioavailability of nutrient and trace metals

419

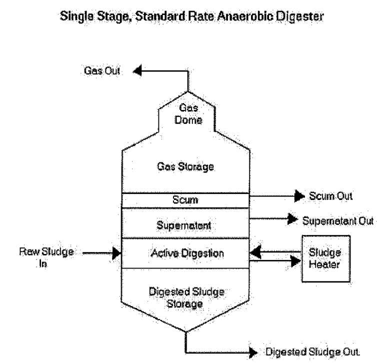
Conditions for Sludge Digestion

Temperature	Optimum General Range	98°F 85-95°F
pH	Optimum General Range	7.0-7.1 6.7-7.4
Gas production	Per pound volatile solids added Per pound volatile solids destroyed	8-12 cu. ft. 16-18 cu. ft.
Gas Composition	Methane Carbon Dioxide Hydrogen Sulfide	65-69% 31-35% Trace
Volatile Acid Concentration As Ascetic Acid	Normal Maximum	200-800 mg/L 2000 mg/L
Alkalinity Concentration As Calcium Carbonate	Normal	2000-3500 mg/L

Loading and Detention Times

	Single Stage Digester	High Rate Digeseter (First Stage)
Loading (1 lb.cu.ft./day of VS	.02 - .05	.1 - .2
Detention time (days)	30 - 90	10 - 15
Capacity of Digester (cu.ft./pop. equivalent)		
Primary	2 - 1	.4 - .6
Primary and Secondary	4 - 6	.7 - 1.5
Volatile Solids Reduction	50 - 70	50

420



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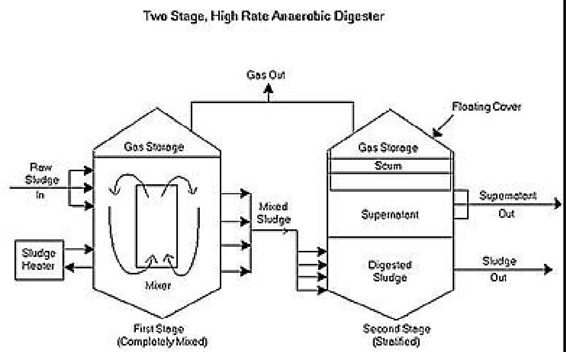

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Cylindrical digesters

- Advantages
  - Large volume for gas storage
  - Can be equipped with gas holder covers
  - Low profile
  - Conventional construction possible
- Disadvantages
  - Inefficient mixing and dead spaces
  - Silt and grit accumulation
  - Scum accumulation and foam formation
  - Digester may need to be taken out of service for cleaning

423

424

Egg-shaped digester

- Advantages
  - Minimum grit, accumulation and foam formation
  - Higher mixing efficiency
  - More homogeneous biomass
  - Lower O & M costs
  - Smaller footprint
- Disadvantages
  - Very little gas storage volume
  - Aesthetically objectionable
  - Difficult to access top-mounted equipment
  - Greater foundation design required
  - Higher construction costs
  - Must use specialty contractors to construct

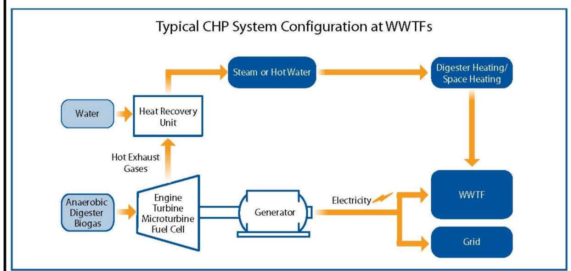
425

426

Combine heat and power (CHP)

- Production of both power and electricity from a single fuel (digester gas)
- A reliable and cost effective option for a WWTP
- Requires anaerobic digestion
- Generate power via a microturbine, a turbine, a fuel cell or a reciprocating engine
- Thermal energy produced by the CHP when generating electricity is used to heat the digester and for space heating

427



http://www.epa.gov/chp/markets/wastewater.html

428

CHP engineering details

- About 1 ft^3 of digester gas can be produced per person per day
- 1 ft^3 of digester gas can provide 2.2 watts of power
- Heating value of digester gas is 600 BTUs per ft^3
- For each 4.5 MGD processed at a WWTP, the generated digester gas can produce 100 kW of electricity and 12.5 million BTUs of thermal energy

429

CHP facility

- Produces power at a cost below retail electricity
- Reduces operating costs by displacing purchased fuels for thermal needs
- Ensures the availability of reliable heat and electricity supply
- Increases energy efficiency, reduces GHG emissions, and generates renewable power

430

CHP electricity/heat

- Sell back to the grid as green power
- Used to operate pumps and blowers used throughout the WWTP
- Used to maintain optimal digester gas temperatures, dry the biosolids and provide space heating

431

Generating technology

- Reciprocating engines best for any WWTP and most widely used technology
- Microturbines and fuel cells can be used to generate up to 1 MW with wastewater flows <50 MGD
- Combustion turbines can be used to generate >1 MW and for wastewater flows >50 MGD

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CHP cost data

- $.03-$.065/ kWh for a 126 kW microturbine
- $.091 - $.102/ kWh for a 300 kW fuel cell
- $.001 – $.038/ reciprocating engine

433

Benefits

- Uses less fuel at the WWTP
- O & M costs reduced
- Displaces fossil fuels for boilers
- Reduces need to purchase electricity
- Since biogas is a green power, can be eligible for renewable energy credits (RECs)
- Monetary sale of RECs can cover capital costs
- If all WWTPs >5 MGD with anaerobic digesters went to CHP, they could generate about 340 MW of electricity, offsetting 2.3 million metric tons of carbon dioxide (equivalent of 430,000 cars)

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WWTP questions

- Flow >5 MGD
- Pay more than $0.06/kWh for electricity
- Reliable high quality power and thermal energy important
- Important to reduce energy costs and increase overall energy efficiency
- Increase facility's environmental performance

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Power Generation - Microturbines

- Advantages
  - Low gas flow
  - Lower temperature
  - Lower emissions of pollutants
  - Flexible
- Disadvantages
  - Low flow range
  - New technology

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Microturbines

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Medium BTU Use - Boilers, Dryers, Space Heating

Advantages:

- Low capital, O & M costs
- Low system equipment and design requirements
- Higher LFG extraction rates possible
- Lower NOx emissions than conventional fuels

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Landfill Gas-Fed Boiler

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More info

USEPA
www.epa.gov/chp

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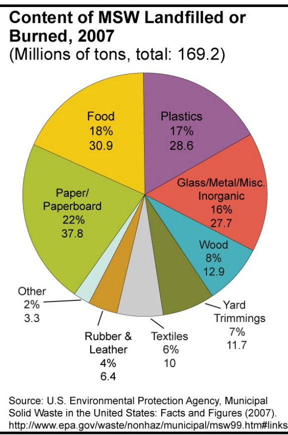

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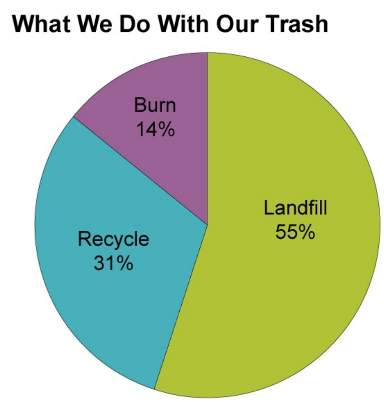

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MSW handling

- Disposal in landfill
  - Main method of choice
- Combustion
  - Expensive
  - Can create significant air pollution problems
  - Banned in DE
  - Can capture heat
- Anaerobic digestion
  - Occurs at wastewater treatment plants
  - A part of landfill gas production
  - Extraction of useful energy possible

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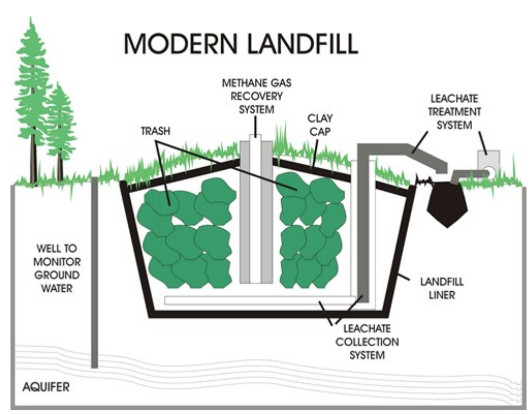

444

Landfill Biogas

- Use a CHP approach
- Gas generation via anaerobic digestion
- Generation over many years
- Typically, 6,000-12,000 ft^3 of gas per ton of waste
- Landfill gas is typically 50-60% methane
- Typical site containing 1.1 million tons of waste can produce 2 MW

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Estimates of Gas Production Rates

- Rapid degradation conditions: 3 to 7 years (4 to 10 L/kg/yr)
- Moderate degradation conditions: 10 to 20 years (1.5 t 3 L/kg/yr)
- Slow degradation conditions: 20 to 40 years (0.7 to 1.5 L/kg/yr)

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Estimating Landfill Gas Production Rates - Gas Generation

- Minimum: Tons in place x 0.25= ft^3/d
- Average: Tons in place x 0.5 = ft^3/d
- Maximum: Tons in place x 1.0 = ft^3/d

Tons in place = Average Depth X Acres x 1000

(Assumes 1200 lb/yd^3)

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EPA Emission Rate Model

$$Q_T = \sum_{i=1}^{n} 2kL_o M_i e^{-kt_i}$$

Where:

- Q_T = total gas emission rate from a landfill, mass/time
- k = landfill gas emission constant, $time^{-1}$
- L_o = methane generation potential, volume/mass of waste
- t_I = age of the i^{th} section of waste, time
- M_I = mass of wet waste, placed at time i
- n = total time periods of waste placement

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Steps for Gas Collection System Design

- Calculate annual gas production (peak)
  - LandGEM (use realistic k, L_o values, for example $k = 0.1\ yr^{-1}$ for 20 yrs)
- Pick type of system (passive, active, vertical, horizontal, combination)
- Layout wells
  - 30-40 scfm/well
  - 100-300 ft spacing

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Steps for Gas Collection System Design - Cont'd

- Size blowers (calculate pressure drop)
- Calculate condensate
- Prepare gas monitoring plan
- NSPS calculations using default values

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Gas Composition - Major Gases

- Methane (45 - 60 % by volume)
- Carbon Dioxide (40 - 60 % by volume)
- Nitrogen (2 - 5 % by volume)
- Oxygen (0.1 - 1.0 % by volume)
- Ammonia (0.1 - 1.0 % by volume)
- Hydrogen (0 - 0.2% by volume)
- Hydrogen Sulfide (0 – 3% by volume)

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Gas production

- May have regulatory issues
  - NSPS
  - NESHAP
  - RCRA Subtitle D

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Beneficial Reuse Applications

- Flares
- Boilers
- Microturbines
- Vehicular Fuel
- Synthetic Fuels
- Electric Power Generation
- Pipeline Quality Natural Gas

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Gas Cleanup

- Particulate removal
- Condensate removal
- Trace compound removal
- Upgrading to natural gas quality

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Pipeline Quality Natural Gas

Advantages

- Large market of stable, continuous, long-term demand
- Easy access to wide energy distribution network
- Low pollutant emissions
- By-product CO_2 has market value

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Pipeline Quality Natural Gas

Disadvantages:

- Strict limits on oxygen and nitrogen restrict LFG extraction
- High parasitic energy requirements
- High capital and operating costs
- Uneconomical for smaller landfills
- Low current and forecast energy prices hinder feasibility

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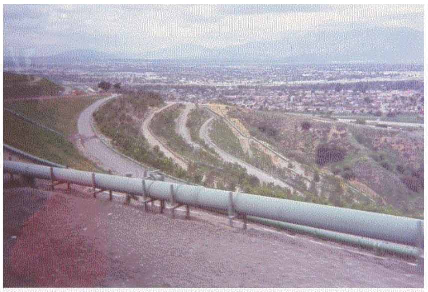
Pipeline



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Vehicular Fuel

Disadvantages:
- Strict limits on oxygen and nitrogen restrict LFG extraction
- High parasitic energy requirements
- High capital and operating costs
- Major engine modifications required
- Limited distribution network
- Uneconomical for small landfills

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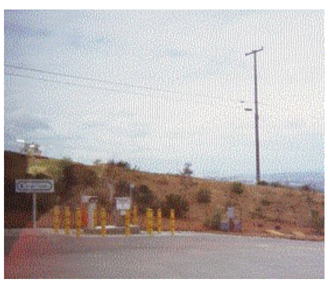
Vehicular Fuel



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Synthetic Fuels and Chemicals

Advantages:

- Large and varied markets for fuels and chemicals
- Low pollutant emissions in processing
- Simplified modular processing system design
- By-product CO_2 has market value

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Synthetic Fuels and Chemicals

Disadvantages:

- Strict limits on oxygen and nitrogen restrict LFG extraction
- High parasitic energy requirements
- High capital and operating costs
- Uneconomical for smaller landfills

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Burning wood

- Wood burning stoves are an efficient alternative to fireplaces
- Burning the right type of wood can have a significant effect
  - Hardwoods are preferred
  - Seasoned wood is preferred
- Wood waste can be used in a power plant

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HYDROGEN FUEL CELLS

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Hydrogen

- Hydrogen is the simplest and most abundant element in the universe
- Main component of water
- One of the basic atoms in carbohydrates
- Most important element in the universe
- Main source of energy
- Most common element used in fuel cells

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Sources of hydrogen

- Water
- Hydrocarbon fuels (fossil fuels)
- Carbohydrates (food and biomass)

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Extracting hydrogen

- Steam reforming
  - Converts natural gas to hydrogen by combining methane with steam
- Coal based steam reforming
  - Combining coal, oxygen and steam under pressure and temperature
- Plasma waste
- Electrolysis
- Biomass gasification
- Thermal dissociation

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Electric vehicles

- Uses hydrogen and oxygen
- Exhaust is water
- Higher voltages used can pose a safety risk
- Hybrid vehicles
  - Series
  - Parallel

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Typical battery types

- Lead acid
- Nickel cadmium
- Nickel metal hydride

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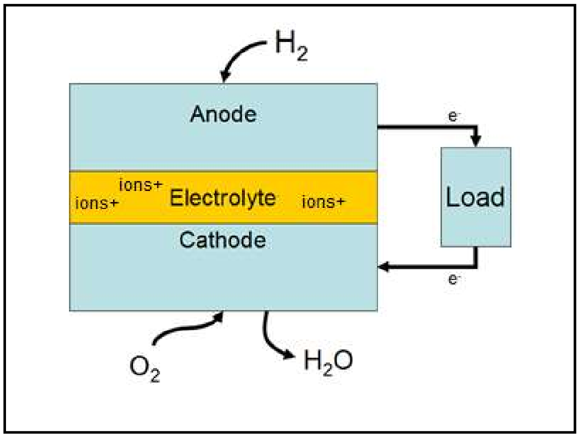

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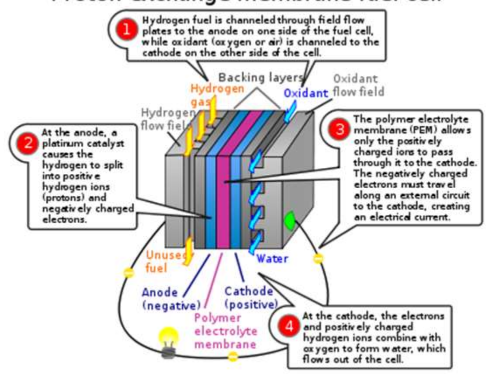
Proton exchange membrane fuel cell



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Likely fuel cell uses

- Rural homes off the grid
- Portable devices that use batteries
- Electric cars
- Other automobiles

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Fuel cell powered vehicles

- Better efficiencies than conventional engines
- Vehicles are lighter because there is no need for heavy mechanical drivetrains
- Infrastructure will need to be provided to supply the hydrogen
- Considerably less environmental effects since there is little pollution
- Currently costly
- Hydrogen can be manufactured locally and doesn't need a refinery
- Operating range is less than a fossil fuel fired vehicle
- Onboard storage of hydrogen is not available or safe
- Currently present maintenance issues since there is little available at this time

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Problems with fuel cells

- Lifetimes and reliability must be improved
- Fuel cell vehicles currently cost over $100,000
- Hydrogen fuel prices must come down
- Hydrogen fuels from fossil fuels are the cheapest option
- Hydrogen gas is easily ignitable
- Transport of hydrogen can be problematic
- Finding an effective way to deliver hydrogen to the fuel cells
- Compressed hydrogen gas has a low density
- Technologies to incorporate onboard partial oxidation reformers in vehicles are immature

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MICROBIAL FUEL CELLS

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Microbial Fuel Cells (MFCs)

Devices that can use bacterial metabolism to produce an electrical current from a wide range organic substrates.

MFC is a device that uses microorganisms to generate an electrical current through the oxidation of organic material

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MFCs

Microbial fuel cells (MFCs) are a device that converts chemical energy to electrical energy during substrate oxidation with the aid of microorganisms that act as biocatalysts.

The energy contained in organic matter is converted to useful electrical power.

An MFC operates as electrons from the microorganisms transfer from a reduced electron donor to an electron acceptor at a higher electrochemical potential.

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The first practical devices to be powered by MFC technology were reported in 2008.

Meteorological buoys capable of measuring air temperature, pressure, relative humidity, water temperature, and transferring data via real-time line of sight radio frequency telemetry were exclusively powered by benthic MFCs.

Benthic MFCs generate power through the microbial oxidation of organic substrates in anoxic marine sediments coupled to reduction of oxygen in the overlying water column.

Electrons are generated from the metabolism of the naturally occurring microorganism in the marine sediments.

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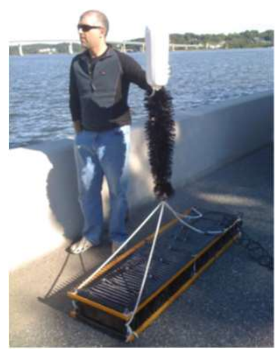

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Possible Sources

The range of compounds include, but by no means limited to:

- Acetate
- Glucose
- Starch
- Cellulose
- Wheat straw
- Pyridine
- Phenol
- *p*-nitrophenol
- Domestic waste water
- Brewery waste
- Land fill leachate
- Chocolate industry waste
- Mixed fatty acids
- Petroleum contaminates

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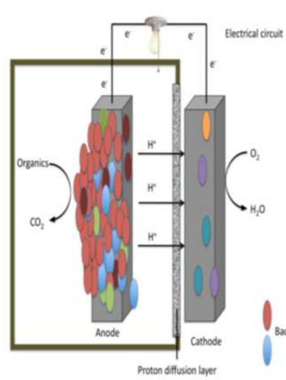

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- Anode: $C_6H_{12}O_6 + 6 H_2O \rightarrow 6 CO_2 + 24 H^+ + 24e^-$
- Cathode: $24 H^+ + 24 e^- + 6 O_2 \rightarrow 12 H_2O$

481

Universiti Kebangsaan Malaysia Study

- Tested On
  - Palm oil mill effluent
  - Landfill leachate
  - Activated sludge

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Results

- An MFC has the ability to generate electricity from the wastewater while simultaneously removing carbon and nitrogen. The highest rate of voltage generation is achieved when the MFC is operated with leachate followed by POME and activated sludge.
- Activated sludge provides the most consistent record for the electricity generation.
- The highest efficiency of COD removal is achieved by activated sludge (37.5 %), followed by leachate (6.11 %).
- The electricity voltage generation and the rate of the carbon and nitrogen removal for the activated sludge have been shown to be the most efficient among the three types of samples.

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Nitrogen Effects from MFC

The activated sludge also showed the highest efficiency for nitrogen removal (65.28 %), followed by POME (48.12 %) and leachate (25.15 %).

	Ammonia N (mg/L)	Organic N (mg/L)	TKN (mg/L)
Before MFC	112	17	129
After MFC	28	17	45

484

Additional Reading

- Alternative Energy for Dummies, DeGunther, Wiley Publishing, Inc., 2009.
- Our Energy Future, Ngo and Natowitz, Wiley Publishing, Inc., 2009.
- Fundamentals of Renewable Energy Processes, 2nd Ed., da Rosa, Academic Press, 2009.
- Renewable Energy: Power for a Sustainable Future, 2nd Ed., Boyle (Editor), Oxford University Press, 2004.
- US DOE Energy Information Administration, http://www.eia.doe.gov

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- THE END -

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