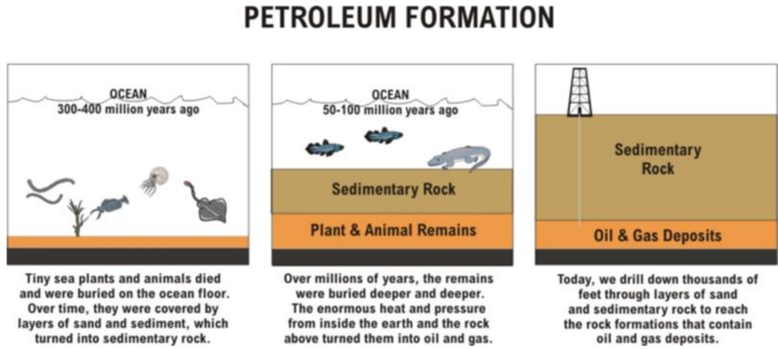
Unit 2.1: Fossil Fuels

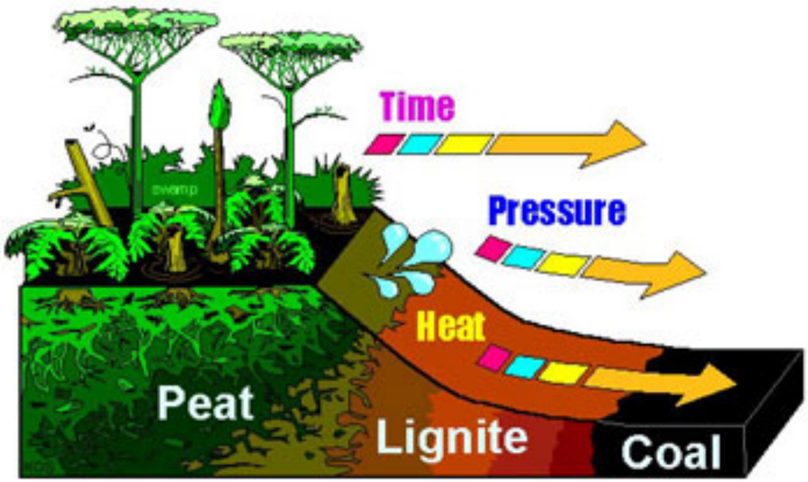
Energy basics

- Energy can take many forms and subforms: mechanical (potential, kinetic), thermodynamic/thermal, chemical, electrostatic, electromagnetic, nuclear, biological (through photosynthesis in plants and the use of ATP in animals)
- Energy can be converted from one form to another but cannot be created or destroyed
- Useful energy is energy available to do work (generally for human use defined as mechanical or electrical work)
- Units: energy - joule = kgm^2/s^2, power - watt = joule/second, energy often measured in kwh, British thermal unit (BTU) = 1btu = 1.055 kilojoules

How are fossil fuels formed: an overview

- Fossil fuels (coal, oil and natural gas) are specialized forms of hydrocarbon compounds (compounds that consist primarily or exclusively of hydrogen and carbon) formed at high pressures and temperatures at some depth in the earth
- Originally, fossil fuels were living things: plants, dinosaurs, mammoths, etc.
- It takes millions of years for the decomposed matter of a deceased critter to be brought to a great enough depth and put under enough heat and pressure to be transformed into a “fossil fuel”
- Ultimately we will become fossil fuels too, but in terms of energy balance, the important issue is the rate of formation and consumption



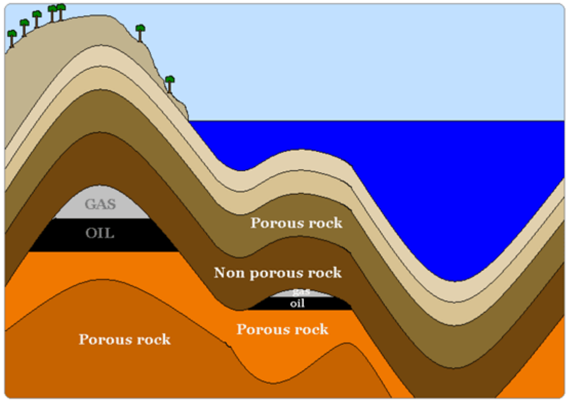


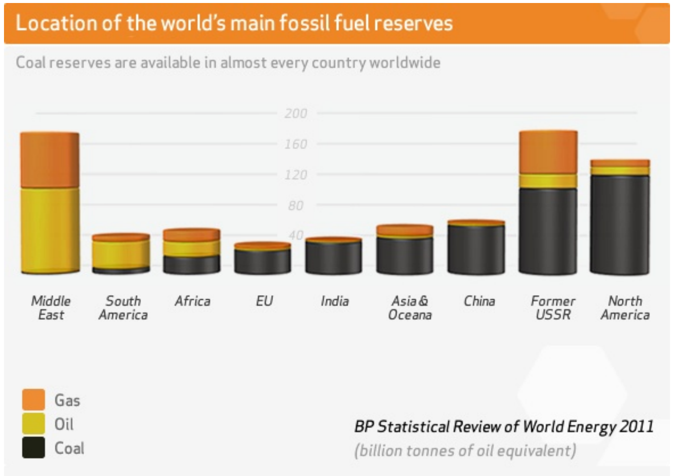
Benefits and drawbacks of fossil fuels

- Benefits
  - Very abundant (have powered our global economy for the last 150 years and will probably continue to be the dominant source of energy for the better part of the 21st century)
  - Relatively cheap
  - Very high energy density (a lot of energy is liberated per kg burned)
- Drawbacks
  - Cause of climate change
  - Cause of geopolitical strife
  - Fundamentally nonrenewable at current consumption rates (despite the vast supplies)

Where are fossil fuels found: an overview

- On a small scale, oil and gas deposits are often found in anticlines (upfolds in sedimentary rock layers)
- Coal is generally found in seams
- On a larger scale oil reserves are quite substantial in the Middle East, coastal Venezuela, the Alberta Tar Sands
- Coal is abundant in the US, the former USSR and China, and natural gas is abundant in the Middle East, the former USSR and the US





Resources, reserves, recoverability, renewability

- Resources – the total quantity of a material for which there is some geological evidence
  - Inferred resources
  - Indicated resources
  - Measured resources
- Reserves – the subset of a resource for which extraction is legally, technically and economically viable
  - Probable reserves
  - Proven reserves
- Recoverability – reserves are recoverable, resources may not be
- Renewability/sustainability – fossil fuels are being extracted a rate that far exceeds the natural formation rate and are therefore not renewable or sustainable in the long run

Types of coal

- Different coal grades have different concentrations of impurities and different properties when they burn
- **Peat** – precursor to coal, can act as an absorber of spilled fossil fuels
- **Lignite** – lowest "grade" of coal (i.e. smallest carbon content, highest concentration of impurities) – dirty, used generally for electricity generation,
- **Sub-bituminous** – fairly low grade, steam electric power, chemical synthesis
- **Bituminous –** higher grade, abundant throughout the US – lowest GHG emissions (source EIA), power generation, manufacturing,
- **"steam coal"** – used for steam engines and for water heating
- **Anthracite** – highest grade of "coal" commonly used as fuel, generally used for space heating
- **Graphite** – highest grade of "coal", but is difficult to ignite and is generally used in pencils and other applications

lignite

bituminous

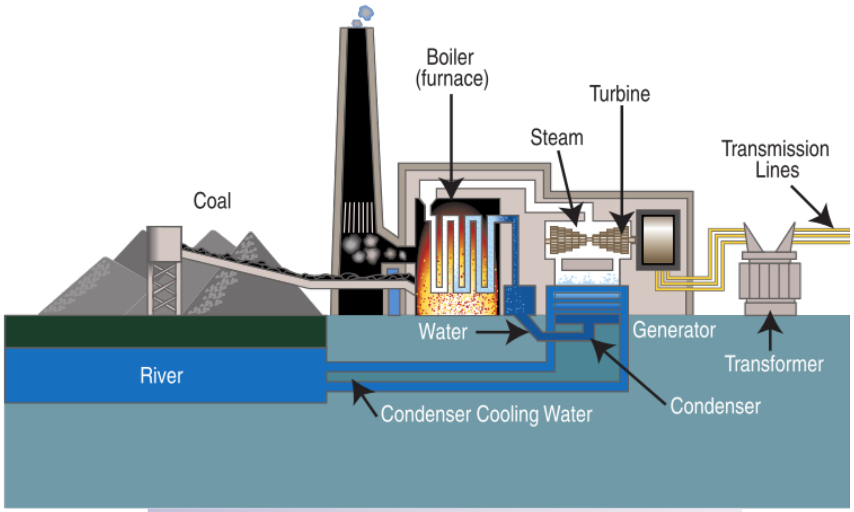
anthracite

Coal mining

- Traditional (shaft) mining
  - smaller environmental impact than mountaintop removal
  - many hazards; methane buildup/fire, collapse, black lung disease
- Mountaintop removal mining
  - much more damaging for the environment; ecosystem destruction, more widespread water pollution by toxic leaching
  - on the whole much safer than shaft mining

Coal fired power plants

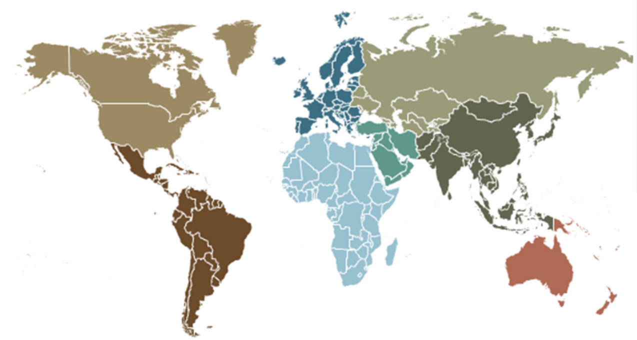
- Coal is burned in boiler room to heat water and create steam
- Pressurized steam is used to turn turbine
- Smokestack allows CO_2 and other gases to escape
- Electric generator connected to turbine converts mechanical rotational energy to electric current
- Energy is distributed via transmission lines
- Condensed steam is returned to river
- Domestic and global distributions



Coal reserves, usage and GHG emissions

- Coal is an abundant fossil fuel with over 100 years of proven reserves (about 950 billion tons of coal reserves globally and usage rate between 5 and 10 billion tons/year)
- Coal comprises roughly 29/30% total energy consumption (oil is slightly higher and natural gas is slightly lower)
- Coal is the "dirtiest" of fossil fuels producing about 1-1.1 kg CO_2 per kilowatt hour (source EIA) (although there are subtle distinctions in grade and impurities)
- Because of this higher emission rate per kwh, coal is responsible for the largest share of GHG emissions from fossil fuels (as compared to oil and natural gas)
- China is ahead of the US in total coal consumption and production, but the per capita coal consumption (and production) in China are comparable to the US

Global Coal Reserves



Countries Resized relative to coal reserves	
World Total	826.0 billion
United States	238.3 billion
Russia	157.0 billion
China	114.5 billion
Australia	76.2 billion
India	58.6 billion
Ukraine	33.9 billion
Kazakhstan	31.3 billion
South Africa	30.4 billion

Sources: EIA, BP Statistical Review of World Energy 2010, show.mappingworlds.com

Rank	Country/Region	Coal production (million tonnes)	share of total[2] (%)
—	*World*	*7,864.5*	*%*
1	China	3,650.0	47.5
2	United States	922.1	13.4
3	India	605.8	6.0
—	*European Union*	580.7	4.3
4	Australia	431.2	6.3
5	Indonesia	386.0	6.2
6	Russia	354.8	4.4
7	South Africa	260.0	3.8
8	Germany	196.2	1.2
9	Poland	144.1	1.5
10	Kazakhstan	116.4	1.5

Statistical Review of World Energy by BP 2013

Current and proposed scrubber technology

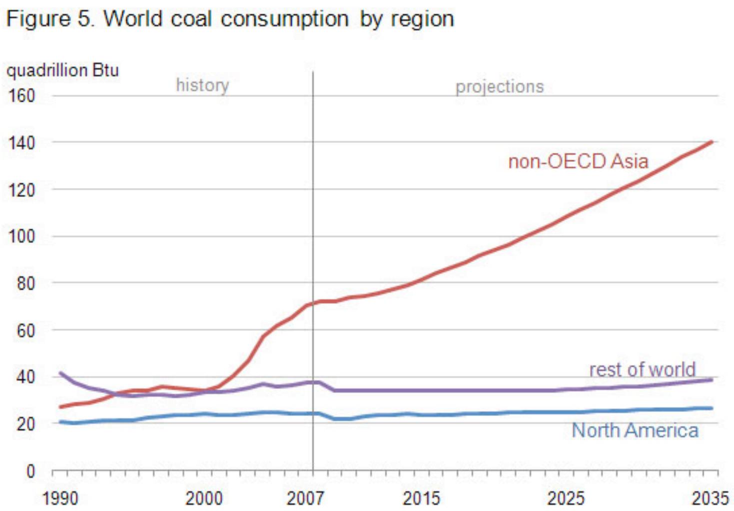
- Already, there are scrubbers in many coal plants to remove SO_2, VOCs, and other impurities from the flue gases
- There are some efforts to create scrubber technologies for CO_2, including one at MIT that could theoretically be installed in existing coal plants
- http://www.environmentalleader.com/2013/06/26/mit-creates-plug-and-play-co2-scrubber-for-existing-power-plants/
- CO_2 scrubbing has some potential at industrial scale, but has yet to be deployed on a massive scale
- "clean coal" is a bit of a misnomer, since no scrubber can remove all of the CO_2; could be called "less dirty coal"

Coal Gasification

- Coal can also be converted to “syngas”; a mixture of methane, water vapor, carbon monoxide carbon dioxide and hydrogen gas via the Fischer Tropsch process
- Coal gasification has been used primarily to diversify the potential applications and in integrated gasification combined cycle (IGCC) plants
- There is some thinking that if coal gasification is done underground and if much of the CO_2 is scrubbed, there is the potential for relatively low-carbon emissions

Coal economics and geopolitics

- Coal is the cheapest of the fossil fuels – both resource and derived energy costs vary, but in general, because of the comparative abundance and ease of extraction, coal is cheaper, per kilowatt-hour than oil or natural gas
- Demand for coal – especially in emerging non-OECD countries (especially China) has been growing very rapidly
- As the middle income countries of the world develop, there may be significant demand for coal because of its low price and abundance (although price will increase when imported over large distances)
- Top national coal importers: Japan, China, India, South Korea, Taiwan
- Top national coal exporters: Australia, Indonesia, Russia, USA, South Africa
- Because of the relative abundance of coal, low price and where the reserves are located there is (relatively) less geopolitical conflict and price volatility (as compared to oil and natural gas)



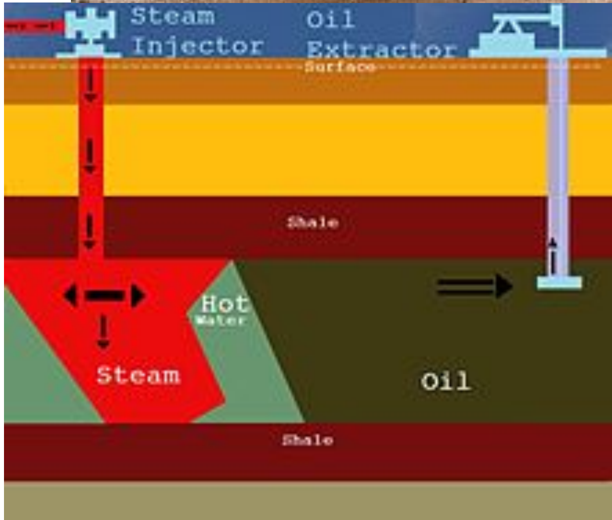
Source: EIA, International Energy Outlook 2010

Chemistry and Types of Oil

- Oil contains a number of different types of hydrocarbons including alkanes, napthenes and aromatic hydrocarbons
- Individual hydrocarbon molecules can vary in chain length from methane to kerosene and longer
- Oil is the liquid form of fossil-based hydrocarbons and there are several types
  - Conventional (crude) oil; this used to be the dominant form (and is the lightest) of oil in use, but is being replaced by heavier oils – naturally relatively uninterrupted liquid
  - “heavy oil” or “very heavy oil”; heavier than crude, often partially biodegraded and often comes from oil sands (liquid oil must be separated from solid particulates to enable a smooth burn)
  - Bitumen; as heavy or heavier than than “very heavy oil”, partially biodegraded and comes primarily from Athabasca oil/tar sands (liquid oil must be separated from sand to enable a smooth burn)

Oil discovery and drilling on land

- When geologists/petroleum engineers suspect an area has favorable geology for oil exploration, they will often conduct seismic surveys and develop a test well
- If the test well and following assessments prove optimistic for oil exploration, there will be an effort to get a permit (generally from the state, rather than federal level)
- Once the permit is issued, more wells can be drilled via oil rigs and the extraction process can begin
- primary recovery phase – pressure causes oil to come to surface and can be transferred directly to storage units and pipelines
- Secondary recovery phase – pressure has fallen and injection of water or natural gas is required to force oil to surface
- Tertiary recovery phase, often steam injection is required

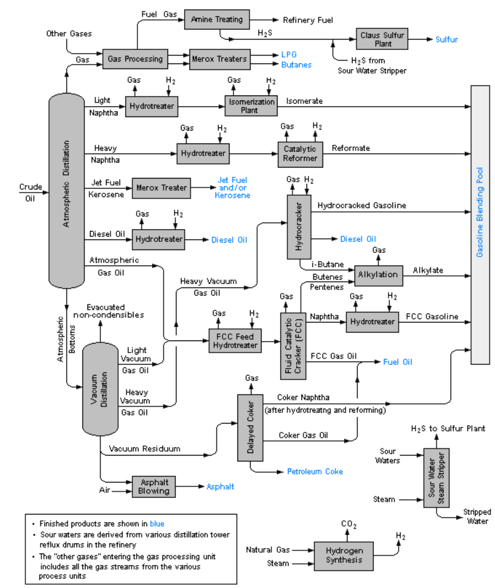


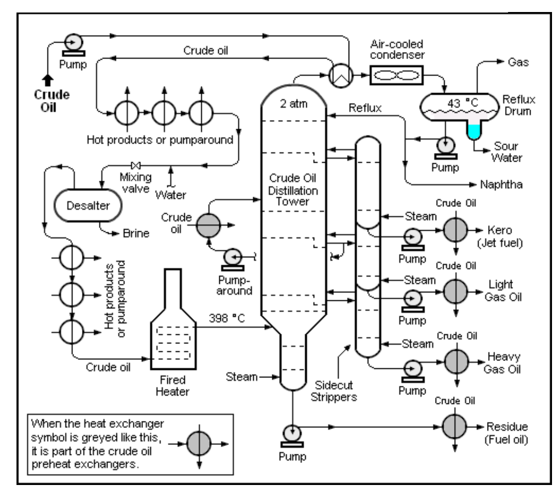
Oil discovery and drilling offshore

- Oil can also be explored and extracted in marine environments – but usually in the continental shelf
- permitting agency tends to depend on geography – close to shore (state waters), further away (federal waters)
- Significant hazards and costs associated with deepwater drilling (BP Deepwater Horizon spill – caused by failure of blowout preventer)
- Cost of bringing equipment out to sea and constructing platform in the ocean in addition to cost of transporting oil back to land
- Hazards of hurricanes, rogue waves, human error, inadequate safety
- Deepest offshore rig – Perdido in the Gulf of Mexico in almost 8000 feet of water
- Efforts by Shell to drill two miles below ocean floor to extract oil

Oil refinement and conversion to gasoline and other products

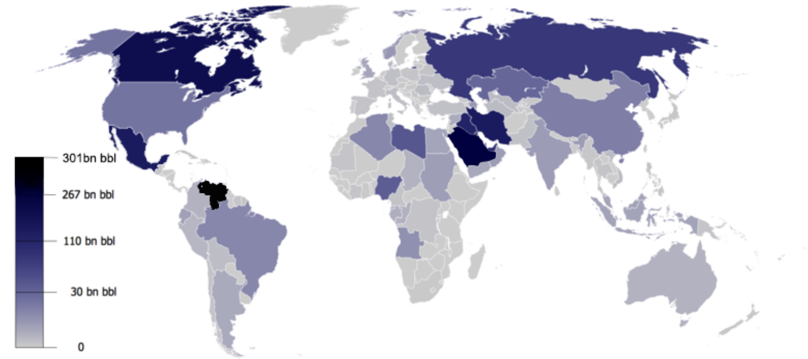
- Once oil is extracted, it must be refined in order to be useful
- Oil is largely used in the transportation and commercial sectors
- Transportation sector as fuel; Gasoline, diesel fuel, kerosene, jet fuel, etc.
- Commercial sector; almost all plastics are petroleum-derivative products
- Some use as heating fuel and in infrastructure to help make asphalt
- Some other material applications: detergents, solvents, polyester, nylon



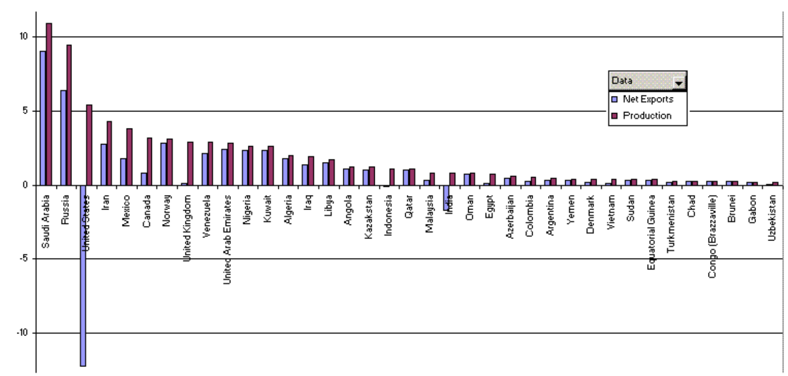


Oil reserves, usage and GHG emissions

- Oil reserves largely in the Middle East, Venezuela, former USSR and Canada
- Total reserves on the order of 1.5 trillion barrels
- Global usage rate about 32 billion barrels a year – 40 years left on the basis of current usage and proven reserves (shortest of the fossil fuels)
- About 0.7-0.8 kg CO_2/kwh – intermediate GHG emissions relative to coal and natural gas
- Usage is very intense – about 33% of total global energy consumption
- Venezuela and Saudi Arabia are contesters for top oil reserves
- Russia, Saudi Arabia and the US are contesters for top oil producers
- US has by far the largest consumption in absolute terms (although China is catching up and per capita usage is higher in some other countries)
- Proven reserves: http://www.eia.gov/countries/index.cfm?view=reserves
- Oil production: http://www.eia.gov/countries/index.cfm?view=production
- Oil consumption: http://www.eia.gov/countries/index.cfm?view=consumption
- Per capita oil consumption: http://www.indexmundi.com/map/?v=91000

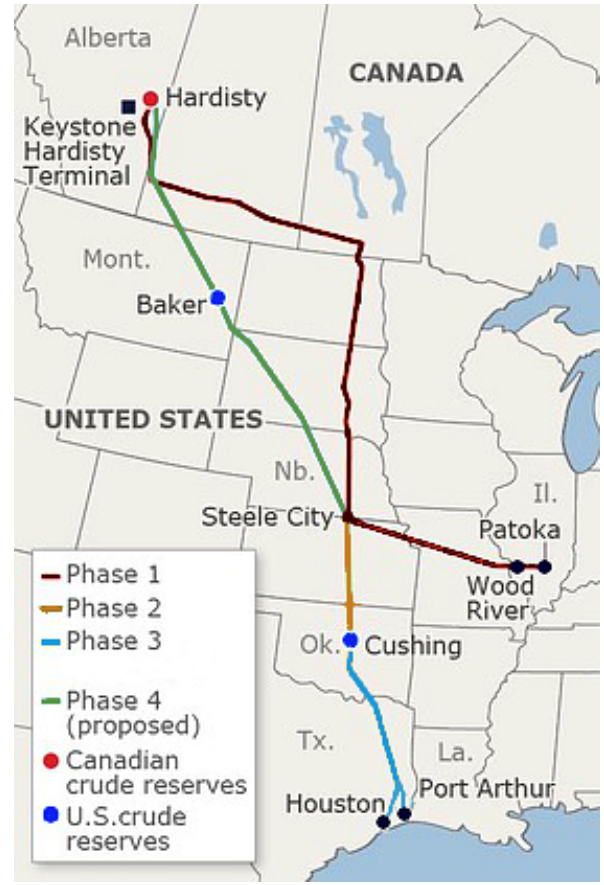


Proven oil reserves by country, 2013 Multiple sources (CIA World Factbook and OPEC)



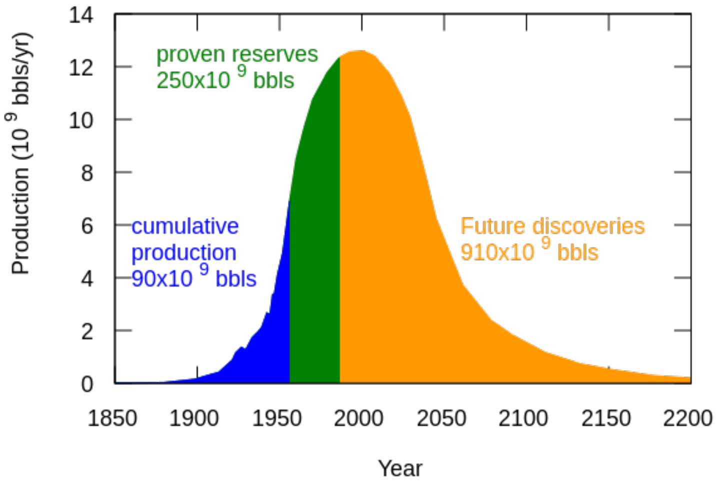
Unconventional sources: the Alberta Oil Sands

- Because of the tremendous demand for cheap, liquid fuel, there is tremendous economic pressure to explore unconventional sources
- There are enormous deposits of oil in the oil/tar sands of Alberta province, Canada
- The oil is not readily available in liquid form
- A large area of land must be mined for the oil resources and a great deal of water and energy must be used to separate the oil from the sand
- These processes are both energetically inefficient (much lower energy yield ratios) and profoundly environmentally costly (significant water pollution, ecosystem impacts and elevation of cancer risk in many First Nation communities near the Athabasca Tar Sands)
- Keystone pipeline phases 1, 2 and 3 have already been completed
- Keystone pipeline phase 4 (XL) is still awaiting Presidential approval
- Although construction of phases 1-3 began during Obama presidency, permit for the first phases were issued under George W. Bush or did not require federal permit
- Obama has yet to render a decision on XL (but did approve the "Alberta clipper pipeline to take Alberta oil to Wisconsin)
- There is a perception that Keystone XL will lead to more energy security (and jobs) in the US
- Some independent research suggests that much of the intention on the part of Transcanada is to ship oil to overseas markets



Peak Oil

- M. King Hubbert's theory – proposed the theory in the 1950s that oil production would follow a bell-shaped curve over time (the increasing phase because of increasing demand and the decreasing phase because of limited supply)
- Some experts would argue that we are reaching or have already reached peak oil extraction – this is likely to be the case in many countries (including the US), but is not yet certain in much of the oil rich nations of the Middle East
- The downsloping side of Peak Oil is likely to be a significant economic challenge: increasing demand and decreasing supply will cause the price to increase dramatically
- Fossil fuel subsidies already artificially suppress the price of oil
- Eventually, the average cost per kilowatt hour of oil based energy production will exceed the average cost per kilowatt hour of alternative energy production
- The more we subsidize the fossil fuel industry and the longer we wait, the higher that break-even price will be and the harder the transition will be
- Criticisms – we keep innovating new technologies to extract more fossil fuels, we keep discovering new deposits and we are also investing in alternatives, so it's not really "that bad"



Geopolitics and Economics of Oil

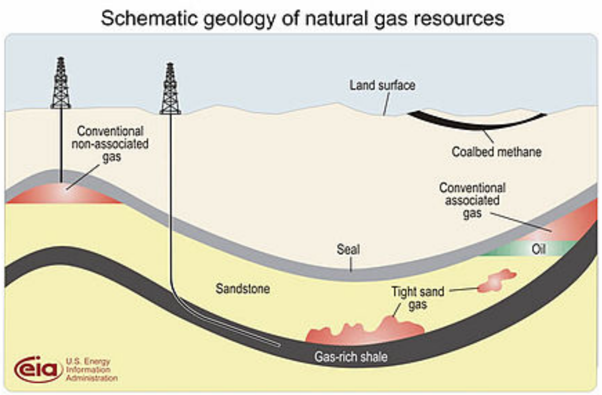
- Geopolitical tensions between the US and major oil exporters in the Middle East, Russia and Venezuela
- Oil price has been historically more volatile than the price of coal – although price volatility is often much more pronounced in various overseas markets than what we Americans experience directly
- This being said, the significant fossil fuel subsidies in the US have helped to stabilize and lower prices (although this is also true of the other fossil fuels)
- Many other countries also engage in oil subsidization and consequently have artificially low gasoline prices, but the US price for gasoline is definitely on the low end of the spectrum (and when you account for our high per capita GDP, the proportion of our income we spend on fuel is quite low)
- Gasoline cost by country http://chartsbin.com/view/1115
- http://www.bloomberg.com/visual-data/gas-prices/
- There are those within the US (and certainly abroad) who claim that the real/primary reason for the US invasion of Iraq and/or Libya was because of oil and to a lesser extent, natural gas
- Many people (both governments and private citizens) in the Middle East (and elsewhere) think of the US as an imperial power that seeks to acquire oil at low cost and will use military force to ensure that that happens
- Even though the above is an overly simplistic view, this mutual mistrust and tension has been and will likely continue to be fodder for tense international relations

Natural Gas

- Gaseous hydrocarbons burned for fuel – generally consists of relatively short chain hydrocarbons (methane, up to butane or pentane)
- Thermogenic (produced by heat and pressure)
- Biogenic (produced by microorganisms in marshes, etc.)
- Found in anticlines and other underground formations, coal seams and chemically bound in methane clathrates
- Shale gas (from shale rock)
- Town gas (from coal distillation)
- Biogas (from methanogenic bacteria) includes landfill gas, release by sewage sludge and methane clathrates – generally not used as fuel
- Natural gas is used in the energy sector for heating, cooling, electricity, transportation (when compressed), and for secondary oil recovery
- In the material sector, natural gas can be used in the manufacture of ammonia (via the Haber process), glass, steel, plastics and paint

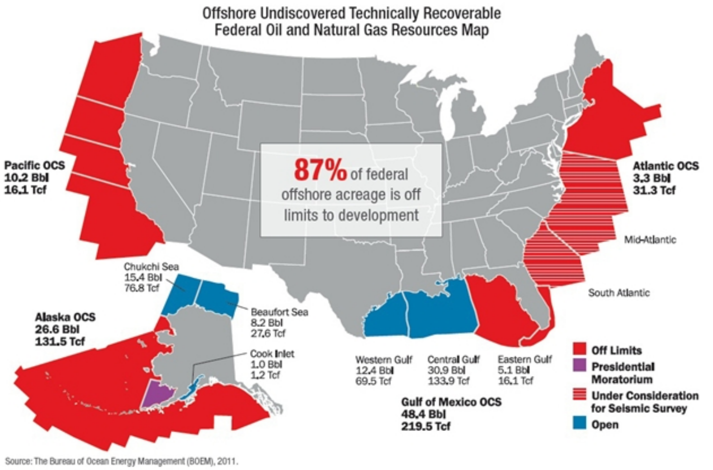
Natural Gas Extraction: onshore drilling

- In the early days of fossil fuel exploration, a fair amount of "associated natural gas" would accompany oil drilling and coal mining efforts and would escape towards the surface through natural fractures in the rock
- There are also separate natural gas deposits that are not associated with coal or oil deposits
- Pipelines would be constructed to transport gas to market and excess would be burned off in flares
- As the concentration of natural gas in a particular deposit decreases, the pressure needed to enable it to escape increases
- Consequently, a fair amount of natural gas extraction is by means of hydraulic fracturing (fracking) – a trend that will likely continue
- Some natural gas is stored and transported in liquid form (LNG)



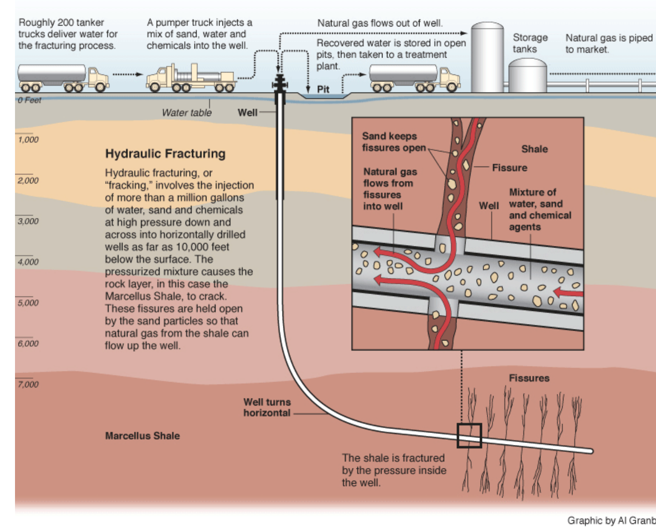
Natural Gas Extraction: offshore drilling

- Many of the challenges of offshore natural gas drilling are comparable to those of offshore oil drilling
- Higher costs, higher potential hazard
- Permitting has been a controversial issue and for part of Obama's administration
- State waters only extend a few miles from shore
- The Obama administration was considering lifting a moratorium on offshore oil and NG drilling in 2010, but then the Deepwater Horizon accident took place and there is a moratorium on Atlantic offshore drilling until 2017



Natural gas extraction: hydraulic fracturing (fracking)

- Process by which a range of fluids are injected into the appropriate geological formations to enable the release and capture of natural gas
- Fracking fluids contain many toxic chemicals
- There is evidence that fracking is not currently being done safely, and the toxic fracking fluids are getting into local water supplies
- Some claims of flammable water because the methane levels are too high
- But natural gas is abundant in the US and has a smaller GHG footprint than the other fossil fuels

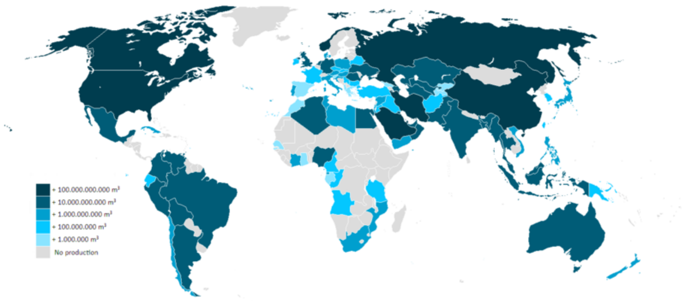


Natural gas processing and use

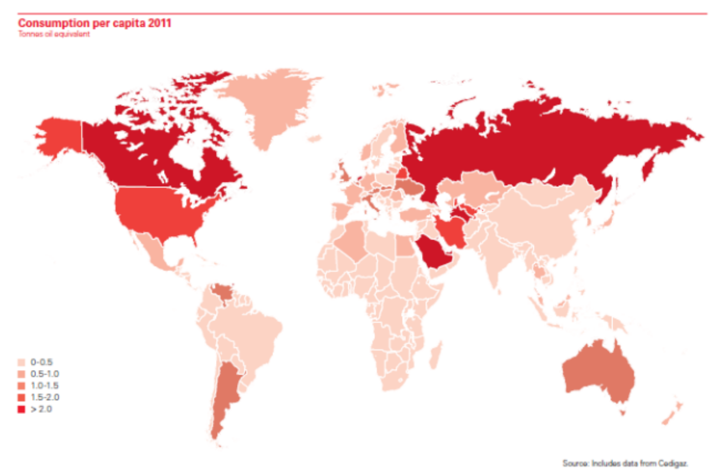
- Natural gas pipelines are impractical across oceans and many existing natural gas pipelines are approaching capacity
- Processing removes acid, sulfur, water, mercury and nitrogen
- Often transported in liquefied form and the converted back to gas at terminal
- For offshore rigs, there is an interest in doing "floating liquefied natural gas" – i.e. liquefication at the site of extraction

Natural gas reserves, usage and GHG emissions

- Total reserves on the order of 200 trillion cubic meters
- Global total consumption ~3 trillion m^3/year – so about 60-70 years left at current consumption rates if proven reserves don't increase (fastest growing fossil fuel in terms of consumption)
- Total natural gas usage accounts for about 25% of world's energy consumption (smallest of the fossil fuels)
- GHG emissions lowest of the fossil fuels; around 0.5-0.6 kg CO_2/kwh (but if there is a large methane release, remember that methane has a greater GWP than CO_2)
- Different reserve estimates vary, but Iran and Russia are the two leaders of reserves, with other nations in the Persian Gulf and Central Asia top contenders, US does have a sizeable supply
- http://world.bymap.org/NaturalGasReserves.html
- The US and Russia are the two clear leaders in production, but Russia has much larger reserves
- Because natural gas is difficult and expensive to transport safely over large distances, consumption tends to be more localized to areas that have high rates of production
- http://www.indexmundi.com/map/?v=137
- While the US clearly has the highest total rate of natural gas consumption, the per capita rate in the US is not as high as some other nations

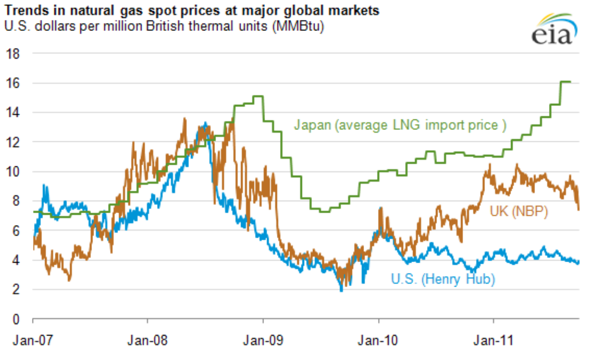


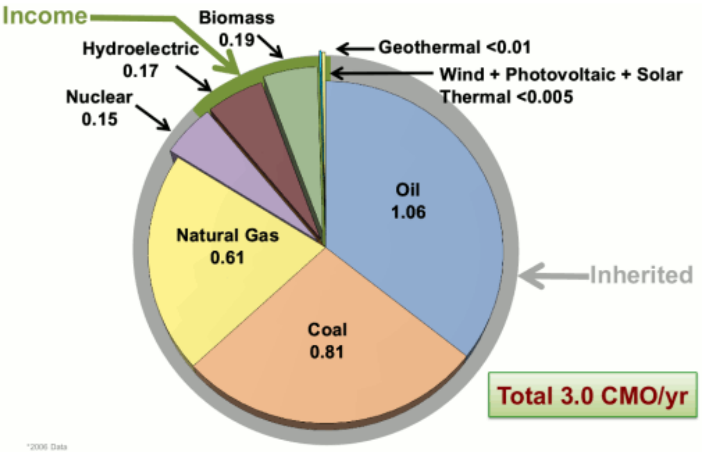
Map of global natural gas production, 2014
CIA Factbook



Natural gas economics and geopolitics

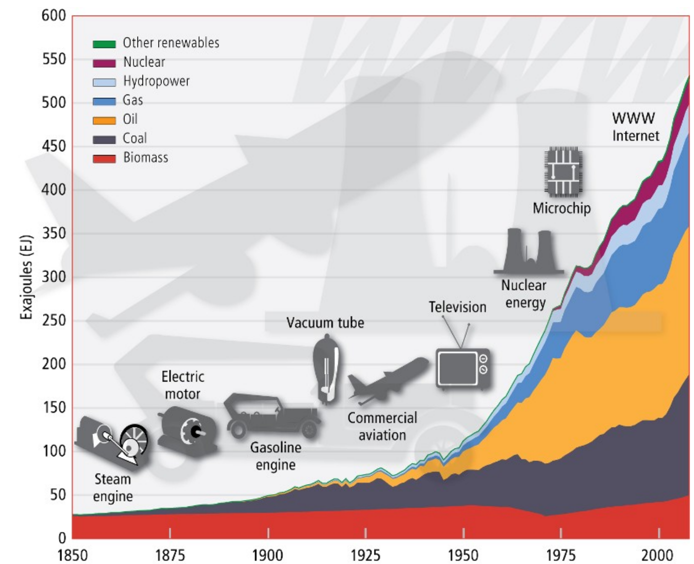
- As with oil, there is generally somewhat more geopolitical tension and price volatility than with coal (although because proportional import/export rates tend to be lower than for oil)
- There doesn't tend to be quite as much price volatility as with oil
- US has lower natural gas prices than many other developed countries (which for the most part don't have the kind of production and reserve levels that the US does)
- There are still issues with subsidies (though not on the same scale as for oil)
- Because natural gas is considered part of a "greener" portfolio and there are abundant resources in the US, there may a great deal of political and economic pressure to deepen natural gas subsidies



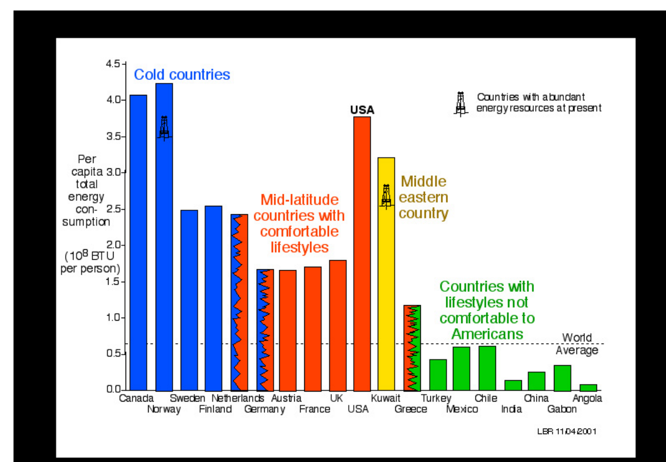


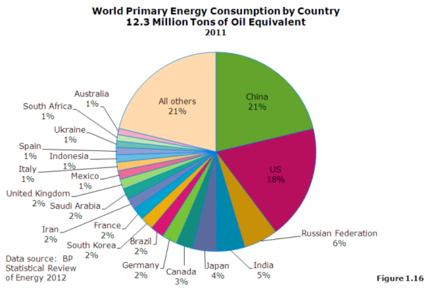
Global energy consumption

- Total world human energy consumption is on the order of the rate of 15 or 16 terawatts (10^{12} watts), which translates to about 500 exajoules ($500*10^{18}$ joules) over the course of a year
- About 85% comes from fossil fuels and the majority of the non-fossil fuels comes from hydro, nuclear and biomass
- Energy consumption correlates to some degree with latitude but to a large degree with affluence/per capita GDP
- http://www.energyrealities.org/chapter/meeting-our-needs/item/per-capita-energy-consumption/erp327B7C729A3B31D2B



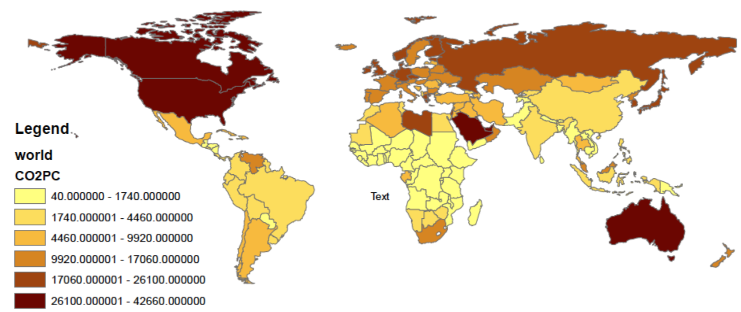
Source: IIASA



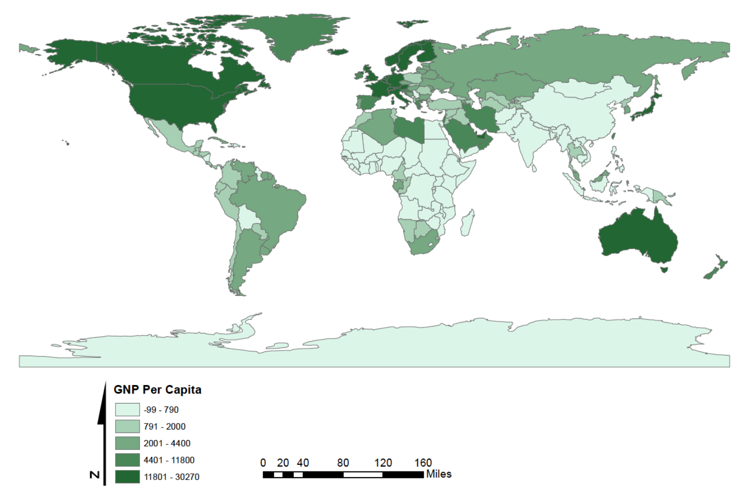


US and regional energy consumption

- Total US energy consumption has actually slightly decreased since the recession in 2008 - we're now down to about 3.4 terrawatts
- http://www.eia.gov/todayinenergy/detail.cfm?id=10
- China is now comparable to the US in total energy consumption and has surpassed the US recently in total GHG emissions (but China has 4 times the population of the US)
- Energy intensity = kwh energy consumed/ $ GDP
- Carbon intensity = kg CO_2/kwh
- Both carbon intensity and energy intensity tend to be less variable across nations than GDP, but there is still some variability

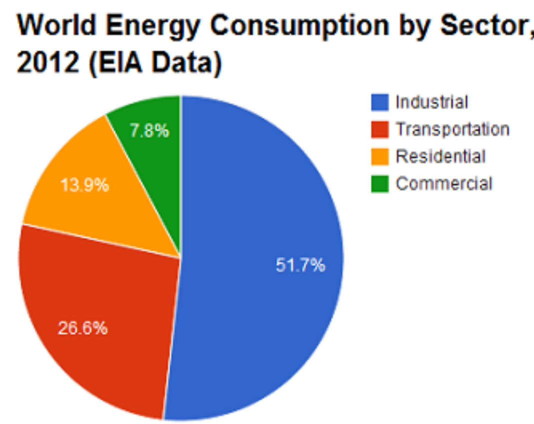


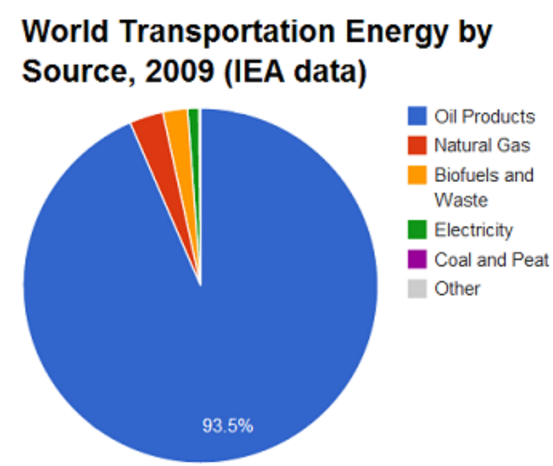
Global CO_2 emissions per capita



World Energy Consumption by Sector

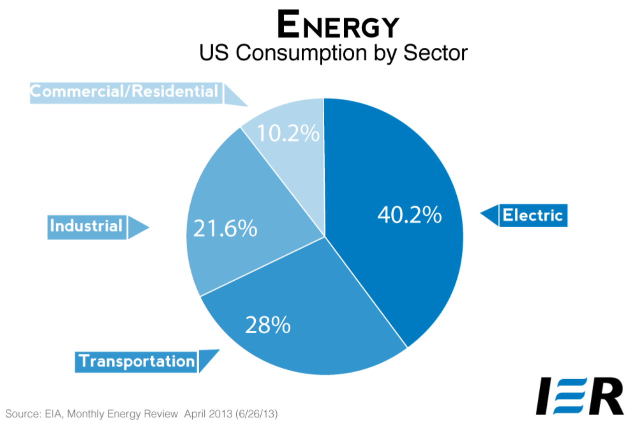
- Industrial sector largest globally around 50% (largely power generation and heating, ventilation and air conditioning (HVAC))
- Most of the transportation energy comes from oil
- Residential and commercial is mostly from electricity and HVAC

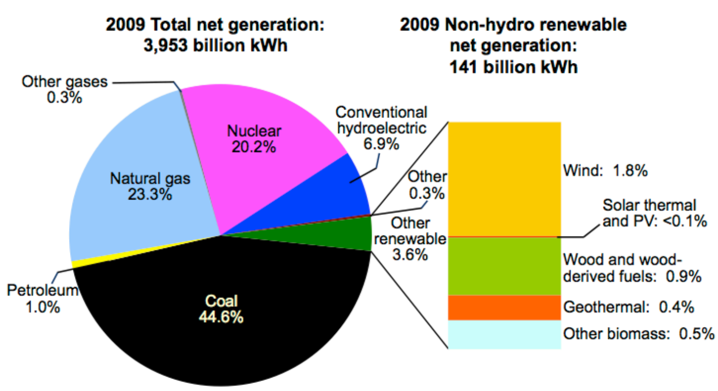




US energy consumption by sector and fuel type

- Comparable percentage on transportation and commercial/ residential, but more electric and less industrial than global percentages
- Agriculture is also a significant sink of US energy (about 15% of our energy goes to food production), but is represented here by electricity and industry
- Heating/cooling needs vary with latitude, agriculture energy inputs are fairly large in an absolute sense in the US and other nations with industrialized ag, but globally tend to account for a relatively small portion of energy use
- Industrial energy use is proportionally large for rapidly industrializing countries, but comparatively lower for nations like the US which have largely switched to a service economy, or poor nations that have yet to industrialize
- Electricity usage, transportation energy consumption and to some degree HVAC tend to be correlated to wealth globally
- That said, densely populated affluent countries (eg., Europe, Japan) tend to have lower transportation energy consumption
- Electricity production is predominantly coal and natural gas driven, with nuclear being a substantial portion of the remainder





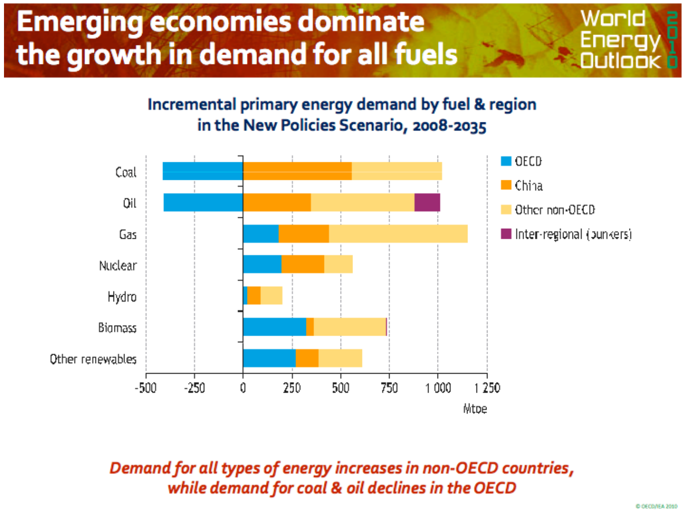
US Electricity production

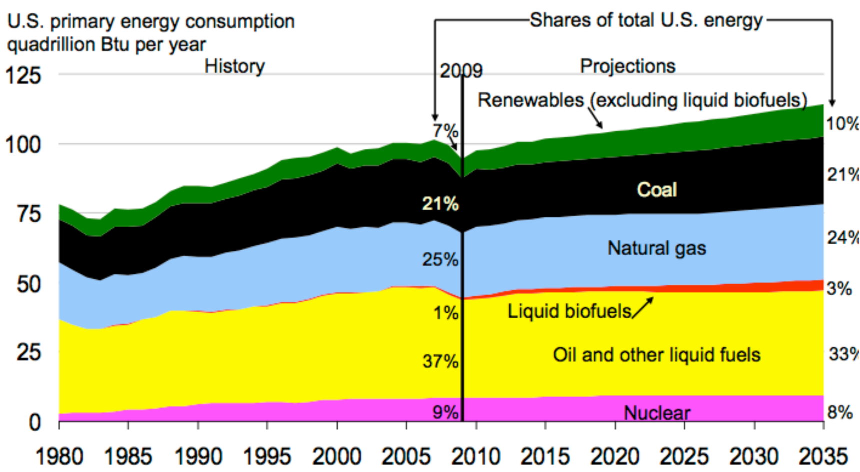
Specific sectoral needs and distinctions

- While coal and natural gas can be substituted for oil for most purposes, transportation generally works best with a liquid fuel (CNG buses and coal steam trains notwithstanding)
- This poses a significant challenge with respect to oil
- Heating costs per degree day are less than cooling costs, but in most areas of the mid and high latitudes, there are many more heating degree days than cooling degree days
- Climate change will change the balance of heating and cooling degree days

Projected energy mix

- Energy demand is expected to grow, especially for middle income industrializing countries (largely because of improvements to standard of living, but also because of population growth)
- Fossil fuels are still expected to be the dominant fuel type for some time, although there may be some reduction in coal and oil demand in OECD countries

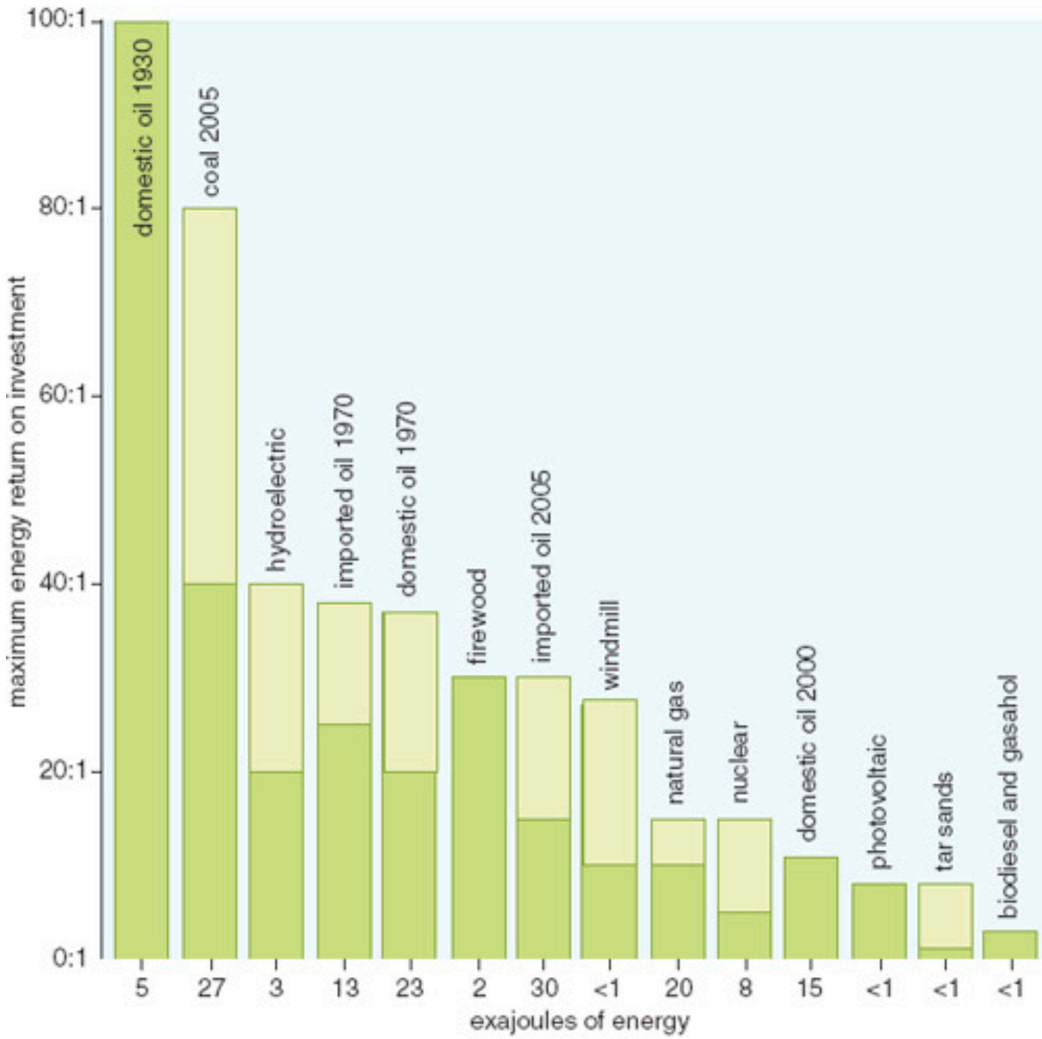




Transportation and distribution of energy

- Transportation and distribution of energy costs additional money and energy
- If energy can be supplied locally, the total impact is reduced
- This being said, the global system of fossil fuel transportation and distribution tends to work pretty consistently
- There still are possibilities for service disruptions (blackouts/brownouts) and environmental contamination (oil spills, toxic mines)
- In contrast, storage and distribution tend to be larger problems for non-fossil fuels

Energy Return on Investment (EROI) of various energy sources

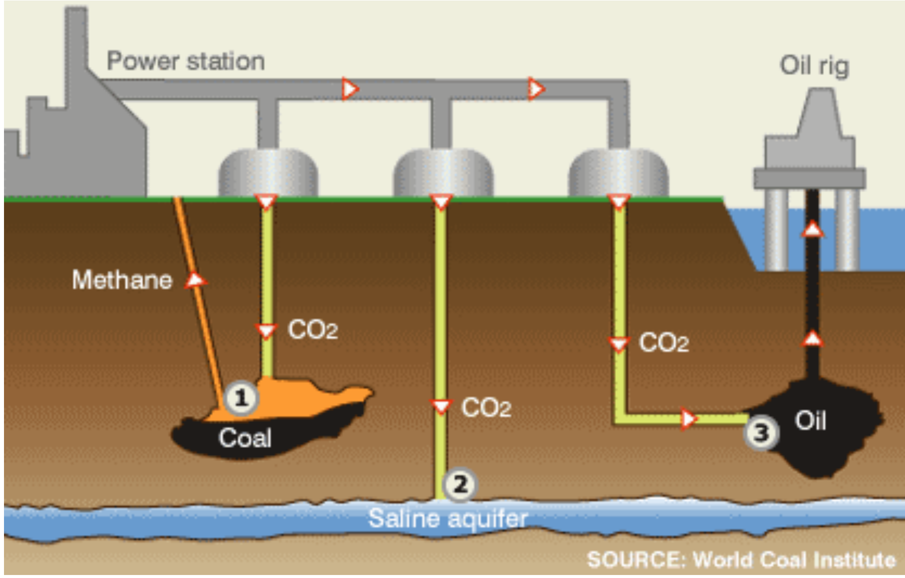


"The EROI of U.S. petroleum declined from roughly 100:1 in 1930, to 40:1 in 1970, to about 14:1 in 2000. Even these figures are relatively positive compared to EROI for finding brand-new oil in the U.S., which, based on the limited information available, appears likely to approach 1:1 within a few decades" (Hall and Day 2009).

- (Lighter colors indicate a range of possible EROI due to varying conditions and uncertain data.)

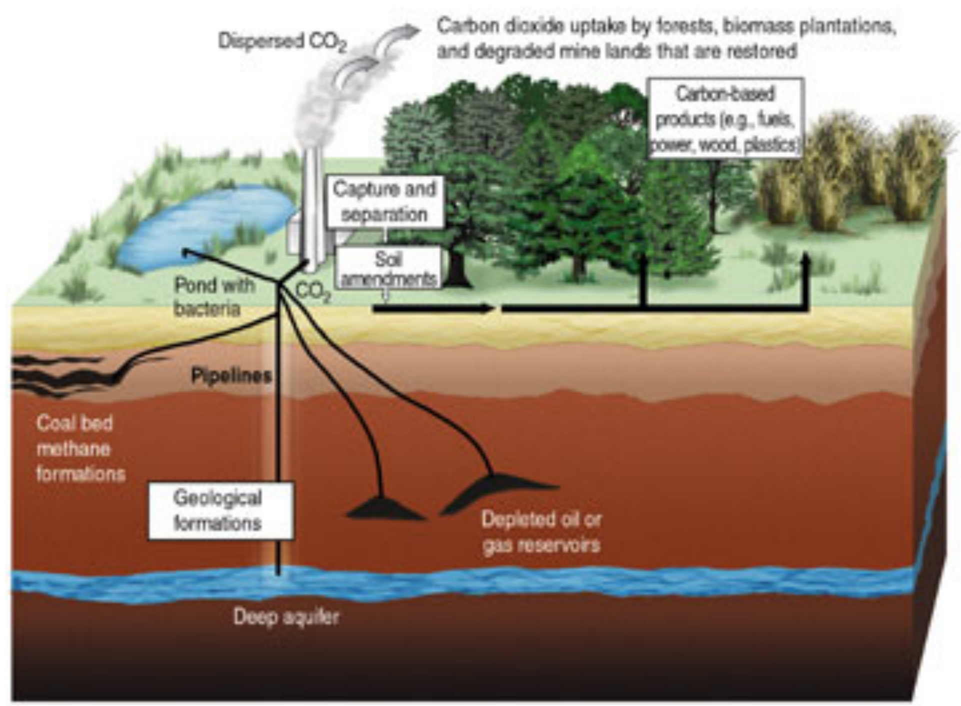
Carbon capture and storage

- The idea behind carbon capture is to capture emitted carbon directly from industrial plants before it escapes to the atmosphere and contributes to additional climate change
- We already discussed coal scrubbing
- There is also the possibility of natural gas injection
- Captured CO_2 could facilitate recovery of methane from oil and natural gas wells
- Only CCS methods actively remove GHGs from the atmosphere



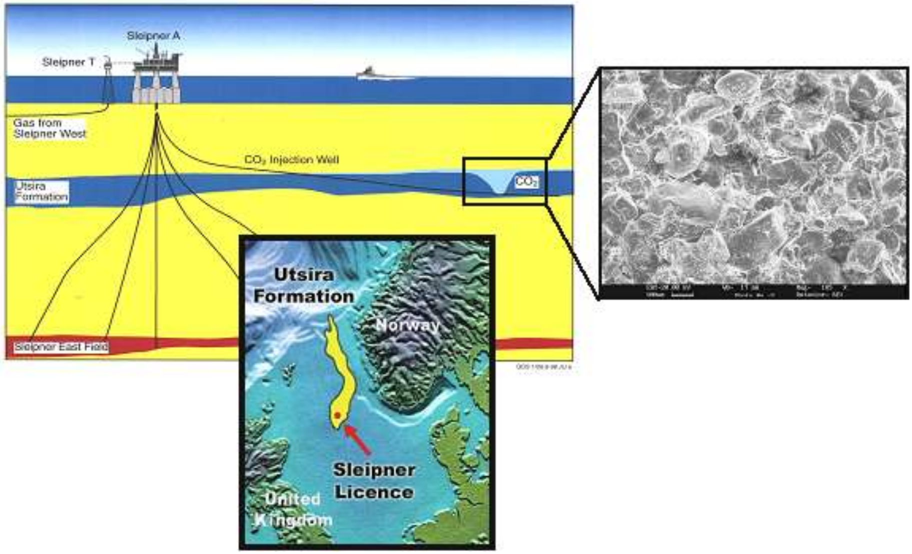
geologic sequestration

- So once you've captured the carbon, where does it go?
- One option is in geologic formations that confine the carbon dioxide and prevent it from escaping
- Another option is deep (generally saline) aquifers that wouldn't be used for drinking water
- Space limitations - finding such geologic features that are large enough to house the amount of CO_2 we have released and safe enough to prevent ground level atmospheric release is very difficult
- Criticisms – carbon that goes into aquifers may eventually get to oceans and carbon in subterranean geologic formations may come to surface



oceanic sequestration

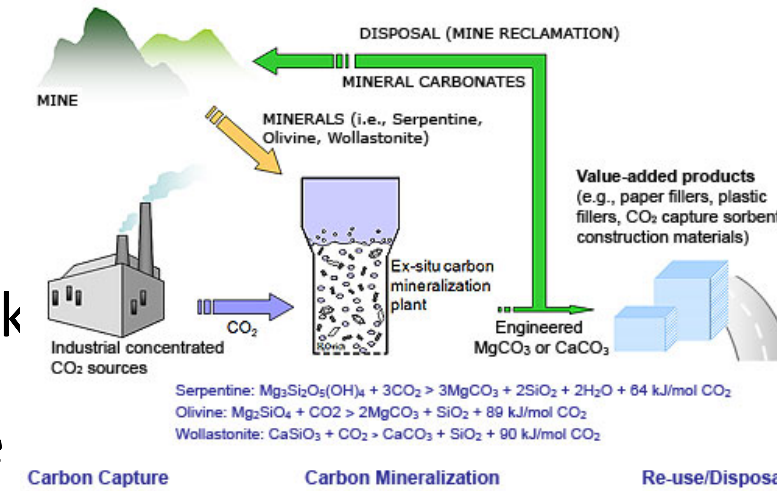
- Another possibility is to try to sequester the carbon in the deep ocean (beneath the thermocline) and take advantage of the natural stratification of the ocean to stall the re-release to the atmosphere; this will ultimately acidify the deep ocean and become much more difficult to manage in the long run
- Iron fertilization – put lots of iron in the surface ocean, thereby stimulating phytoplankton to photosynthesize, thereby amplifying the CO_2 sink role of photosynthesis; many unknowns in terms of long term chemical and biological ramifications, or the actual rate of CO_2 uptake

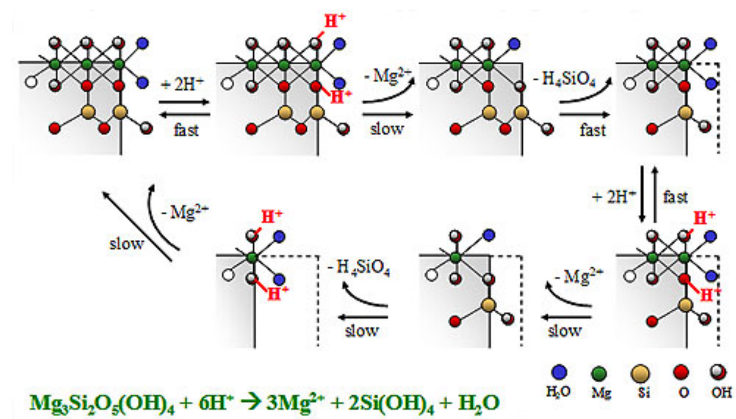


Sleipner oil field in the North Sea has submarine geologic sequestration

Mineral sequestration?

- Combine the carbon dioxide directly from air with other chemicals to produce a chemically inert mineral
- Klaus Lackner at Columbia and others have done some proof of concept work but there is nowhere near adequate funding to bring this to industrial scale yet
- http://www.columbia.edu/~ap2622/research_carbon.html
- This being said, it may the best hope for viable CCS without added biological or chemical problems





Some final thoughts on fossil fuels

- We wouldn't have the population or the economy we have, if not for fossil fuels
- Energy demand will continue to rise
- Energy use and prosperity tend to be well correlated
- Because of this, some people argue that the net good outweighs the bad
- Transitioning to a predominantly non-fossil fuel economy will take significant effort and will have upfront costs
- Transitioning to a predominantly non-fossil fuel economy will be absolutely necessary to limit the impacts of climate change
- Even leaving climate aside, simply from a resource sustainability perspective, there are very powerful reasons to make the transition to a predominantly non-fossil fuel economy ASAP
- Don't necessarily hate all the players, but hate the game; many coal miners, oil platform workers, etc., are decent, reasonably honest, hard-working blue collar folks who are just trying to provide for their families and the fossil fuels they extract are incredibly helpful in supporting the economy we have
- To do right by this population in light of a changing climate, any serious effort to roll back fossil fuel production should have meaningful transitional training and employment provisos so those people can transition to other jobs in the energy sector as the energy sector changes
- This being said, we desperately need to get off our addiction to fossil fuels, have a real, adult discourse on climate change and the fossil fuel execs who profit from scientific distortion and policy delays are real barriers to a better future for the collective good