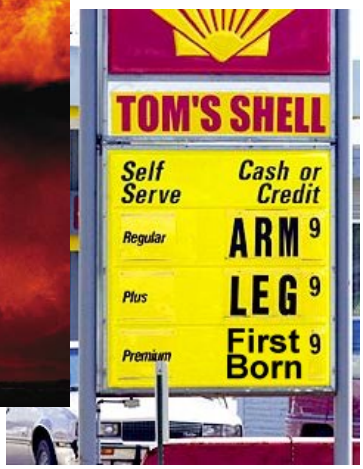
CEEES/SC 10110-20110

Energy Resources



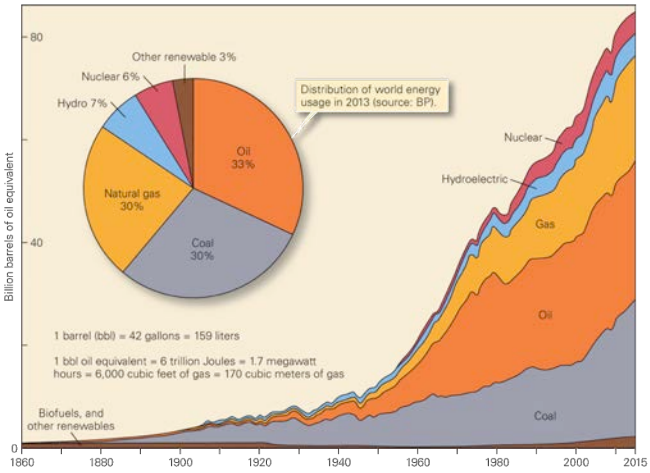
Earth

Portrait of a Planet
Fifth Edition

Chapter 14

Energy

The capacity to do work;
To cause something to happen;
or
To cause change in a system.



Two basic types of energy: Kinetic and Potential.
Hydroelectric power uses kinetic energy; burning fossil fuels releases the potential energy in gasoline through a chemical reaction:

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O + Energy$$

Sources of Energy

Five fundamental energy sources:

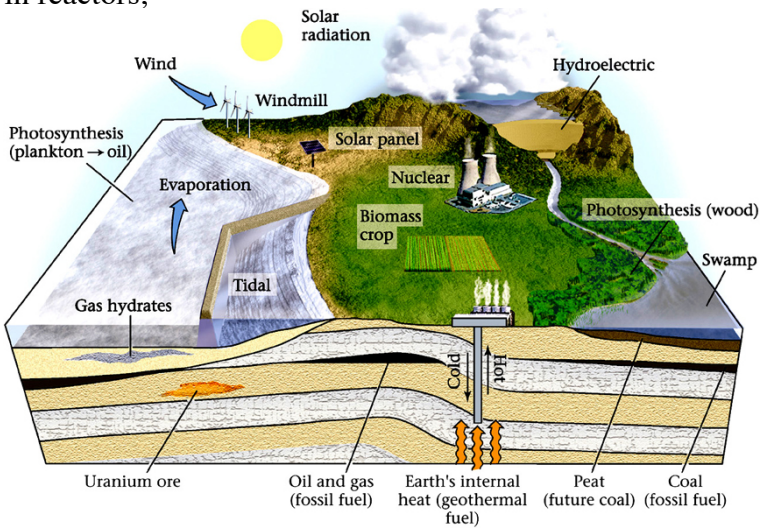
Nuclear fusion energy from the Sun: generated by nuclear fusion and transported to Earth via electromagnetic radiation;

Energy from gravitational pull (tidal pull of the Moon and Sun);

Energy from nuclear fission in reactors;

Primordial energy of accretion (and radioactive decay) stored in the Earth: referred to as ***geothermal energy***;

Energy stored in the chemical bonds of compounds: Dynamite! For fossil fuels, biomass fuels, and wood this stored energy is photosynthetic in origin.



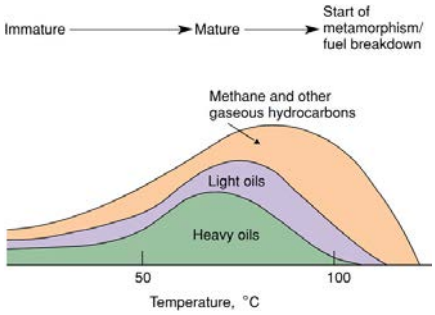
Oil & Gas

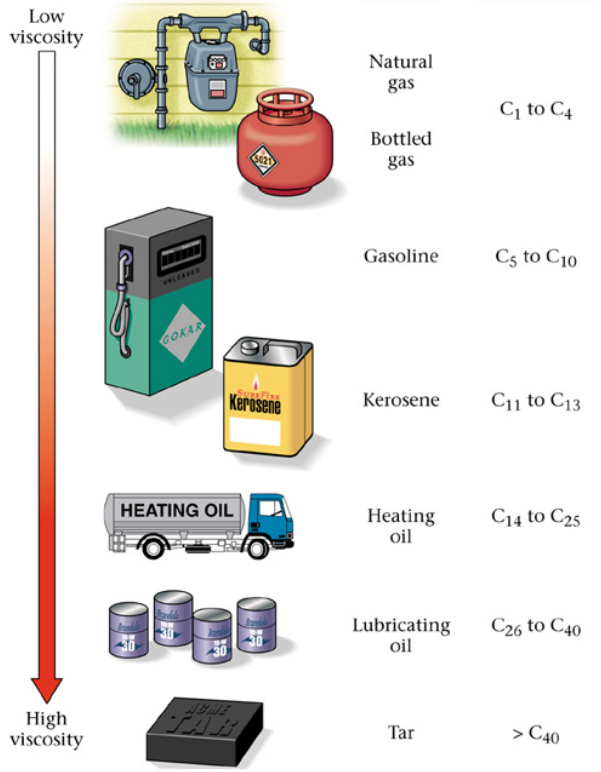
Made up of hydrogen and carbon = hydrocarbons.

Many uses for these hydrocarbons.

The shorter the chain the less viscous is the organic chemical.

Natural Gas is found with oil - at the top of oil fields. Or found in isolation, dependent on the temperature. Burns cleaner than oil (< impurities).
More abundant than oil.





Product	Number of carbons in the hydrocarbon molecule
Natural gas	C_1 to C_4
Bottled gas	
Gasoline	C_5 to C_{10}
Kerosene	C_{11} to C_{13}
Heating oil	C_{14} to C_{25}
Lubricating oil	C_{26} to C_{40}
Tar	> C_{40}

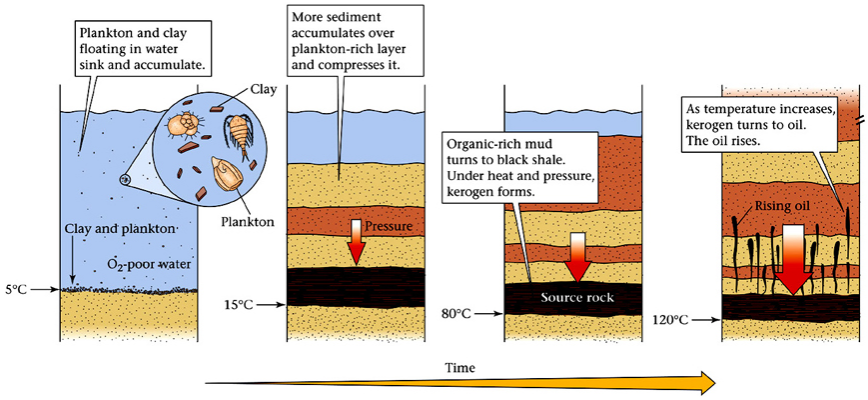
Oil & Gas

Formed from dead plankton & algae that are deposited in quiet oxygen-poor water - typical source rock = organic shale.

Burial to 2-4 km sees slow transformation of the organic remains to waxy molecules = ***kerogen***.

Shale containing kerogen = oil shale.

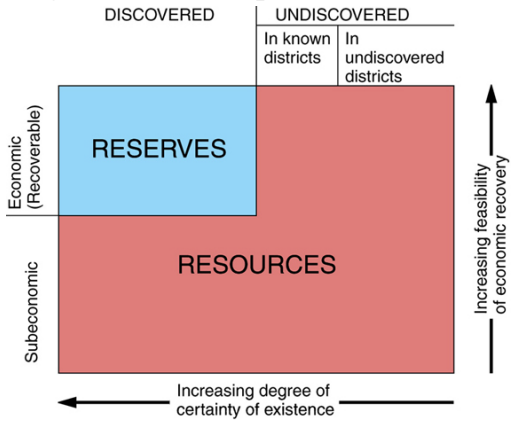
>90˚C: kerogen breaks down to form oil + natural gas;
>160˚C: all remaining oil is converted to natural gas;
>250˚C: all organic matter forms graphite.

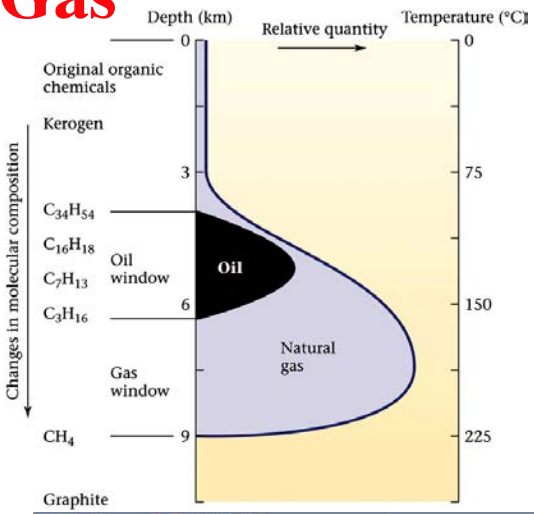


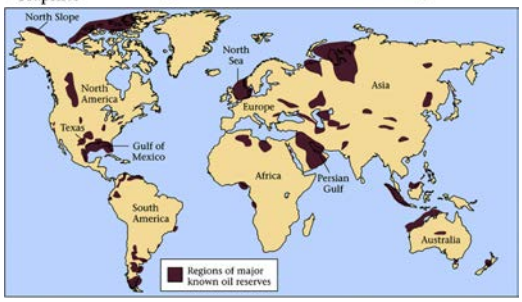
Oil & Gas

Oil forms over a relatively narrow temperature range = the **oil window**.

Depth at which oil can be found in a given area is dependent on the local geothermal gradient - typically the depth is 3.5-6.5 km, although in areas of low geothermal gradient oil can persist to 11 km.







Hydrocarbon Reserves

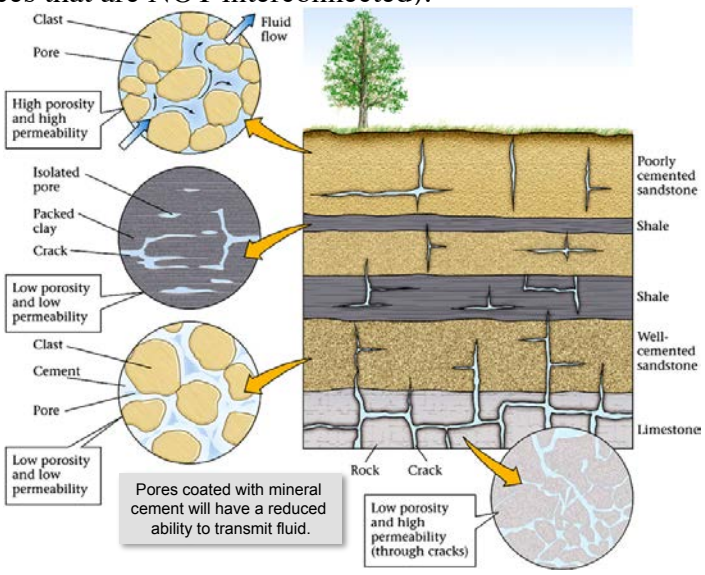
Oil & Gas

Hydrocarbon System: source rock + reservoir rock + migratory pathway + oil trap.

Source Rock = organic-rich shale. ***Hydrocarbon generation*** occurs if the source rock resides in the oil window.
BUT - shale does not allow oil to be pumped from it because in is non-porous and impermeable (i.e., few pore spaces that are NOT interconnected).

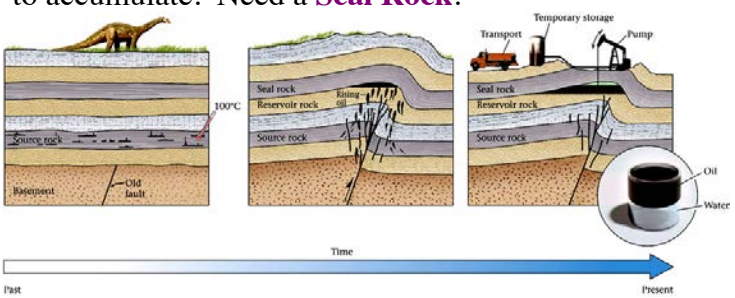
Drill into a **reservoir rock** - one that (potentially) contains oil and is porous (gaps between grains) and permeable (the pores are interconnected allowing flow). The reservoirs rock may not contain pore spaces, but could be highly fractured (i.e., flow is still possible).

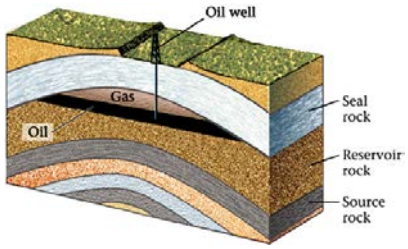
Oil < dense than rock - migrates upward from source to reservoir rock = **migration pathway**.



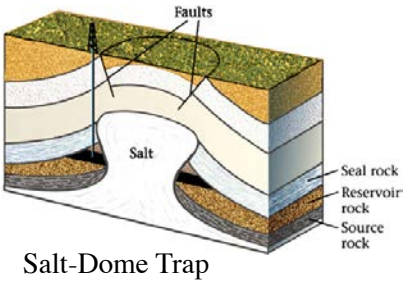
Oil & Gas

Oil Seep: oil migrates all the way to the surface.
Oil Trap: geological feature that prevents oil from getting to the surface allowing it to accumulate. Need a **Seal Rock**.

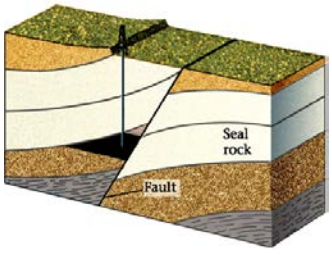




Anticline Trap

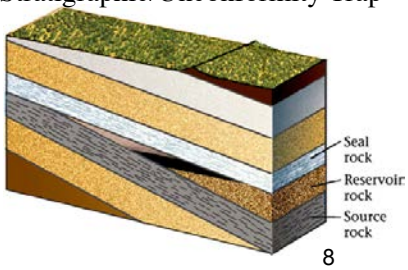


Salt-Dome Trap



Fault Trap

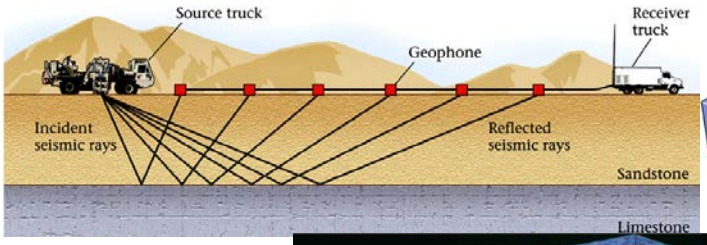
Stratigraphic/Unconformity Trap

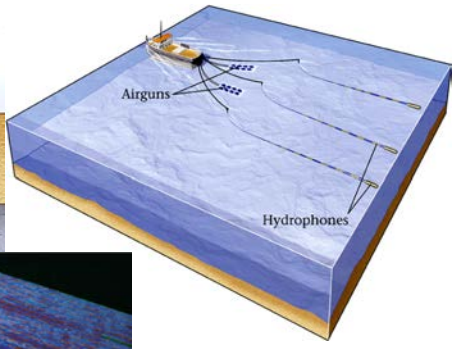


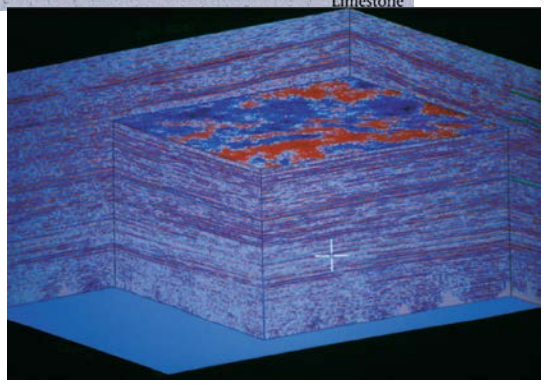
Oil & Gas

Exploration

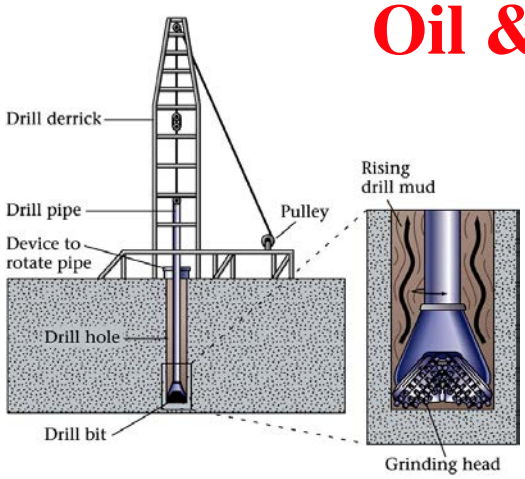
Seismic reflection: defines geologic structures that are indicative of oil traps. Geologists make recommendations about drilling - a deep well can cost ≥ $10 million!





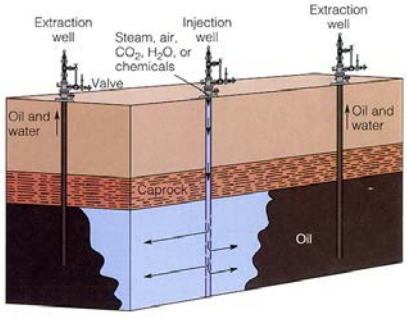


Oil & Gas

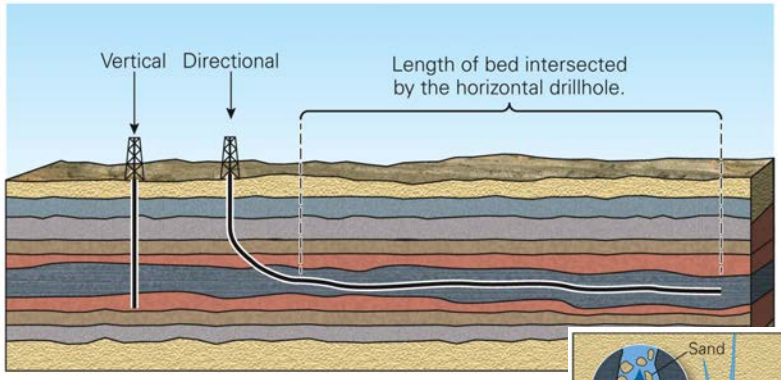


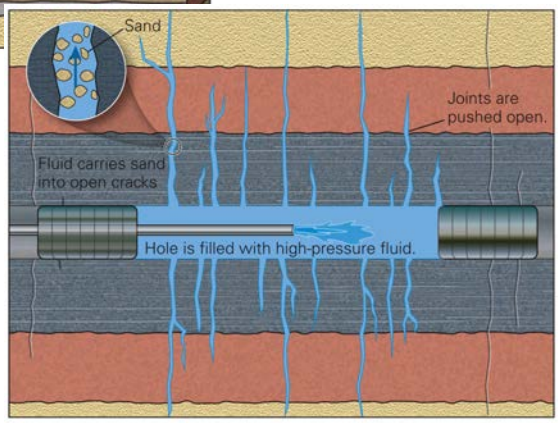
Drill from platforms or vessels. Can drill vertically and any angle to horizontal.

Only ~ 30% of oil recovered by pumping. More extracted by increasing the fractures in the reservoirs rock or pumping steam into the reservoirs to liquefy more oil. These are processes of ***secondary recovery***.



Oil & Gas





Drilling can proceed in any direction. Many wells are now drilled horizontally after reaching a target depth to increase yields. Many wells today are artificially stimulated by hydrofracturing ("fracking"), a process that cracks subsurface rock using high-pressure water with additives and sand.

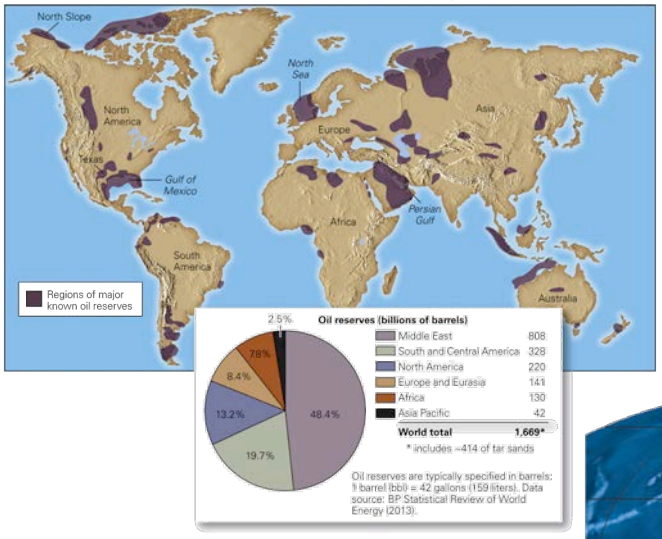
Oil & Gas

When the hole is completed, the drill rig is removed and a pump is set up. Oil pumped out of the ground is stored in on-site tanks for periodic removal by truck or is added to a pipeline for transport across the countryside.

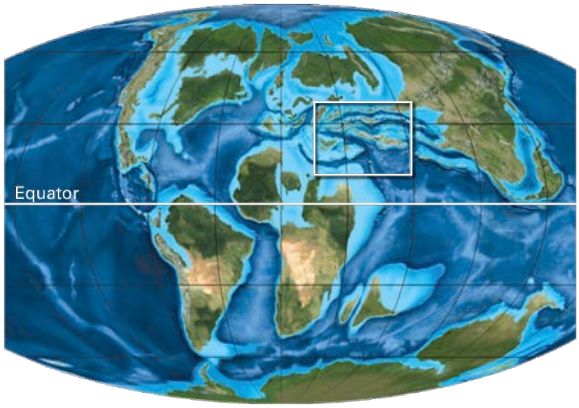
Oil & Gas Refining

- All crude oil must be refined.
- Transported to a refinery by pipeline or tanker and is distilled into separate compounds.
- Lighter molecules rise to the top of distillation columns; heavier molecules remain at the bottom.
- Heavy molecules may also be "cracked" into small compounds.

Oil & Gas



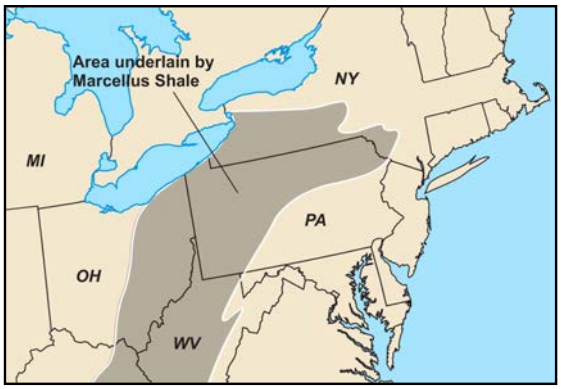
Oil reserves are distributed on all continents—some onshore and some offshore. Regions bordering the Persian Gulf contain the world's largest reserves because of the last 150 Ma of its geologic history as it was situated in the tropics between the Jurassic and the late Cretaceous.



High biological productivity created abundant source rocks, which were overlain by thick successions of porous sandstones. With the closure of Tethys, compression and shortening folded strata to create excellent structural traps.

Oil & Gas

- Natural gas consists of volatile short-chain hydrocarbons (methane, ethane, propane, and butane).
- Gas floats on top in an oil reservoir; below the oil window, gas occurs without oil.
- More abundant than oil and a cleaner fuel. Utilization requires expensive high-pressure pipelines and ships.



- Natural gas in the Marcellus Shale has greatly increased U.S. domestic gas reserves and has stimulated the economy in the northeastern United States.
- This gas is extracted using directional drilling and hydrofracturing ("fracking") - controversial due to environmental concerns.

Other Hydrocarbon Deposits

Gas (Methane) Hydrates

Crystalline solids of gas and water. Formed in >300 m of water (pressure).

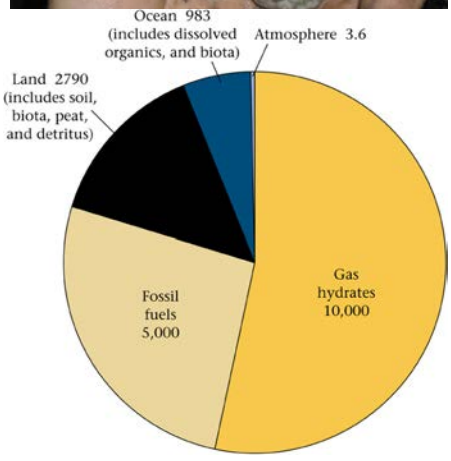
Abundant in marine sediments.

Huge resources are estimated – the continental shelf off the Carolinas is estimated to contain 1,300 trillion cubic feet of gas!

Technological development required in order to tap these resources.

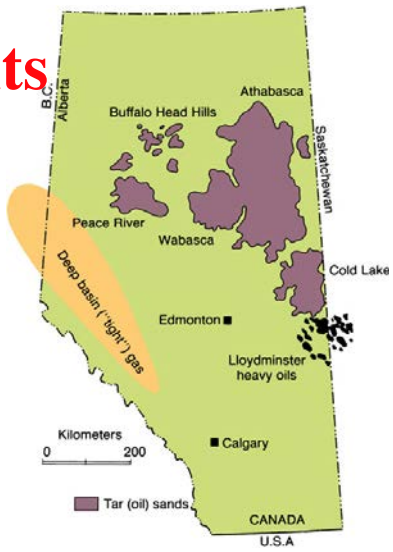
If methane hydrates are released they would exacerbate the greenhouse effect as methane is a far more efficient greenhouse gas than CO_2.

They are stabilized by cold temperatures.



Other Hydrocarbon Deposits

Tar (Oil) Sands



Athabasca Tar Sands, Alberta – 5,000 km^2.
Could yield 600 billion barrels (almost as much as the world has already consumed!), but the hydrocarbons are too viscous to pump.

Tar Sand: sedimentary deposit saturated with an asphalt-like organic substance composed of heavy hydrocarbons = ***Bitumen***.

Bitumen forms when migrating organic compounds come into contact with the atmosphere, pedosphere, and groundwater, but exact origin is unclear.

Extraction: surface mining like coal.

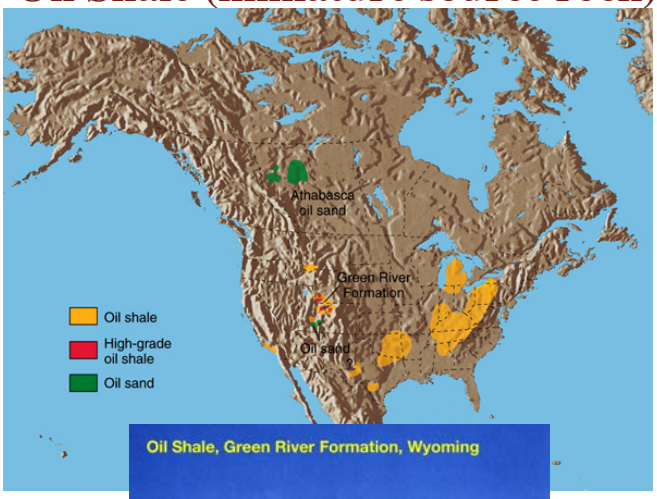
Treated with pressurized steam to soften the bitumen, which rises and is collected & treated to remove sulfur (+ other impurities).

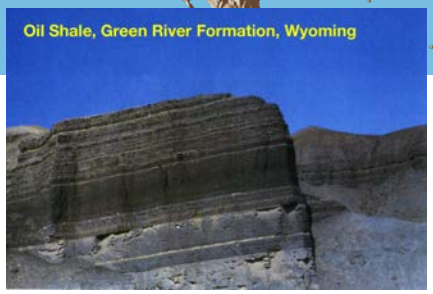
Hydrogen is added so it can be refined as crude oil.

Mining & processing tar sand requires nearly half as much energy as the end product can yield!

Other Hydrocarbon Deposits

Oil Shale (immature source rock)





Fine-grained clastic sedimentary rock that contains ***kerogen*** instead of oil.

Kerogen forms from buried plant matter at temperatures and pressures too low to produce liquid hydrocarbons (i.e., hasn't cooked enough).

Green River Formation of Wyoming & Colorado: contains ~2,000 billion barrels of oil (as much as already used *plus* the estimated remaining oil reserves). Capable of producing 10,000 barrels of "***syncrude***" (synthetic crude oil) per day.

Comprises half of the world's oil shale – it's huge!

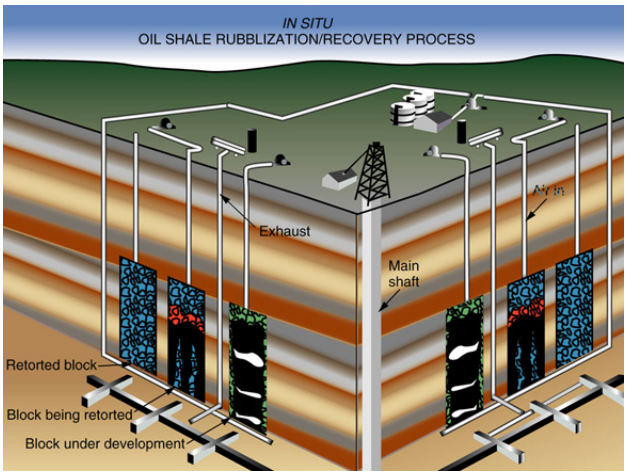
Other Hydrocarbon Deposits

Oil Shale (cont.)

Extraction: surfacing mining (as for tar sands) and in situ methods.

Below ground heated air is injected to vaporize the ***kerogen***, which rises to the surface and condensed to form ***shale oil***.

For kerogen to be a worthwhile source, it must yield more energy than is required to mine it – currently this is not the case, but interest is increasing because of the vast reserves.



Coal

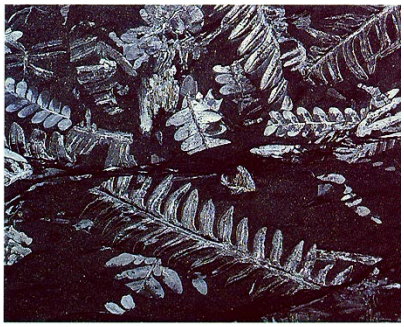
Coal forms from land plants grown in swamps/marshes (anoxic after burial so remnants are preserved). Much more abundant than oil.

Oil migrates after formation; only found where geologic formations allow oil traps. Coal is more widespread.

Present day coal-forming environments: Great Dismal Swamp, Virginia; Okeefenokee Swamp, Florida.

Coal occurs in "seams" (layers) and is strip mined or mined underground.

Consists of C + H compounds, but more impurities than oil (N + S form acid rain when coal is burned and acid mine drainage when mines are abandoned). Heavy metals are present.



Coal

Most found in the Carboniferous (286-354 Ma). Also in the Cretaceous (64-144 Ma).

Formed by successive transgressions and regressions - quickly buried the plant material.

Accumulate organic matter initially forms ***peat*** (lots of peat deposits in Ireland). Peat has a high moisture content and contains <50% carbon. Any contained mineral matter will not burn and remains as ash.

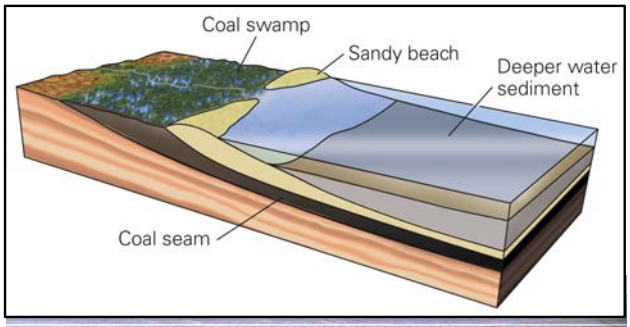


TABLE 14.1 Types of Coal

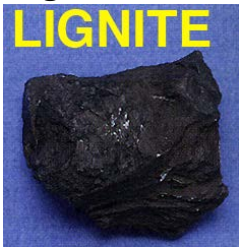
Material	% Carbon	Energy Content[1]	Rank
Peat	50	1,500 kcal/kg	
Lignite	70	3,500 kcal/kg	Low-rank coal
Bituminous coal	85	6,500 kcal/kg	Mid-rank coal
Anthracite coal	95	7,500 kcal/kg	High-rank coal

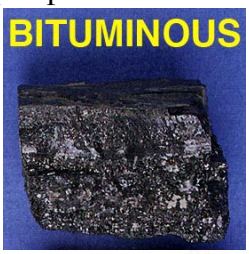
Coal

Formation

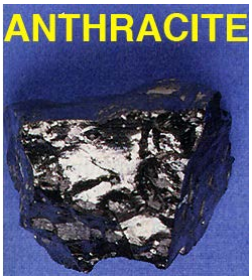
If buried, peat is transformed to 3 types of coal depending up depth of burial.

Lignite: brown-coal, 50-60% carbon, gives off more heat than peat.

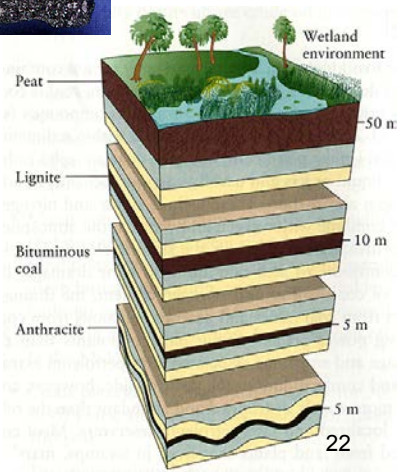




Bituminous Coal: buried deeper than lignite, compressed – removes more water. Harder, brown-black rock, 60-90% carbon.



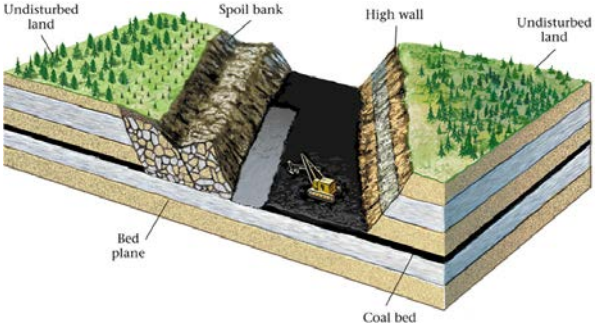
Anthracite Coal: if bituminous coal is heated, it is transferred into a black, shiny rock with >90% carbon.



As C content increases, the coal rank increases.
Coal bed thickness is ~one tenth that of the peat layer.
A 3 m coal bed = 30,000 years of peat accumulation.

Coal

Strip Mining: Drag lines used. Strip off the overburden, extract coal, replace overburden (coal <100 m from surface).



Coal

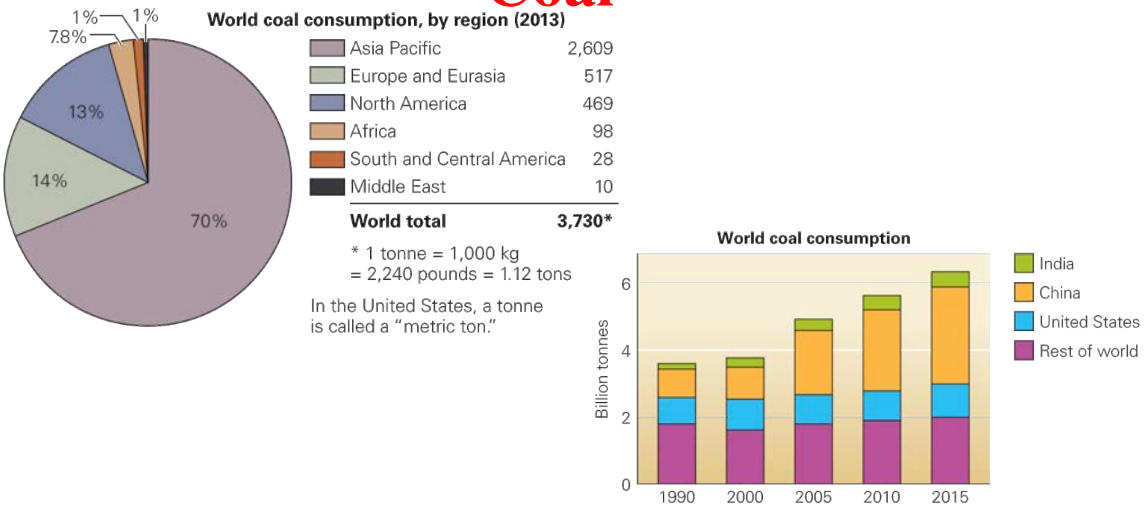
Underground Mining: More dangerous - roof collapse; methane build-up and explosion can occur.
Also - black lung.

Coalbed methane = energy source. Trapped in strata too deep to be reached by mining. Extract groundwater from drill hole and methane bubbles in. Water commonly contaminated with salts and heavy metals - pumped back underground.

Coal is messy - scrubbers used on chimney stacks of power plants to remove SO_2 and dust, but then disposal of the waste can be problematic.

Coal Gasification: clean-burning gases produced from coal by: 1) pulverize coal; 2) mixture of steam & O_2 passes over the coal at high pressure; 3) coal heats up, but does not ignite - produces H, CO, etc. Ash, S, and Hg are concentrate in the waste.

Coal



Almost every continent has coal reserves. The amount of coal consumed globally is increasing. China and India account for an increasing proportion of total coal consumption.

Environmental Impacts

Coal fires in underground mines are a major problem because so much coal is left (propping up the mine roof).

Many cannot be extinguished and burn for years because maze of tunnels allows oxygen in.

Caused by lightening strikes, spontaneous explosion (methane), and human error!

20% equivalent of China's annual coal production is burning underground.

Beneath the now abandoned mining town of Centralia, PA, an underground fire has burned for almost 50 years and may continue to do so for centuries.

Residents used an abandoned surface pit as a landfill and decided to burn it before their 1962 Memorial Day celebrations. This ignited a coal seam.

>$10 million spent on putting the fire out but the fire continues to spread, moving uphill, sideways, downhill. It leaps from place to place by hydrogen explosions.

Environmental Impacts

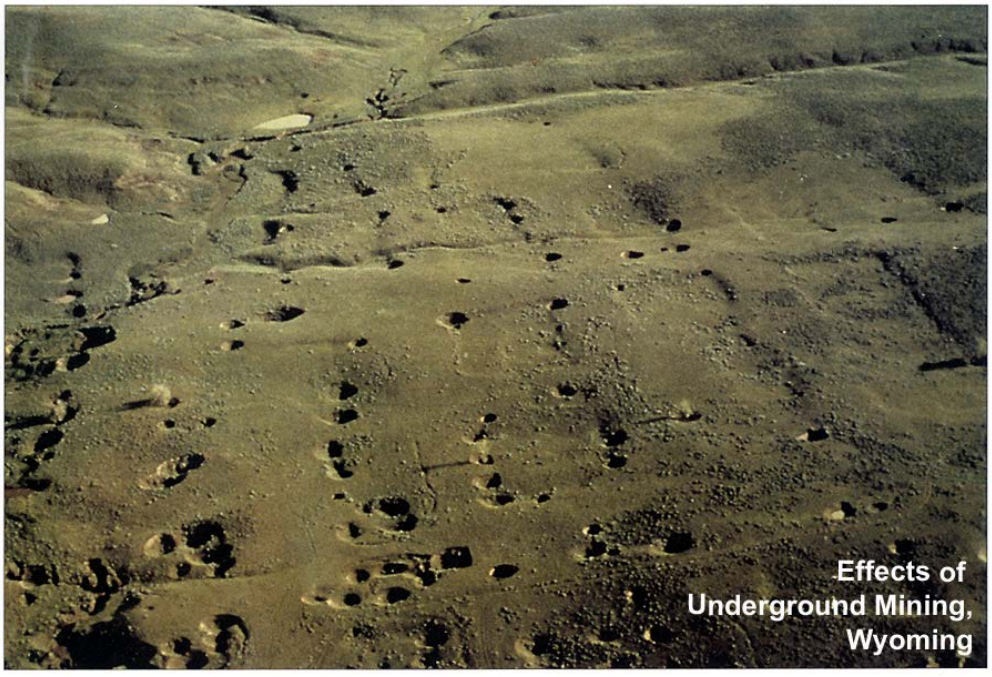
Extreme underground temperatures boils off groundwater creating steam that marks the location of the underground fires.

Temperatures have exceeded 500˚C, fumes = CO, CO_2 – both deadly and odorless. Town relocated at a cost of $42 million. All structures condemned.

Town now looks like a bomb site – deep craters and cracks.

Fire is now too deep and extensive to be controlled and is moving towards the next small town.

Environmental Impacts



Nuclear Power

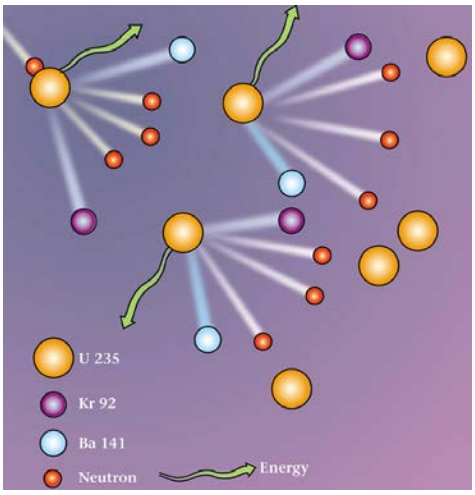
Fission: splitting atomic nuclei into smaller ones.

Fusion: combining atomic nuclei into larger ones.

Both release energy.

Only fission is commercially viable.

Cook Nuclear Plant
Michigan



Nucleus of interest = ^{235}U (92 protons, 143 neutrons). Only ~0.7% of Uranium - needs enrichment by at least 2-3 times.

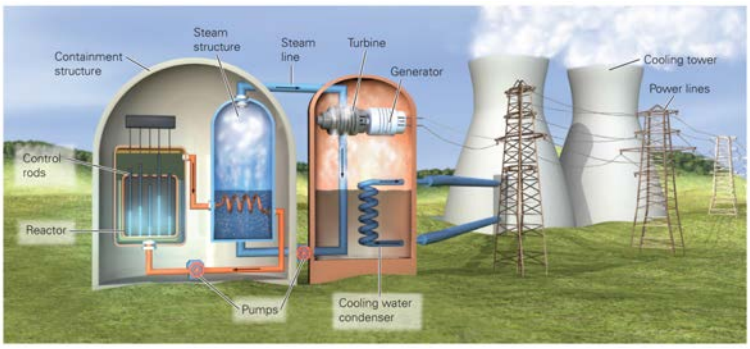
Fire a neutron into the nucleus induces splitting into two different nuclei (not always the same) plus neutrons so the reaction continues (chain reaction).

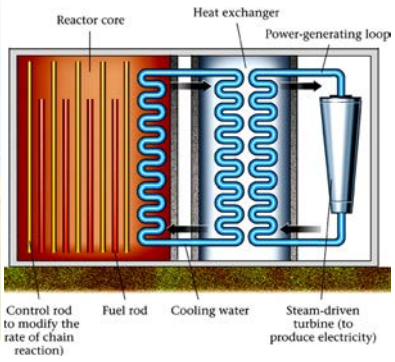
Produces radioactive daughter products - waste disposal is a major issue.

Nuclear Power

Controlling this reaction in a nuclear reactor is the basis of the nuclear power industry. Controlled by controlling the number of neutrons available.

Energy released heat to produce steam and drive turbines to produce electricity.





Nuclear Fission

^{235}U is rare (0.7%) and ^{238}U does not undergo fission – fuel must be replaced.

95% of Uranium deposits are found in sedimentary or metamorphosed sedimentary rocks.

Formed by weathering of U-rich source rocks – granites and carbonates

Granites – U is concentrated in the final dregs of crystallization;

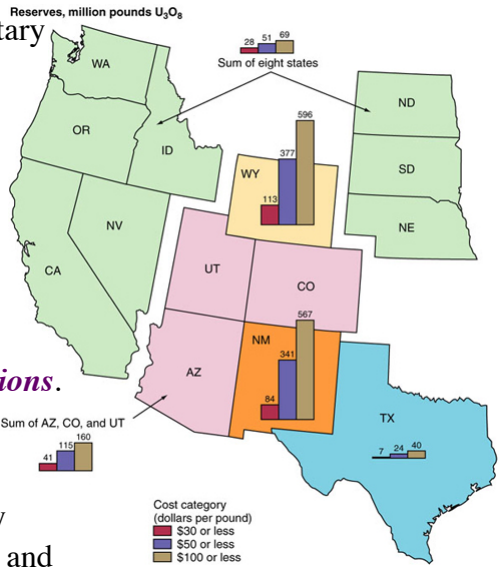
Carbonates – it is precipitated out with the mineral.

U is particularly mobile under oxidizing conditions.

Typical oxidation states: U^{4+} (insoluble); U^{6+} (soluble). Groundwater problem!

If the water passes through sandstones, they may encounter reducing conditions (carbon, sulfides) and precipitate, thus enriching the sandstone.

Locations of U.S. Uranium Reserves



Environmental Impacts

Waste Disposal

Big problem because waste can remain radioactive for hundreds of thousands of years.

Underground tunnels drilled into a mountain that is tectonically quiet and with a low water table.

Interiors of impermeable salt domes (as salt "flows" any fractures will heal).

Landfills surrounded by an impermeable clay layer.

Landfills in regions where groundwater is of such a composition that is will react with the waste leaving insoluble minerals.

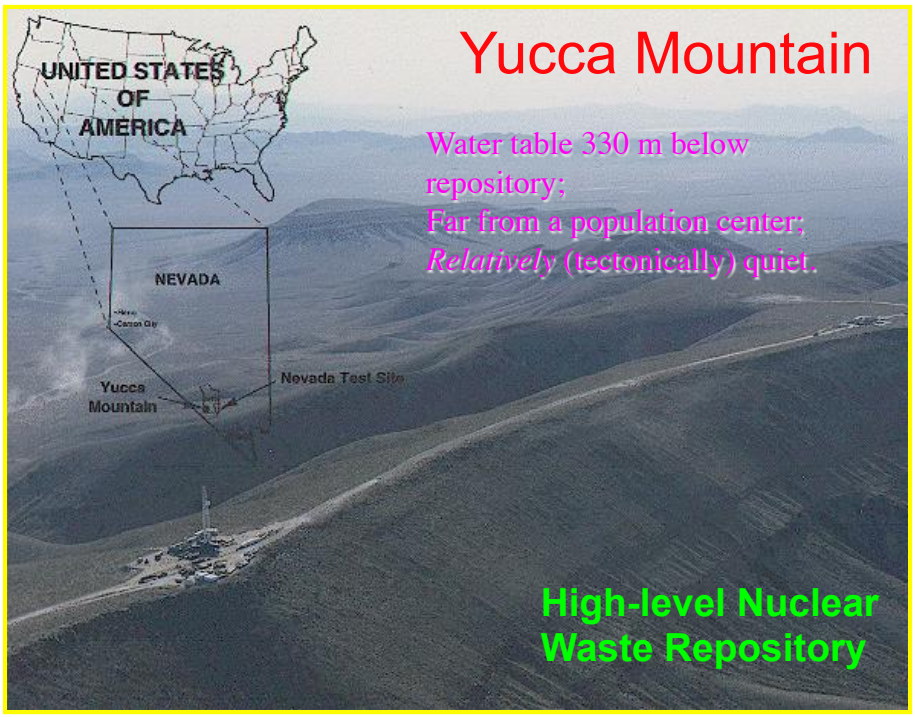
Oceanic trench - the waste will eventually be subducted.

Meltdown

Loss of fission control:

- 1979–Three Mile Island, Pennsylvania: a stuck valve allowed radioactive coolant to escape.
- 1986–Chernobyl, Ukraine: reactor explosion spread radioactivity globally.
- 2011–Fukushima, Japan: loss of coolant led to partial meltdown and hydrogen explosions.

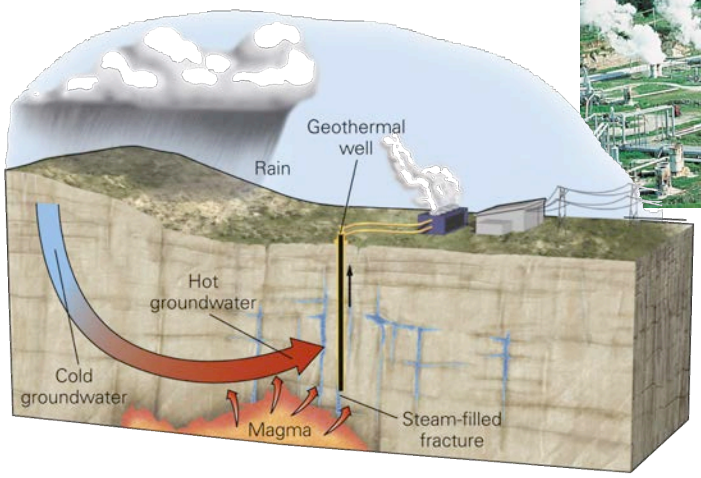
Nuclear Power



Environmental Impacts - Fukishima

Geothermal Power

Use heated groundwater either as steam directly to drive turbines and generate electricity or to pump hot water directly to buildings for heat, etc.
Important in Iceland, New Zealand and a few areas of the western US.



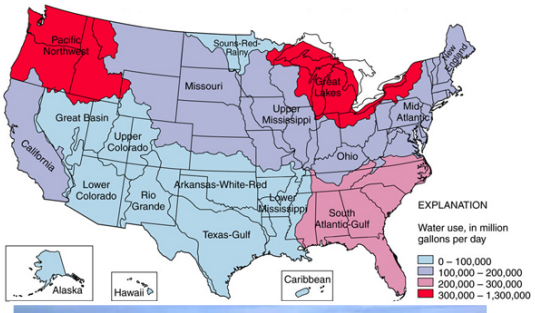
Hydroelectric Power

Currently provides ~4% of US energy.

Requires damming of rivers to ensure constant water supply.

Clean power – no chemicals added to water, no dissolved/airborne pollutants produced.

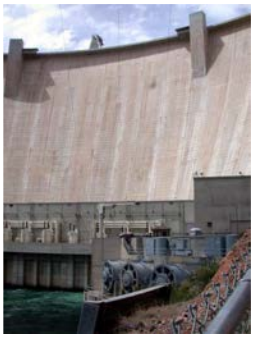
Renewable resource (as long as water continues to flow!).



Limitations: Silting up of reservoirs, habitat destruction, water loss by evaporation, earthquakes, dam failure.

Dam failure is a major risk – several dozen failed in the US during the 20th century (poor construction, ignoring the local geology).

Ecosystem destruction.



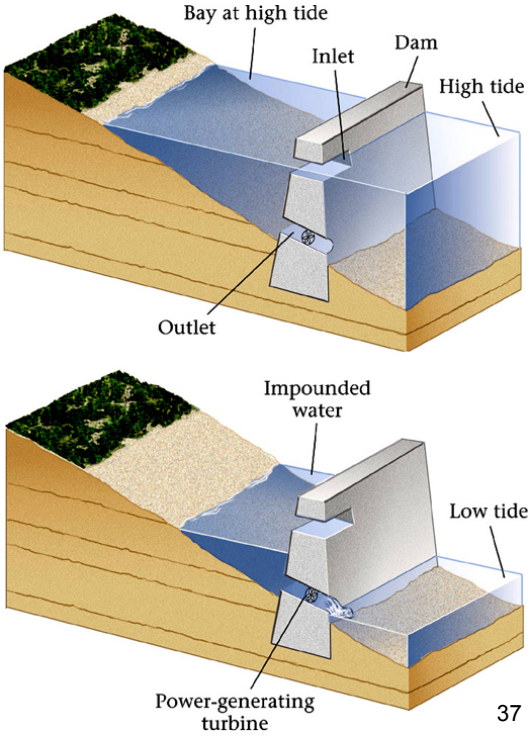
Hydroelectric Power

Tidal Power

Energy represented by tides is too dispersed in most places – average high & low tides = 1 meter difference.

Bay of Fundy has the largest tidal surge in the world (> 15 m).

Worldwide, tidal power is estimated as being only 2% of the potential of conventional hydroelectric power.



Wind Power

Steady winds drive a large turbine to produce electricity. Wind-derived electricity is renewable and carbon-free. High-tech wind farms are sprouting worldwide. Wind farms have negative aesthetic impacts and turbine blades are noisy and kill birds.

Solar Energy

Total solar energy reaching the Earth's surface far exceeds the energy needs at present and in the foreseeable future.

The Sun is inexhaustible – predicted to last for another 5 billion years!

It is pollution-free.

Several practical limitations on its use also exist.

Suns energy is dissipated over the surface of the Earth – to collect the energy, collectors need to cover a wide area.

Day to day weather conditions are also critical!

Sunlight for warmth: collection & storage for when the sun is not shining.

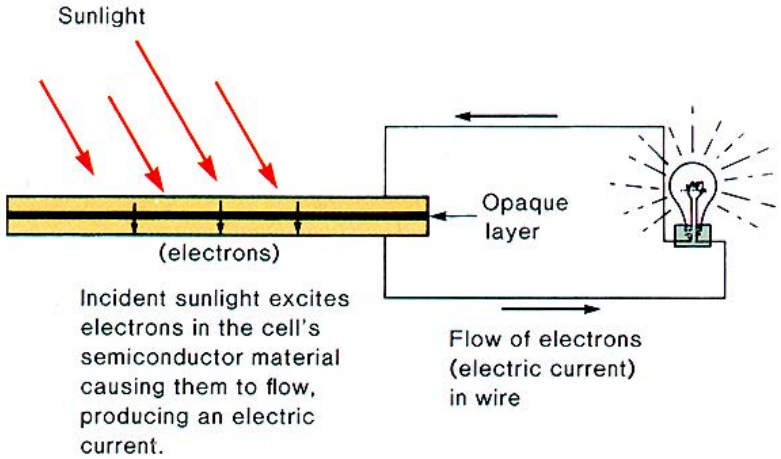
Solar Energy

Solar Electricity

Sunlight can produce electricity using photoelectric cells (solar cells).

No moving parts; no pollutants emitted.

Power satellites, Mars rovers, and remote areas.



● FIGURE 14.17 Schematic diagram of a photovoltaic (solar) cell for the generation of electricity.

Solar Energy

Limitations: cost is several times higher per unit of electricity than from fossil or nuclear fuels.

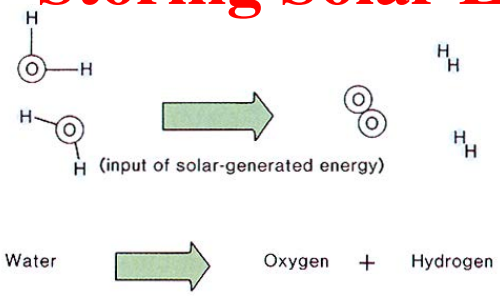
High cost is due to technology and scale (industry not large enough for "mass production").

Solar cells are inefficient: 20% (50 watts per m^2). A 100-megawatt power plant requires 2 km^2 of collectors.

Basically need lots of space and capital investment.

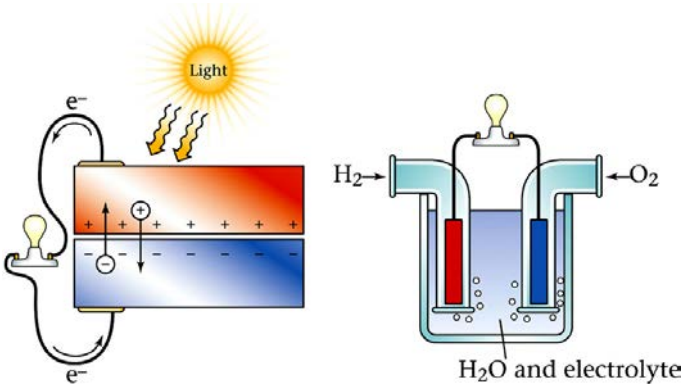
Storing electricity is also problematic, as battery technology is not advanced (batteries are inefficient).

Storing Solar Energy: Fuel Cells



Solar electricity breaks water down to H + O. Burn the H later to produce energy & water.

A fuel cell is the reverse process - 40-80% of the reactions energy produces electricity.



Problem: have to store H, which is explosive. Fuels need to survive crashes in order to be used in cars.

Biomass

Biomass energy is really another form of solar energy.

Biomass fuels = unfossilized fuels (e.g., wood; combustible refuse; waste plant material after harvest).

Biomass fuels release CO_2 like fossil fuels, but unlike fossil fuels they are renewable.

Biomass

Alcohol as Fuel

Gasohol: 90% gasoline + 10% alcohol (cleaner burning) and allows existing engines to use this without modifications.

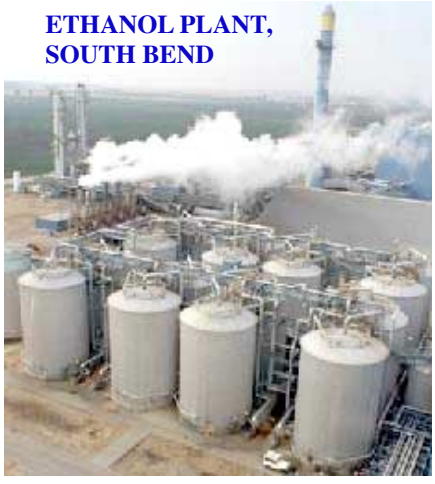
Proportion of alcohol could increase in the future.

Some vehicles developed to run solely on alcohol, but need widespread fuel distribution.

Fleets (e.g., taxis) developed because they can be re-fueled at a central location.

Derived from grains, principally corn.

Extends supply of gasoline.



ETHANOL PLANT, SOUTH BEND

Biomass

Biogas

Gas from garbage (e.g., Chicago). Breakdown of organic waste yields methane (CH_4).

Straight landfill gas is too full of impurities.

Sanitary landfills (simply, each days trash is covered with a layer of dirt) are suitable for methane production.

Gas thus produced can be mixed with purer natural gas to extend the natural reserves life.

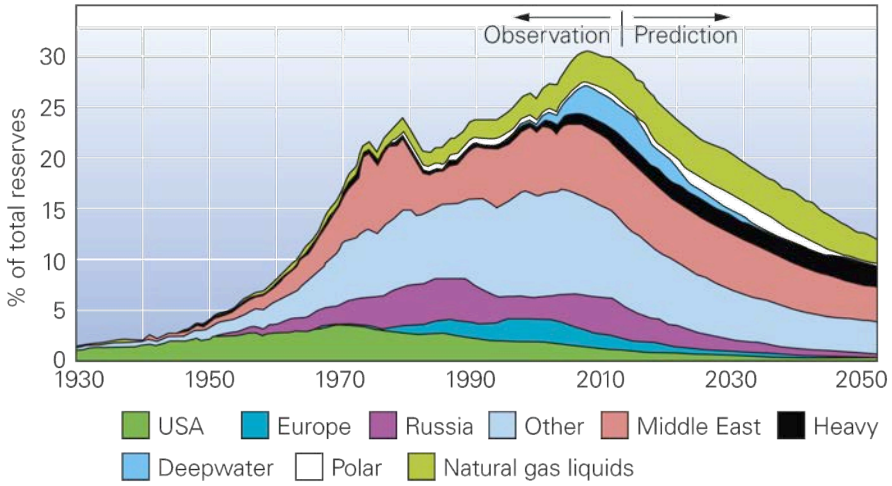
Where large quantities of animal waste are available, this can constitute a significant local gas supply.

Environmental Issues

Energy production has clear adverse environmental impacts. Oil drilling and production scars the landscape. Spills from oil storage tanks, pipelines, and ships contaminate surface water and groundwater and may devastate large areas of coastline. Coal mining creates pits, spoil piles, and acid mine runoff.
Fracking: Earthquakes, contaminated groundwater.

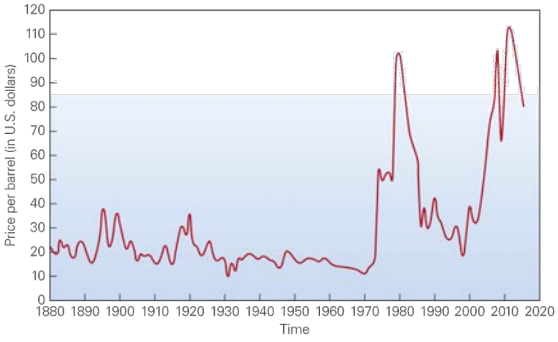
The Oil Crunch

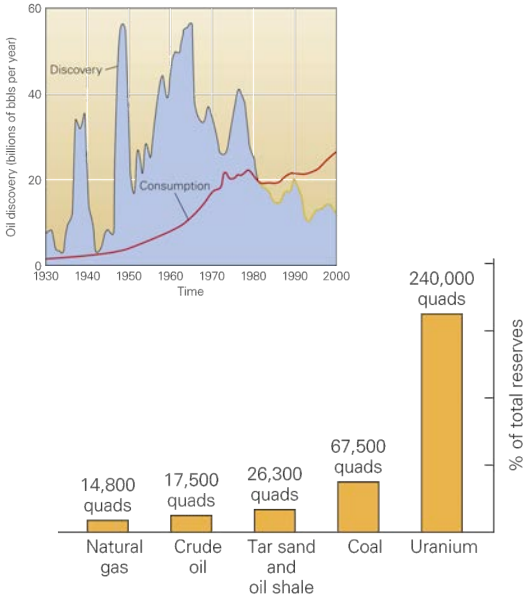
M. King Hubbert correctly predicted the peak of U.S. oil production to be 1971. We are now close to the peak of global oil production. Oil extinction is likely to occur between 2050 to 2150. Humanity faces many changes as oil runs out.



The Oil Crunch

Oil prices have been fluctuating dramatically in recent times. Despite short-term dips, the consumption rate of oil has increased over time but the rate of new discovery has not. Other sources of energy have more abundant reserves.





Summary

Energy: Kinetic & Potential.

Sources of Energy: Sun, Gravity, Nuclear, Primordial, Chemical bonds.

Oil & Gas: Kerogen, Oil Shale, Source Rock, Oil Window, Resources & Reserves, **Hydrocarbon Generation**, Reservoir Rock, Migration Pathway, Oil Seep, Oil Trap, Seal Rock, Exploration, Secondary Recovery.

Other Hydrocarbon Deposits: Gas Hydrates, Tar (Oil) Sands, Bitumen, Oil Shale.

Coal: Swamps (anoxia), Transgression & Regression, Peat, Lignite, Bituminous, Anthracite, Strip Mining, Underground Mining, Coalbed Methane, Coal Gasification, Underground Coal Fires, Subsidence.

Nuclear Power: Fission, Fusion, ^{235}U, Nuclear Reactors, U Deposits, Waste Disposal (Yucca Mountain).

Geothermal Power: Steam & Hot Water.

Hydroelectric Power: Dams, Tidal.

Solar Energy: Solar Cells, Limitations.

Fuel Cells.

Biomass: Unfossilized Fuels, Alcohol (Ethanol), Biogas.