Nonrenewable Energy Resources

Chapter 12

- First Earth Day 1970s
- 1969 Santa Barbara - oil well explosion & rupture (blowout)
  11.4 million liters spilled into Santa Barbara channel
- 1989 Prince William Sound, Alaska supertanker that crashed into area
  42 million liters
- 2010 BP Deepwater Horizon oil well Gulf of Mexico
  killed 11 workers, injured 17
  780 million liters

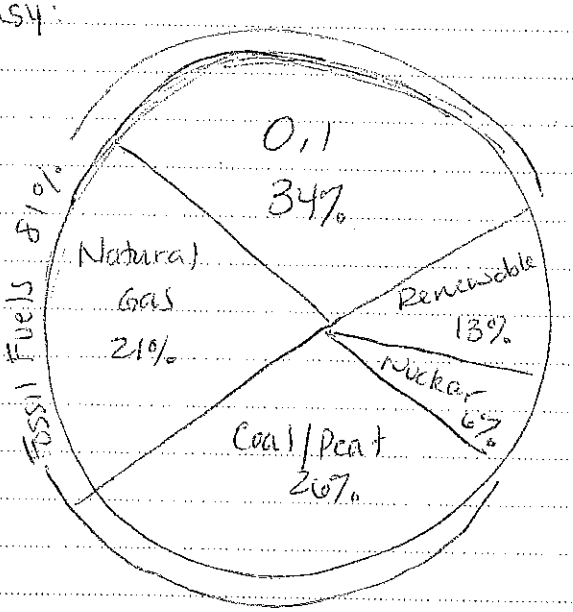
nonrenewable - once used up can't be replenished

two categories -

① fossil fuels - derived from biological material that became fossilized millions of years ago
Ex. coal, oil, natural gas

② nuclear fuels - derived from radioactive materials that give off energy

Worldwide Energy:



Commercial Energy - those that are bought & sold, such as coal, oil & natural gas. Sometimes wood, charcoal & animal waste are bought & sold

Subsistence Energy Sources - those gathered by individuals for their own immediate needs

US Energy Patterns -

1875 - Predominantly wood
1875 - 1900s - Coal
1900s - 1950 - Natural Gas & Oil
1970s - mixed in nuclear energy
Today - Oil, Natural Gas & Coal

° way to determine the best source to use is to consider energy efficiency; both the efficiency of the process of obtaining the fuel and the efficiency of the process that converts it into the work that is needed

° Embodied Energy - all other energy inputs

° EROEI - Energy return on energy investment

$$EROEI = \frac{\text{Energy obtained from the fuel}}{\text{Energy invested to obtain the fuel}}$$

Ex. In order to obtain 100J of coal from a surface coal mine, 5J of energy is expended

$$EROEI = \frac{100\,J}{5\,J} = 20$$

° Primary sources of Energy - Coal, oil, & natural gas

° Secondary sources of Energy - electricity

energy carrier - something that can move & deliver energy in a convenient, usable form to end users

° turbine - large device that resembles a jet/fan engine. As energy in steam turns turbine shaft @ center of turbine turns the generator which generates electricity

° electrical grid - network of interconnected transmission lines that connect power plants together & links them with end users of electricity

° Combined cycle - natural-gas fired power plant (two turbines & generators)

° Coal plant 35% efficient

° Capacity - maximum electrical output

US ~ 500 MW

° Most power plants do not operate every day & year due to maintenance, refueling or repairs

° Capacity factor - the fraction of the time the plant is operating

Ex. thermal power plant 0.9 or greater

wind - 0.25

° Cogeneration - use of a fuel to generate electricity & produce heat

aka combined heat & power

- efficiency as high as 90%, whereas steam alone 75% or electricity alone 35%

° Coal, oil & natural gas come from deposits of organic matter that were formed over 50 million - 350 million years ago

Coal

coal - solid fuel formed primarily from the remains of trees, ferns, & other plant materials that were preserved 280 million - 360 million years ago

4 Types

① Vegetation dies & is buried under anaerobic conditions forming peat. The peat is compressed between sediment layers to form lignite

② Further compression yields sub-bituminous & bituminous coal

③ After more pressure & time anthracite forms

* based on age, exposure to pressure & energy content

° largest coal reserves - US, Russia, China & India
° greatest producers of coal - China, US, India & Australia

pros
- energy dense
- plentiful
- easy to exploit/mine
- economic cost low to mine
- little refining before burned
- easy transport (barge, truck, train)

cons
- contributes to acid rain
- subsurface coal more expensive to obtain
- health consequences (black lung)
- contains number of impurities including sulfur which is released to the atmosphere when burned
- Ar, Hg & Pb found with coal
- SO_2 air pollutant produced
- Coal plants slow to reach operating capacity

Ex. Knoxville Tenessee 2008
retaining wall that contained ash gave way & spilled 4.1 billion L of ash from burned coal covered 121 ha of land
cleanup still ongoing

Coal Pollutants - CO_2, Sulfur, toxic metals ex. mercury

Petroleum

° Petroleum - fluid mixture of hydrocarbons, water, & sulfur that occurs in underground deposits
- formed from the remains of ocean dwelling phytoplankton that died 50 million to 150 million years ago
→ found in locations where porous sedimentary rocks (sandstone) capped by nonporous rocks
→ contains natural gas - gas flare @ oil wells to prevent explosion

° Crude oil - liquid petroleum removed from ground
- refined into a variety of compounds
ex. tar, asphalt, gasoline, diesel & kerosene

° Petroleum is also the raw material for petrochemicals such as plastics, lubricants, raw materials for pharmaceuticals & cleaning solvents

° Top Petroleum Producing Countries -
Saudi Arabia
Russia
US
Iran
China
Canada
Mexico

° Pros: liquid form convenient to transport & use, energy dense, cleaner burning than coal, quick ignition
→ environmental hazard, significant refining, hydrocarbons, Hydrogen Sulfide

° Cons: releases CO_2, only 85% as efficient as coal, contains sulfur & trace metals such as mercury, lead & arsenic, spills (Exxon Valdez 1989, 2010 BP Deepwater Horizon → 780 million liters, 1991 Persian Gulf War → 912 million liters

° Roughly 85% of the oil entering marine waterways came from runoff from land and rivers, airplanes, and small boats and personal watercraft including deliberate and accidental releases of waste oil

° ANWR (Artic National Wildlife Refuge) Debate
- allow for oil exploration ~95 billion liters - 1.6 billion liters
- natural gas potentially there
- will affect pristine wildlife habitat & affect people in that

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Natural Gas

- 80-95% CH_4 (methane)
- 5-20% ethane, propane & butane
- used for electricity & industrial processes
- creates N fertilizer
- Residences - cooking, heating, dryers & water heaters

Pros

- ½ homes use natural gas
- easy to transport
- Cogeneration - efficiency up to 60%
- effluent for cooking, heating

Cons

- emits methane & CO_2
- leaks / explosions
- thumper trucks
- uses large quantities of H_2O
- groundwater contamination
- pipeline to transport beads new

Other Fossil Fuels: Oil Sands & Liquefied Coal

Oil Sands - slow-flowing, viscous deposits of bitumen mixed with sand, water & clay

Bitumen - called tar or pitch is degraded type of petroleum that forms when a petroleum deposit is not capped with nonporous rock

- much more energy intensive to mine bitumen
- uses 2-3L H_2O for every L of bitumen
- needs to be refined

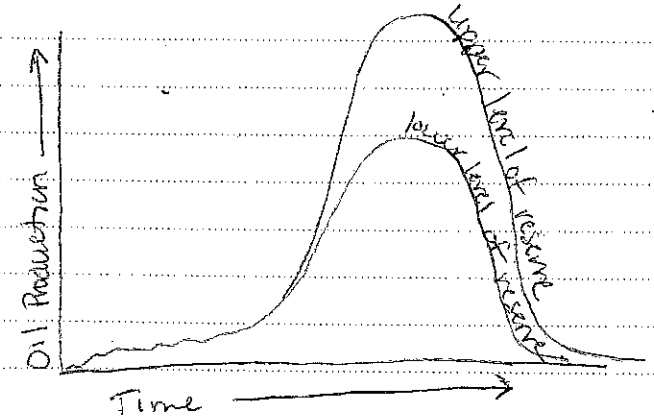
CTL (coal-to-liquid) - process by which solid coal is converted to a liquid form using technology

- used by Germany in WWII
- expensive
- environmental impact

energy intensity - energy used per unit of gross domestic product

The Hubbert Curve

- 1969 M. King Hubbert - geophysicist who made a graph that shows oil use



Hubbert Curve - projected the point at which world oil production would reach a maximum & the point at which we would run out of oil

- predicted oil extraction & use would increase steadily until roughly half the supply had been used up
- about 40 years left (80% oil used)

Peak oil - extraction & use would begin

between the fuel the fission reaction became to- ent

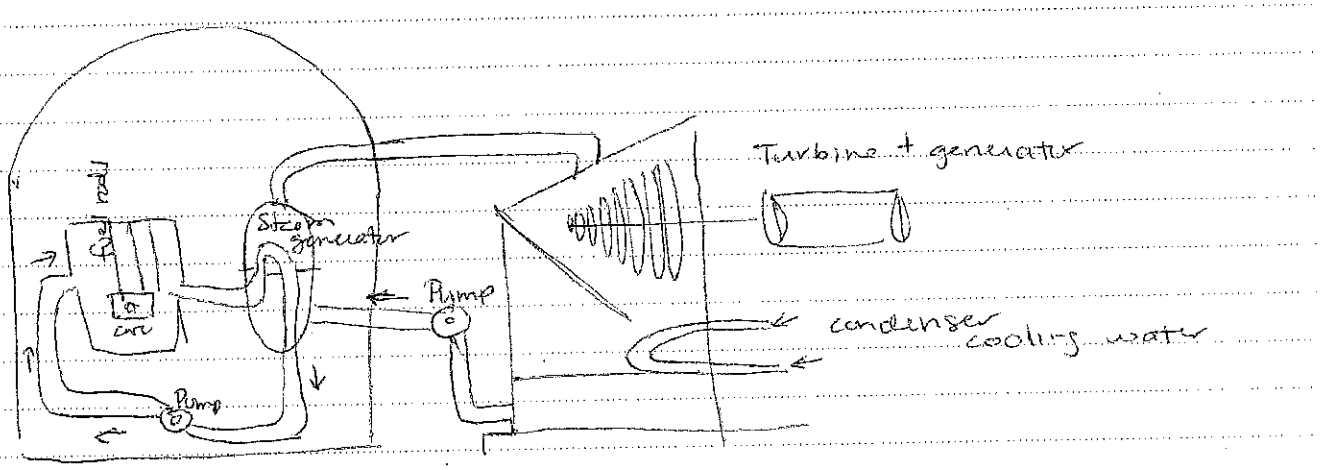
- run out of conventional oil supplies in less than 40 years
Natural Gas supplies slightly longer
Coal supplies at least 200 years
- A conventional nonrenewable fuel that doesn't contribute to significant greenhouse gases is uranium

Nuclear
- relatively low emission of CO_2
- uses uranium-235 (^{235}U) as its fuel source - goes through a process known as fission

fission - nuclear reaction in which a neutron strikes a relatively large atomic nucleus which then splits into two or more parts, the process releases additional neutron and energy in the form of heat. Additional neutrons promote additional fission reactions
- used heat to produce steam
- 1g ^{235}U contains 2-3 million times the energy of 1g coal
- neutron colliding with ^{235}U splits uranium into smaller atoms such as barium & krypton

$$1 \text{ neutron} + {}^{235}U \rightarrow {}^{142}Ba + {}^{91}Kr + 3 \text{ neutrons}$$

- byproduct - radioactive waste



Containment structure encloses nuclear fuel contained in fuel rods & steam generator. ^{235}U processed into pellets & put into fuel rods. Nuclear fission is used to heat up the water where steam is produced to turn a turbine which turns a generator

Control rods - cylindrical devices that can be inserted between the fuel rods to absorb excess neutrons, thus slowing or stopping the fission reaction
- done because nuclear rods left uncontrolled will become too hot & melt which could lead to a nuclear accident
- inserted during maintenance or emergency
- 900kg ^{235}U to produce 3kg nuclear fuel
- most uranium occurs with ^{238}U - doesn't fission easily

Pros
- don't produce air pollution during operation - "clean energy"
- way to become independent from foreign oil
- low CO_2 emissions
- independence from imported oil
- High energy density

Cons
- release of radioactivity
- uncertainty to appropriate locations for radioactive waste disposal
- fall into hands of individuals making a nuclear weapon
- possibility of accidents
- unpopular
- expensive to build
- possible terrorist attack

Accidents
March 28, 1979 - Three Mile Island, PA
° operators did not notice that a cooling water valve had been closed the previous day. Oversight led to lack of cooling water which the reactor then overheated & partially melted down
° unknown amount of radiation leaked to environment
~ 200,000 people evacuated area
April 26, 1986 Chernobyl, Ukraine
° occurred during a test of the plant
° violated safety regulations by disconnecting emergency cooling systems & removed control rods ⇒ overheated & led to an explosion
° 31 plant workers & firefighters died from radiation exposure & burns
° winds blew radiation across Europe
~ 4,000 cancer deaths
~ 5,000 cases of thyroid cancer

Radioactive Waste - nuclear fuel that can no longer produce enough heat to be useful in a power plant but continues to emit radioactivity
3 kinds of waste
① high-level waste - form of fuel rods
② low-level waste - form of contaminated protective clothing,

tools, rags & other items used in routine plant maintenance
③ uranium mine tailings - residue left after uranium ore is mined & enriched
- Disposal of all 3 types regulated by the government
- ^{235}U half life of 704,000,000 years
- measure radiation
  becquerel - (Bq) measures rate at which a sample of radioactive material decays
    1 Bq = decay of one atom/second
  curie - unit of measure for radiation
    37 billion decays/second
- currently required to keep spent fuel rods at plant
  - stored in pools 6m deep - shields from radiation
  - running out of pool space so putting waste in lead barrels
- radioactive waste can't be incinerated, safely destroyed using chemicals, shot into space (expensive), dumped on ocean floor or buried in ocean trench
  ⇒ potential for large amounts of radioactivity to enter atmosphere or ocean
  - must be stored permanently somewhere where it can't leach into groundwater, far from human habitation & be secure against terrorist attacks & be able to be transported there
- 1978 US Dept Energy looked at Yucca Mt, Nevada as a possible storage site
  - generated enormous protest
  - research presented soundness of site but change in president's project cancelled

Fusion Power
Nuclear fusion - reaction that powers the Sun & other stars, occurs when lighter nuclei are forced together to produce heavier nuclei
- great deal of heat generated
- H ion + H ion = He atom
- seemingly unlimited source that require H as an input & produces small amts of radioactive waste
- Need temps 10x that of sun
- Currently only way to do it is to suspend superhot material into a magnetic field but amt. energy required greater than output of energy

Achieving Energy Sustainability

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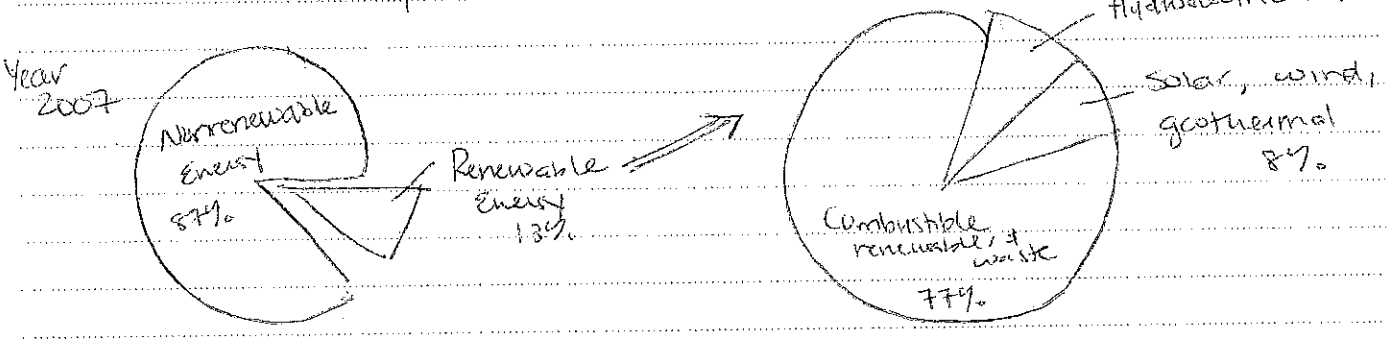
nonrenewable - finite amount to consume

potentially renewable - sources of energy can be regenerated rapidly as long as its not consumed quicker than it can be replenished

nondepletable - amount available tomorrow does not depend on what is used today.

renewable - energy source that is potentially renewable or nondepletable

13% of energy use worldwide



Nonrenewable = natural gas, coal, oil, nuclear

potentially renewable = wood, biofuel

- overharvesting - deforestation / degradation of land

Nondepletable = wind, solar, hydroelectric, geothermal

- kill unintentionally birds, bats, fish, require heavy metals to produce photovoltaic solar panels

energy conservation - finding ways to use less energy

ex. lower thermostat during cold months, turning off computer when not in use etc.

- Gov't facilitate energy conservation by taxing electricity, oil, natural gas (discourages use), tax credits
- some companies use a tiered rate system - customer pay a lower rate for first increment of electricity they use & pay higher rates as use goes up.
- Ex. energy efficient appliances, LED lights

Power Plants need to be able to handle high use periods or brownouts or blackouts occur. must provide enough energy to satisfy

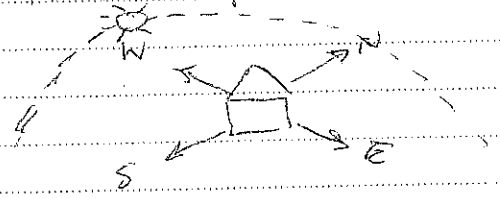
peak demand - greatest quantity of energy used at any one time

Sustainable Design

- Improves efficiency of building / communities
- Building

Ex. skylight, high efficiency windows, adequate insulation & sealing of cracks, high efficiency heating & cooling systems, insulated foundation walls / basement floors

- orient house in correct direction
  Ex. N. Hemisphere



Passive solar design - technique that takes advantage of solar radiation to maintain a comfortable temperature in the building
- stabilizes indoor temps w/o pumps/mechanical devices
- face windows in south facing wall to warm in winter
- Dark material on roof/exterior to absorb solar energy
- Light material on roof to reflect solar energy
- Overhang on roof helps block light at midday to keep house cooler
- window shades help reduce solar energy entering house
- solar panels
- use materials with thermal inertia to build structure
  thermal inertia - ability of a material to retain heat or cold
  Ex. stone + concrete
- green roofs - help cool + shade buildings + improve air quality
- Recycled items used in construction. For instance denim as insulation + fly ash from coal in foundation
- California Academy of Science Building ⇒ very efficient

Biomass
- encompasses wood, charcoal, animal products, plant remains + municipal solid waste (MSW)
- wood/manure 10% world energy consumption
- Biomass can be processed/refined into liquid fuels such as ethanol + biodiesel
  biofuels - liquid fuels created from processed or refined biomass
  3.5% energy use in USA

modern carbon - carbon in biomass
fossil carbon - carbon in fossil fuels ⇒ buried for millions of years + has been out of circulation
* Theoretically modern carbon burning should not result in a net increase in atmospheric CO_2 concentration because it has recently been there

Biomass pro - potentially renewable, eliminates waste from environment
available to everyone, minimal technology
con - deforestation, erosion, indoor/outdoor pollution,
possible net increase of greenhouse gases, CO, Chapter 13
particulate matter, NO_x, toxic metals

Also, the biomass that will grow plant will take up the CO_2 released by burning the modern carbon = overtime carbon neutral

carbon neutral - an activity that does not change atmospheric CO_2 concentration

- 2 to 3 billion use wood for heating / cooking

net removal - removing more timber than is replaced by growth

* unsustainable practice that leads to deforestation, soil erosion, increased water temperature, fragmentation of habitat

- use charcoal as fuel source in most of developing world
- where wood is scarce (Africa & India) people use dried animal manure as fuel for cooking / heating
  * beneficial by removing harmful microorganisms from surroundings
  * released particulate matter & other pollutants into air
    ⇒ respiratory illness (emphysema to cancer)
- produces CO, NO_x, particulate matter when burning fossil fuels

Biofuels

Ethanol - is an alcohol that is made by converting starches & sugars from plant material into alcohol & CO_2
  * corn, sugarcane, wood chips, crop waste or switchgrass

Biodiesel - substitute for regular petroleum diesel
  * soybean or palm or algae (oil extract)

- USA world leader in ethanol production followed by Brazil
- gasohol - 9 parts gasoline 1 part ethanol

Flex-fuel vehicles - vehicles that can run on either gasoline or E85

* Ethanol has lower energy content than gasoline so less mileage/gal

- Corn - growing more fossil fuels
- Switchgrass - perrenial crop - minimizing soil disturbance / erosion
- Corn & sugarcane produce ethanol more easily due to sugar content

Biodiesel - direct substitute for petroleum based diesel fuel

- usually more expensive
- B20 80% petroleum 20% biodiesel
- diesel cars can be modified to be 100% straight vegetable oil

Liquid Biofuels: pros - potentially renewable, reduce dependence on fossil fuels, reduce trade deficit, more environmentally friendly
cons - loss of agricultural land, higher food costs, low gas mileage, possible net increase in greenhouse gas emissions (CO_2 + methane)

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Hydroelectricity - electricity generated by the kinetic energy of moving water
- 3rd most common type of renewable energy
- 20% energy world wide
- Lead producers: China, Brazil, USA
- amount of electricity generated at a plant depends on its flow rate, the vertical distance the water falls or both
  Higher the fall - more potential to generate electricity

Run of the River: water is retained behind a low dam & runs through a channel before returning to the river
- relatively little flooding occurs upstream
- seasonal changes of river flow are not disrupted
- generally small
- electricity generation can be intermittent
- if water flow low can't generate electricity or if frozen

Water Impoundment: storing water in a reservoir behind a dam
- most common type because it allows for on demand electricity generation by controlling gates to determine flow rate

largest dam in world → Ex. USA Grand Coulee Dam Washington State
→ China Three Gorges Dam Yangtze River
- approximately 11% china's total energy demand

Tidal energy: comes from the movement of water, although the movement is driven by the gravitational pull of the moon
Ex. France, Korea, Canada
- tides need to have great change in order to work

pro - non depletable, no cost after initial investment
con - disruptive effect on marine life, geographically limited

Dams

pros
- once built minimal amount to keep up
- generate large amts of energy w/o creating air pollution, waste products or CO_2 emissions
- usually less expensive for consumer than gas
- recreational activities in reservoir
- economic opportunities
- flood control
- nondepletable
- low cost to run

cons - siltation or accumulation of sediments behind dam
- upfront expensive costs
- reservoir floods huge area & displaces terrestrial organisms/people
- methane
- only can have so many in an area
- only certain species can live in habitat created by reservoir vs. free flowing river
- alters river dynamics/flood patterns
- some species depend on flooding/seasonal changes ex- salmon, trout, fish eat- clams & mussels
- release greenhouse gases (methane from decaying plants during construction & after dam built)

- create fish ladders to help some seasonal species although predators lead to monitor them

Siltation - accumulation of sediments behind dam on bottom of reservoir

→ reduces amount of water impounded over time due to build up. Fixed by dredging which uses fossil fuels

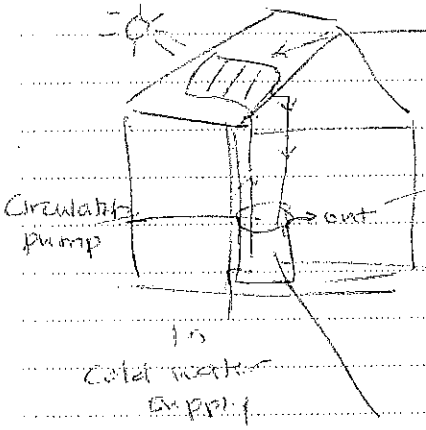
Some dams being dismantled: 1992 Edwards Dam removed in Maine
2007 Marmet Dam removed in Oregon

- Land native fish (bass, alewives, steelhead, salmon) return to water ways

Active Solar energy - technologies capture the energy of sunlight with the use of technologies

ex. small-scale solar water-heating systems
photovoltaic solar cells
large scale concentrating solar thermal systems

Solar water heaters



solar collector - heats circulating liquid (usually nontoxic antifreeze)

Hot water out → use for house

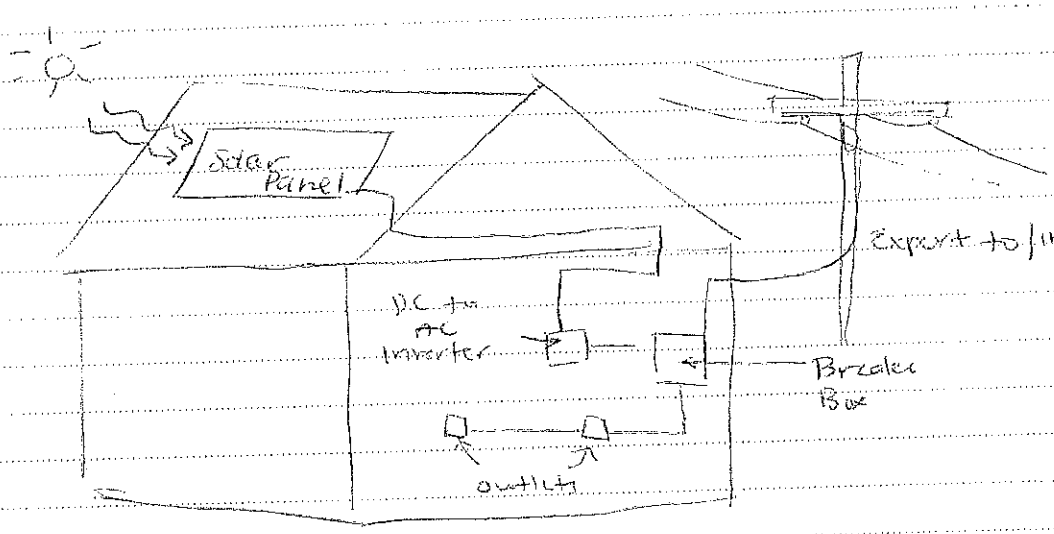
Hot water tank

heat exchanger - transfers heat from circulating fluid to water

Photovoltaic Solar Cells (PV) capture energy from the sun as light, not heat and convert it directly into electricity

- makes use of semiconductors - very thin ultrathin layers of material that generate low-voltage electric current when exposed to direct sunlight
- 12 - 20% efficient in converting the energy of sunlight into electricity
- can be on or off the grid
- US parking meters use it

PV System:



Concentrated Solar Thermal systems (CST)
- large scale application of solar energy to electricity generation
- uses mirrors/lenses/tracking systems to focus sunlight
- uses energy of sun + produce steam
- found mostly in deserts
- large amount of land required + can't generate at night

Active Solar Energy Systems

Pros
- can generate hot water or electricity w/o air pollution, water pollution or CO_2
- can produce on hot sunny days when demand is highest
- may be less expensive if uft grd solar panel vs. running transmission lines to house
- Germany - Subsidized solar panels
- US - tax breaks + rebates
- 30-50 years of energy
- nondepletable
- after initial investment no cost to harvest energy

Cons
- 5-20 years to pay back
- expensive to manufacture + install
- uses great deal of energy, water + toxic metals + industrial chemicals (may be released to environment during manufacturing process)
- battery reliance on some systems (manufacturing, recycling, disposing, storage)
- end of life cycle of solar panel + no plan
- geographically limited
- high initial cost

Geothermal energy - heat that comes from the natural radioactive decay of elements deep within Earth.

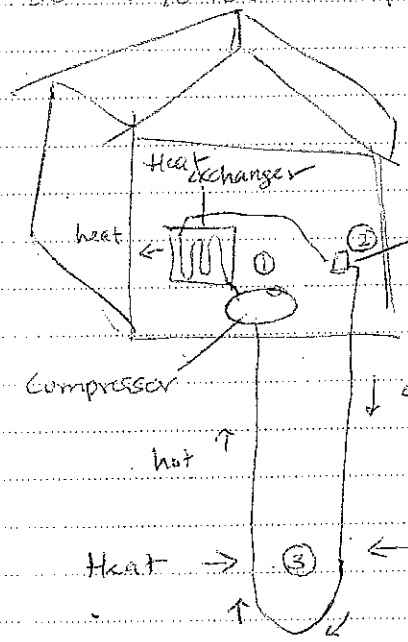
- US
- ~~Russia~~
- Iceland
- China

} largest producers of geothermal energy

- can be used directly as a source of heat
  - piped directly into household radiators for heating home
  - used heat exchangers to collect heat by circulating cool liquid underground, where it is heated & return to surface (Iceland heats 89% of homes this way)
  - can be sustainable energy if return water back to ground

ground source heat pump - technology that transfers heat from the ground to a building

- 3m underground fairly constant year round 10°C - 15°C (50-60°F) due to sun & ground's ability to retain heat
- don't remove steam or hot water from ground
- can be installed anywhere
- 30-70% less energy to heat & cool a building than furnace or AC



① Circulating fluid is compressed to form hot gas. Heat is given off into the house from the heat exchanger as the gas cools to form a liquid

② Fluid expands & cools, becomes a gas that is much cooler than the ground through which it will move

③ Warmer ground will heat cool fluid which cycles through buried tubing. Thus heat from the ground is essentially "pumped" into the building

Pros

- nondepletable
- after initial investment, no cost to get energy
- can be installed anywhere (ground source heat pump)

Cons

- emits hazardous gases/steam
- geographically limited

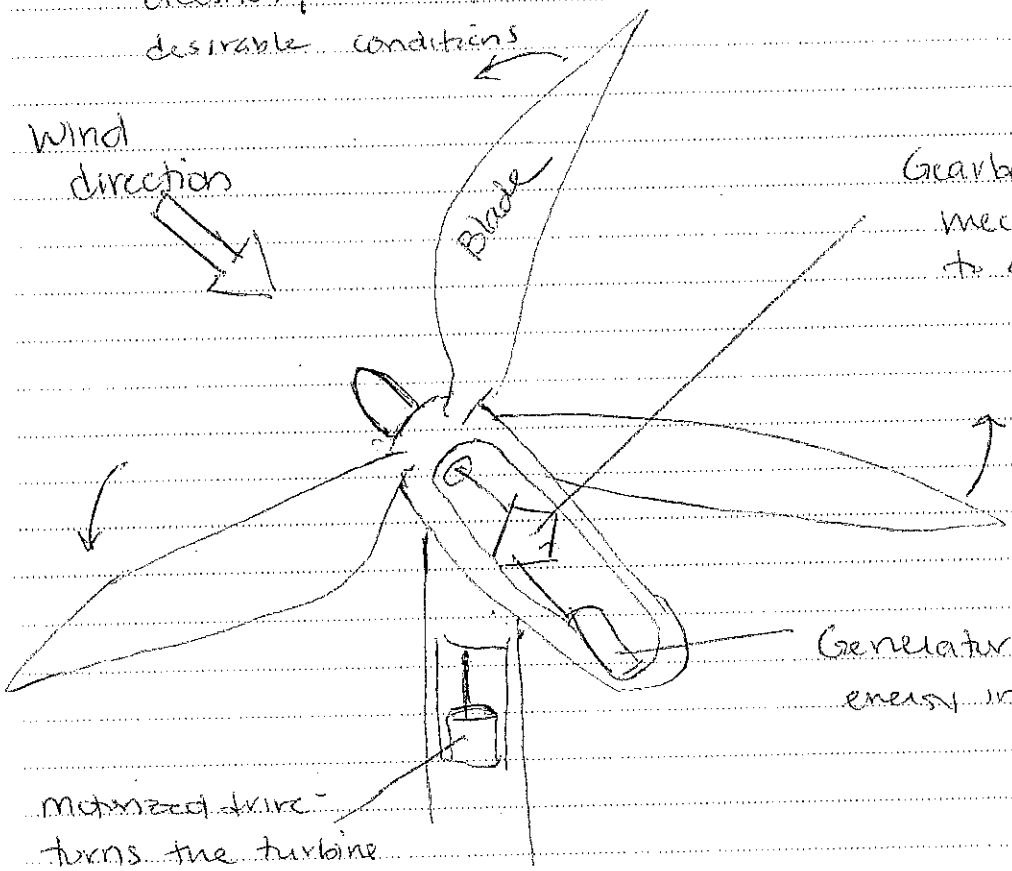
Wind energy - energy generated from the kinetic energy of moving air

1. USA
2. Germany
3. Spain
4. China
5. India
6. Italy

} Generation capacity worldwide

*Denmark greatest percentage of electricity from wind in world

- on tower ~100 m, blades 40-75 m → produces 25% of electricity of time - ocean more time because more desirable conditions



- offshore wind projects: Denmark, Netherlands, United Kingdom, Sweden
  - Cape Wind Project - Cape Cod, MA Nantucket Sound 130 wind turbines with potential to produce 420 MW of electricity
  - Block Island Wind farm

pros
- no substantial fossil fuel input required
- sustainable energy source
- share land with other uses (grazing cattle for example)
- low up front cost
- nondepletable

cons
- rely on batteries for stage if off grid system
- noise
- aesthetic
- bird / bat collisions
  ~4 deaths / turbine / year
- shadow effect
- only generate when wind
- geographically limited

Hydrogen Fuel Cell

fuel cell - device that operates through a electrical-chemical device that converts fuel such as hydrogen into an electrical current
- generated by reaction of hydrogen w/ oxygen

$$2H_2 + O_2 \rightarrow \text{energy} + 2H_2O$$

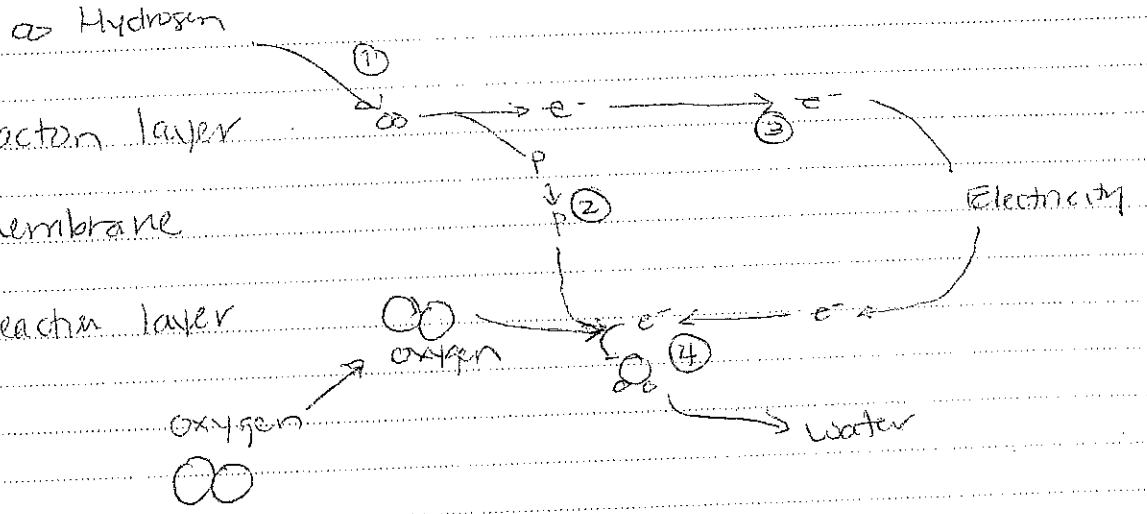
- forces protons from hydrogen gas through a membrane, while electrons take a different pathway. movement of protons in one direction & electrons in another generate the electrical current
- Hydrogen gas not naturally found usually in compounds
- Commercially available hydrogen produced by energy intensive process of burning natural gas to extract hydrogen. CO_2 waste product

electrolysis - electric current applied to water to "split" it into hydrogen & oxygen
- some algae / bacteria give off H_2

- 80% efficient converting potential energy of hydrogen & oxygen into electricity & by product only H_2O

pros
- 80% efficent
- by product H_2O

cons
- obtain H_2
- be able to safely deliver H_2 (flammable)
- storage of H_2 (liquid or gas)
- H_2 production energy intensive process
- lack distribution network



① H_2 molecules split into protons H^+ and electrons
② Protons move across membrane
③ Electrons take alternative route (electric current)
④ O_2 split + combine with protons + electrons to form H_2O

Technical End
- US outdated + lose billions every year

Solution: smart grid - efficient, self-regulating electricity distribution that accepts any source of electricity + distributes it automatically to end users