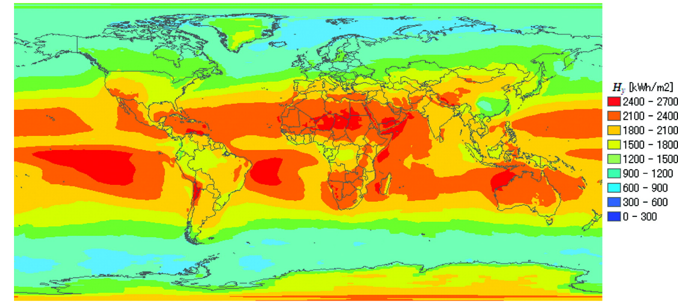
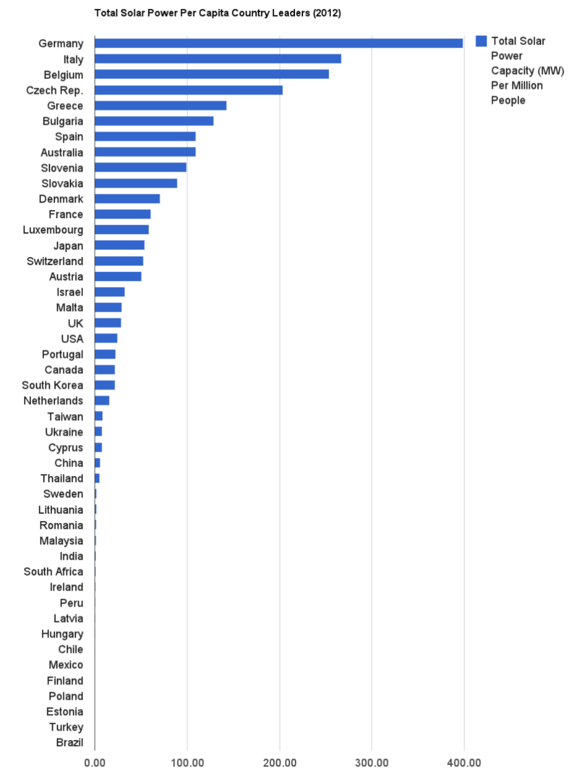


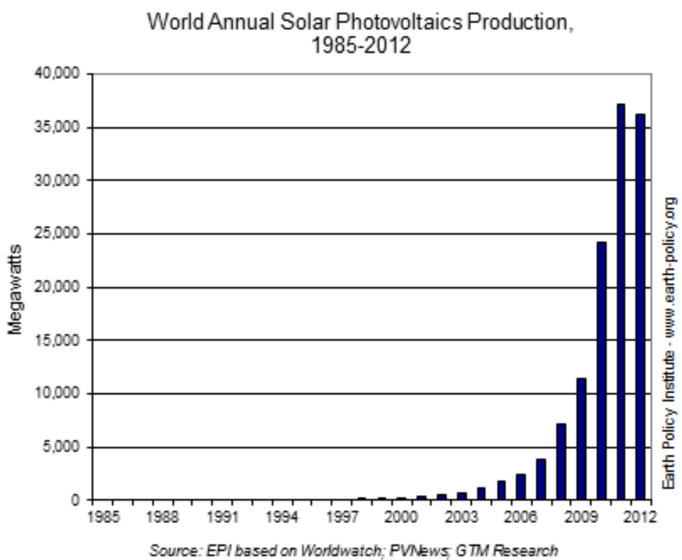

Unit 2.2: Alternative and Renewable Energies


Solar energy overview



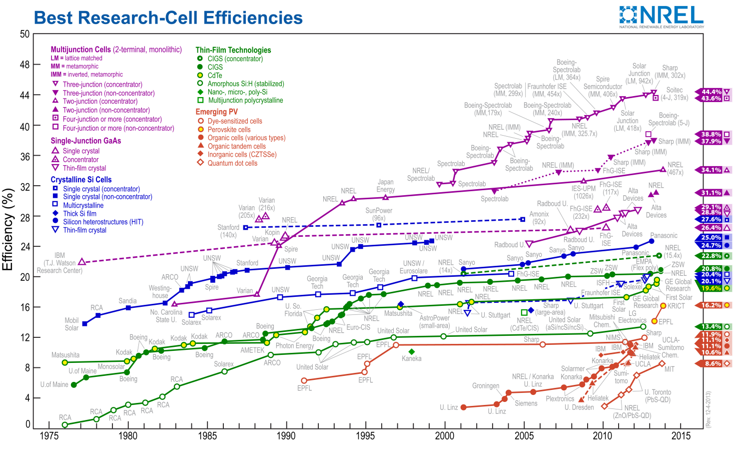
- Solar energy is by far our most abundant renewable energy resource
- There is certainly enough supply of solar energy to meet the world's energy needs many times over
- Global solar potential is at it peak in the arid subtropics (function of irradiance and clouds)
- Some of the global leaders in solar energy use are not nations one might expect (eg. Germany is at the top of the list per capita and in absolute terms), although China now leads in production of PV panels
- Rapidly growing resource – now over 100 GW installed, 30GW+ produced in recent years (less than 1 GW a decade ago)

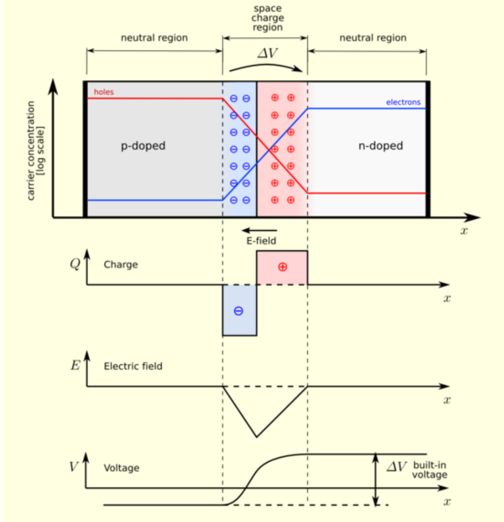




Solar energy – photovoltaics (PV)

- Panels of silicon designed to act as semiconductors and take advantage of photovoltaic effect to convert solar energy into direct current electricity
- Monocrystalline and polycrystalline silicon most commonly used
- Photon energy causes electron in valence band of silicon to jump one or more energy levels to conduction band
- Excited electrons are accelerated to a material with a built-in potential, inducing an electromotive force
- With crystalline silicon, p-n junctions are generally used – subtypes; monocrystalline and polycrystalline
- Most predominant form of solar energy
- As solar energy goes, PV technology is somewhat inefficient (but variable depending on the material) and efficiency is improving
- Can be used on individual homes and businesses for electric needs
- Within the US is a leading state in solar investment and Rutgers Livingston campus has the largest campus solar energy project in the country and one of the largest solar energy canopies in the country
- Because of direct conversion of sunlight into electric energy, storage is difficult, making large scale production difficult (due to intermittency – solar panels don't work at night!)





Solar energy - thermal

Parabolic mirror

- Solar energy is reflected and focused by onto an absorber tube which gets very hot
- The tube is filled with thermal conducting fluid (synthetic oil, molten salt, etc.) which can heat to several hundred degrees °C
- Heat is transferred to water, which boils and drives a Rankine cycle steam turbine leading to electricity production
- Several different possible designs; parabolic mirrors, power tower, dish designs, enclosed parabolic mirrors, Fresnel reflectors
- Potentially higher efficiency than PV – thermal efficiency a function of how hot it gets (higher temps – more potential efficiency)
- Easier to store thermal energy than electricity, so solar thermal has better potential for large scale production and limiting intermittency
- Largest plant in the world in the Mojave desert, but also a lot of exploration in Spain
- There are a handful of very large facilities, but price is currently a hindrance to wide scale investment

Power/central tower

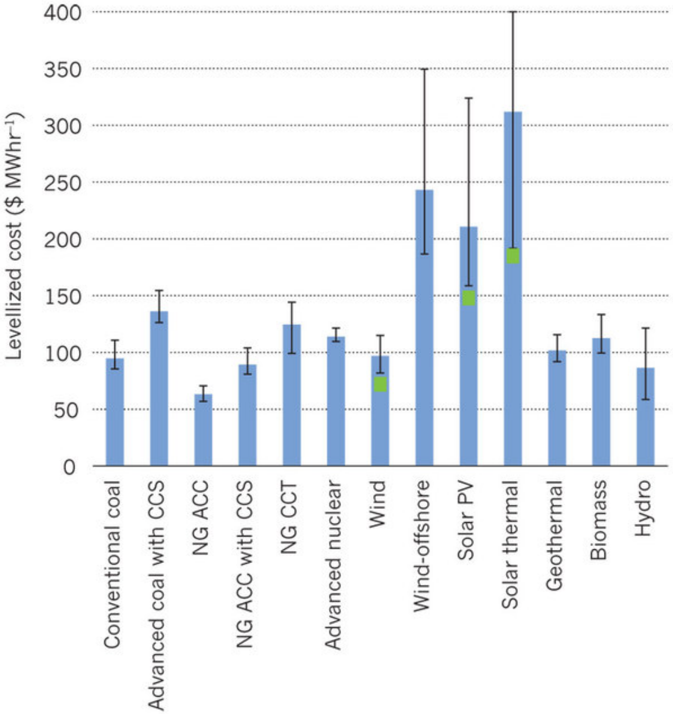
Dish tower

Solar energy – thin films

- More recently emerging technology with potential for high efficiency and relatively low cost
- Still fundamentally PV technology; can be made with amorphous silicon, thin film silicon, cadmium telluride, copper indium gallium selenide (CIGS), dye sensitized solar cell or organic solar cells
- Thin film of semiconductor material (nanometers to micrometer scale thickness) placed on flexible substrate
- More cost competitive than standard PV
- Recent breakthroughs in CIGS efficiencies up to about 20%
- Still lower than conventional PV efficiency, but market penetration is a function of both conversion efficiency and cost
- Still a relatively small share of total solar energy portfolio
- Lower space efficiency means that home heating&electric impractical
- Flexibility opens the door for new potential applications

Solar energy – challenges and limitations

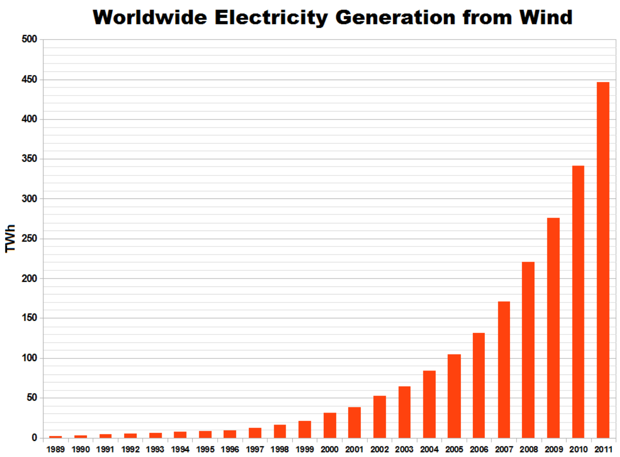
- Solar energy can be very effective for electricity generation and potentially for HVAC, but cannot effectively substitute for liquid fuels in the transportation sector
- No fundamental limit to how much energy could be produced
- Efficiency of solar energy conversion and cost are two significant challenges
- Distribution of solar energy from areas with high sunshine to areas of high population could increase costs
- Intermittency and storage are other challenges (great so you have energy when the sun is shining, but what about night, or on cloudy days and winter)?

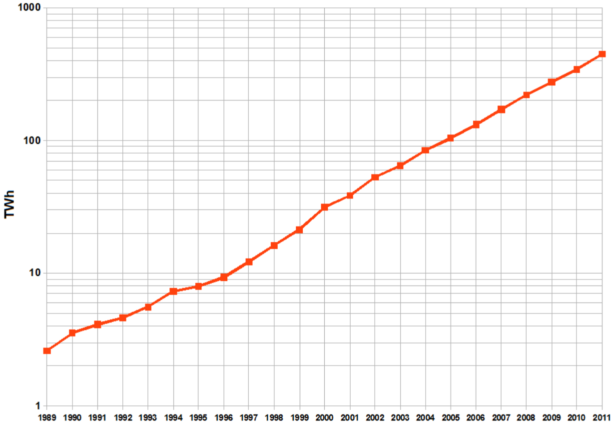


Taken from article in Nature 2012 by Steven Chu

Wind Power

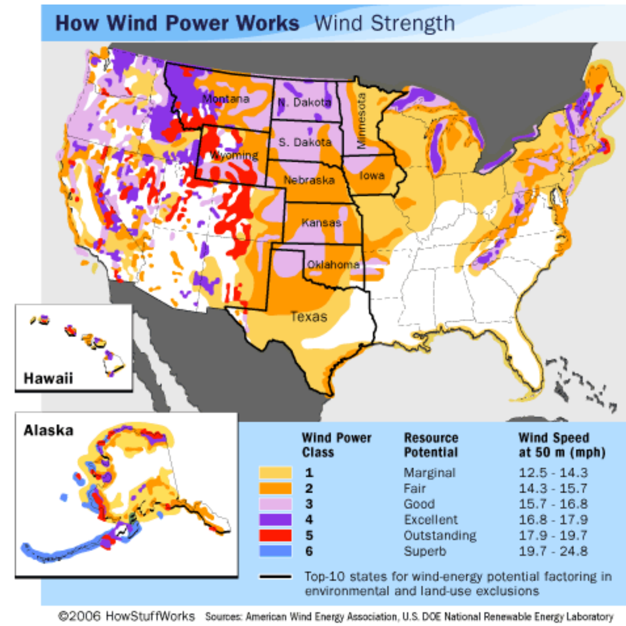
- Old history as a technology
- Wind drives turbines which turn an electric generator, producing electricity
- 280+GW global installed capacity, ~460 TWh/year generation rate (a good bit larger than solar)
- Energy derived from wind energy is proportional to cube of wind speed – so more steady wind really important (generally, if the average sustained wind is not almost 10 mph or stronger, it's not worth it)
- Wind turbines must be spaced appropriately (to avoid adjacent turbines interfering with each other)
- Efficiency now approaching 50%
- Turbine design has evolved over time, but now, typical turbines are on the order of 130-300 feet in diameter, although the largest is around 650 feet tall and over 400 feet diameter
- Wind speeds will be higher at higher elevation, but larger wind turbines will rotate slower
- For onshore or offshore, energy yield is limited by Betz's law to under 60% efficiency

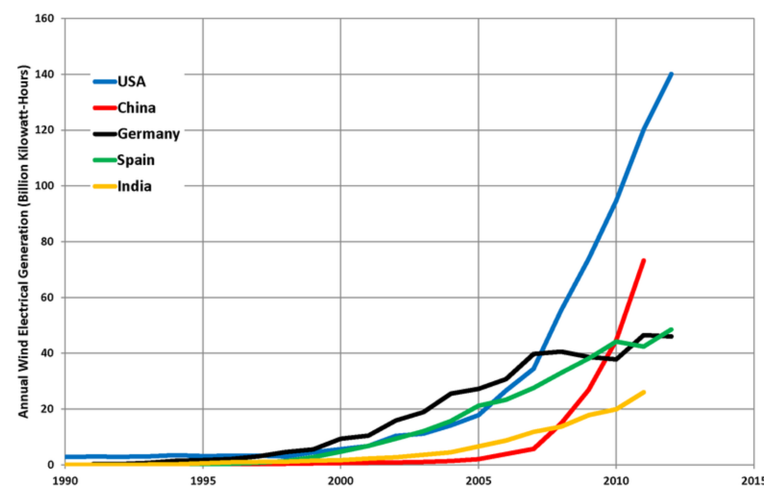




Wind energy onshore

- Onshore production may be more efficient than offshore depending on distance, cost and efficiency of distribution lines
- Exact efficiency is a function of wind speed and the rating of the machine
- permits must be issued by state or federal powers
- Onshore wind production is larger than offshore
- The US leads the world in onshore production
- Within the US, greatest production in Texas and California
- Can be relatively cheap, especially if transmission lines don't have to be too long





Wind energy offshore

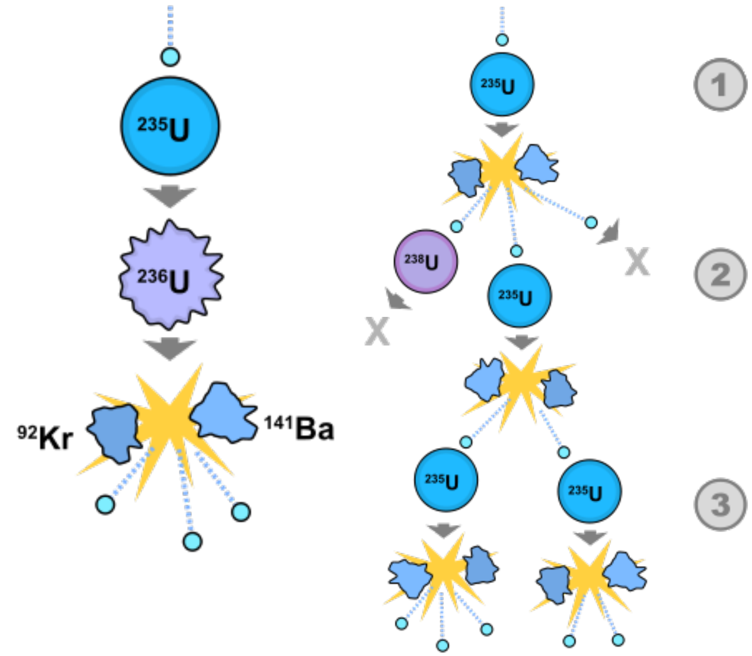
- Turbines out at sea can imply higher cost to transmit energy back to shore via submarine transmission lines and assemble turbines out at sea
- Potentially more energy yield depending on wind strength and reliability
- Deepest wind turbines in about 50 meters of water in the North Sea
- Northern European countries using the North Sea are the leaders in offshore wind energy production (all the largest 25 offshore wind projects are in: UK, Denmark, Sweden, Belgium, Sweden, Germany, the Netherlands (and China))
- Denmark uses offshore wind to supply 30% of its electric needs
- In the US, Cape Wind (first large scale approved offshore project in the US – in the Nantucket Sound) and some exploration along the mid-Atlantic and Pacific coasts
- Jersey Atlantic Windfarm first operational offshore wind farm in the US (2006)

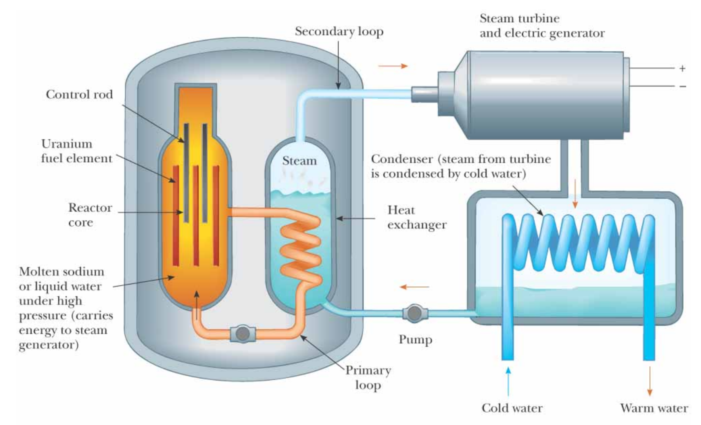
Wind energy challenges and limitations

- Intermittency and storage
- Efficiency losses over long distribution lines
- Less supply than solar
- Noise – wind power can be very loud (especially with quickly rotating blades)
- Some concerns about safety
- Bird hazard – some birds die (not just a product of "birdbrain", near the blades, the wind motion is altered and a bird that gets too close can be pulled towards blade)
- Aesthetics – many people don't like the look of large scale turbines and think their property values will decrease
- While there is enough wind on the planet to meet all our needs, the cost and energy of transmitting the energy from the windy areas to population centers means that the actual supply potential is more limited,
- storage, intermittency and distribution can be significant challenges

Nuclear fission

- While fission reactions can occur spontaneously as a result of radioactive decay of certain isotopes (thorium, ^{235}U, ^{238}U), the vast majority fission is induced by bombardment of fissionable radioactive isotopes (^{239}Pu, ^{235}U, ^{238}U, and ^{233}U) with neutrons
- Fissionable isotope – an isotope that will undergo a fission reaction if the bombarding neutron has a high enough energy
- Fissile isotope – an isotope that will undergo a fission reaction with neutron bombardment at any energy level
- For large scale energy production, a self-sustaining chain reaction must be established (often in a "breeder reactor")
- Energy is liberated by breaking the strong forces of the atom
- Radioactive decay, fission of original isotopes and by-products and gamma ray releases a great deal of thermal energy (83 million MJ/kg, as compared to 46 for gasoline or 24 for coal)
- Energy is then absorbed by water, molten salt or some other (usually liquid) fluid and used to make steam, and drive a steam turbine
- Need for adequate cooling water to prevent meltdown
- Rate of reaction can be modified by use of neutron control rods which can absorb neutrons split off from the reaction





Nuclear Energy production v. nuclear weapons

- In total fission energy production, the US is at the top of the list with 102 GW in 2012 (out of 375 globally); next on the list are France, Japan, Russia, and South Korea (IAEA)
- Considerably more nuclear energy production than wind or solar
- France has the largest share of its energy from nuclear, followed by Belgium, Hungary, Sweden, Czech Republic
- Australia, Russia and Canada produce the most uranium for global consumption, although some other nations (like Niger) with very low consumption rates have fairly abundant natural resources and produce a good portion
- Weapons grade isotopes of uranium and plutonium must be highly refined into fissile material
- Naturally, most uranium (over 99%) is ^{238}U which is fissionable, but not fissile, whereas ^{235}U (and ^{239}Pu) are fissile
- Centrifuge separation must be used on uranium to make it sufficiently enriched to be fissile
- Relatively few countries have weapons grade nuclear material: China, Russia, North Korea, Pakistan, India, Israel, France, the UK, South Africa and the USA
- An issue of tremendous geopolitical consequence – particularly with regard to Iran
- Global uranium proven reserves estimated at 5.4 million metric tons
- But estimated reserves of another 10 million metric tons
- Global consumption around 70,000 metric tons/year
- 200+ years of uranium left

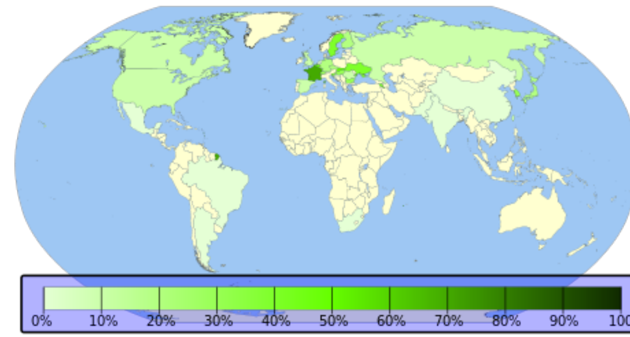
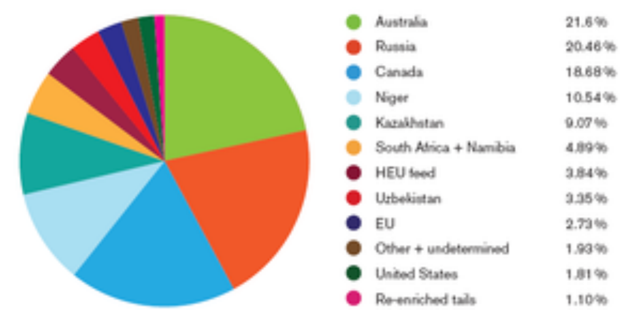
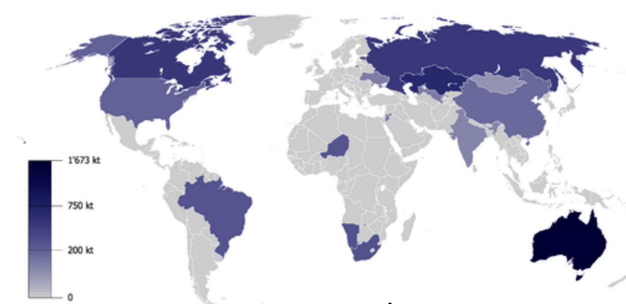


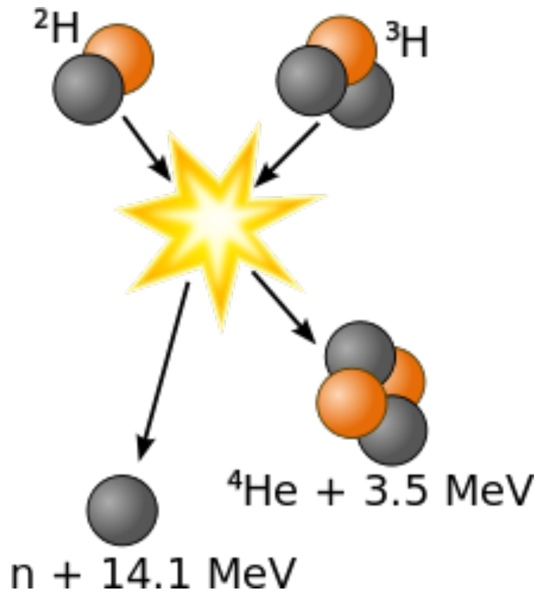
Figure 4: Origins of uranium delivered to EU utilities in 2009 (% share)



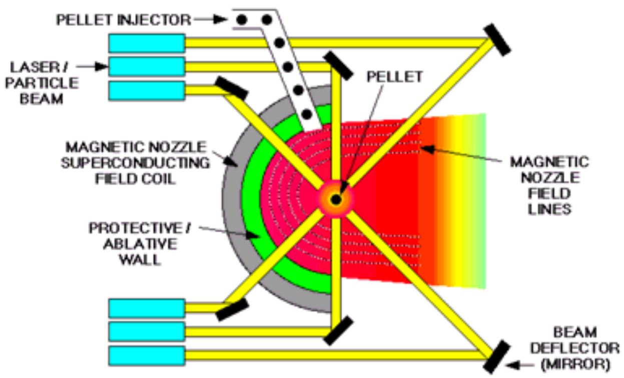


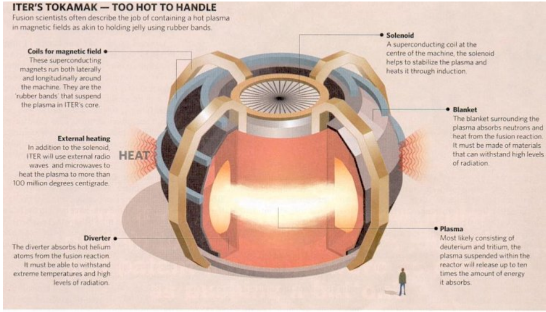
Uranium reserves by country

Nuclear fusion



- Energy is derived from smashing hydrogen or other light atoms together to make slightly larger atoms
- Same process as our Sun's core
- Is not yet commercially viable
- Requires tremendous energy and focus input on the fusing atoms to overcome electrostatic repulsion and force them together
- In order to enable fusion, the material must be heated to such a high level that it becomes plasma (100,000,000 C+)
- Energy yield is potentially enormous (1 kg of deuterium-tritium fusion could release ~340 TJ of energy)
- Various confinement methods; inertial/laser, magnetic/toroidal
- Requires a great deal of R&D and energy to get to energetic break even and even more effort to get to cost break even
- So far, laboratory fusion experiments have produced very short reactions (measured in nanoseconds)
- Recently some inertial confinement methods have gotten to about 80% of energetic break even
- Costs many 10s of billions of dollars
- Holds significant potential – could potentially address electricity needs
- If thermal heat can be dealt with effectively, there are a number of advantages (it's been a technology that's "20 years in the future" for 60 years
- higher energy density/energy yield than fission
- No hazardous waste product requiring disposal



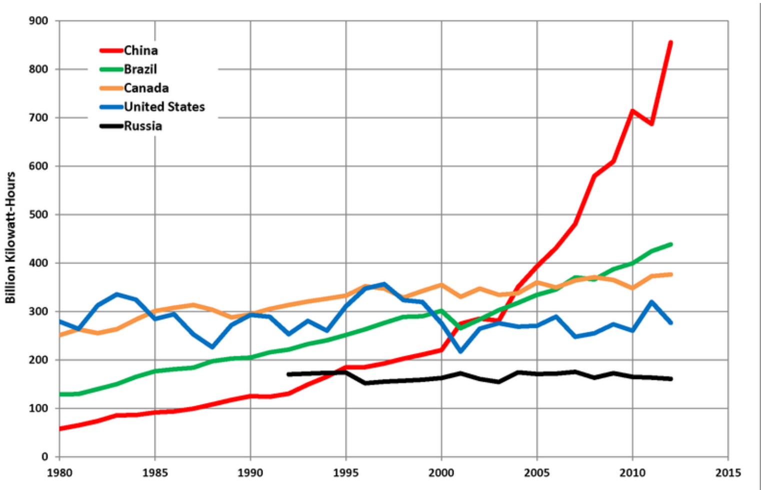


Potential, limitations and challenges of nuclear energy

- There are several ways in which nuclear reactors can fail – but perhaps most dramatic is a core meltdown, where insufficient coolant leads to a melting of parts of the core and the leaching of radioactive material into the coolant fluid, potential breach of the containment and potential environmental release
- Chernobyl, Three Mile Island, Fukushima
- Security concerns (terrorist attack on plant intended to release radiation to environment or nuclear material getting into the wrong hands and being weaponized)
- Nuclear waste disposal and transport make this is a significant challenge to do at large scale (Yucca Mountain had been considered as a potential geologic storage, but that has been scuttled)
- Naturally occurring radioactive isotopes (for fission) are still a finite resource
- Public perception – fears are at times exaggerated (and by point of comparison, there have been tragedies (both human and environmental) in the operation of fossil fuel resources as well)
- The enormous cost of nuclear fusion

Hydroelectric energy

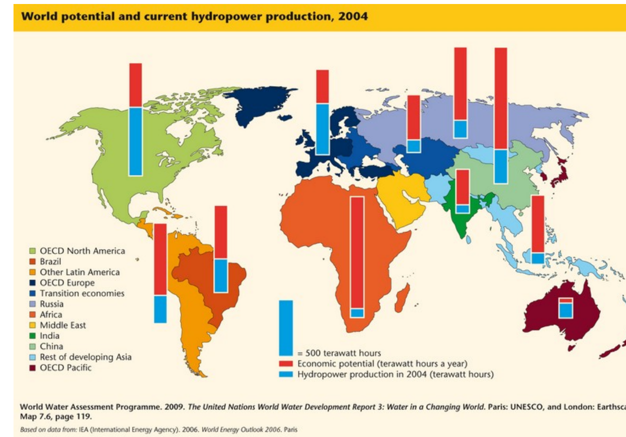
- Use power of falling water to turn turbines and produce electricity
- Current technology can be quite efficient at converting mechanical energy to electricity (much more so than solar or wind)
- Already explored in many regions around the world – especially those with dramatic topography and major rivers
- Total hydroelectric production comparable to nuclear fission (on the order of a few petawatt-hours/year)
- Hydroelectric dams have some regulation regarding release of sediments and water for ecosystem health
- China produces the most (after the installation of the Three Gorges Dam), Brazil is now in second, then Canada, the US and Russia
- Hydropower exists on a wide range of scales (3 Gorges Dam has installed capacity of 22GW) and Itaipu Dam has largest operation, but some hydropower dams are small or mid-size



Hydroelectric energy – challenges and limitations

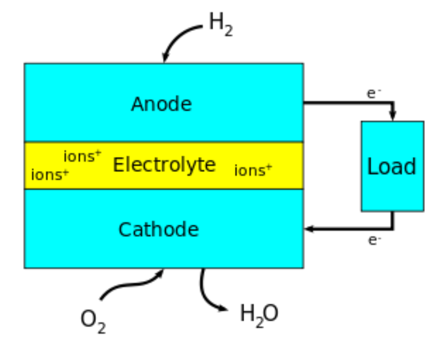
Nominally, part of the Colorado River "delta"

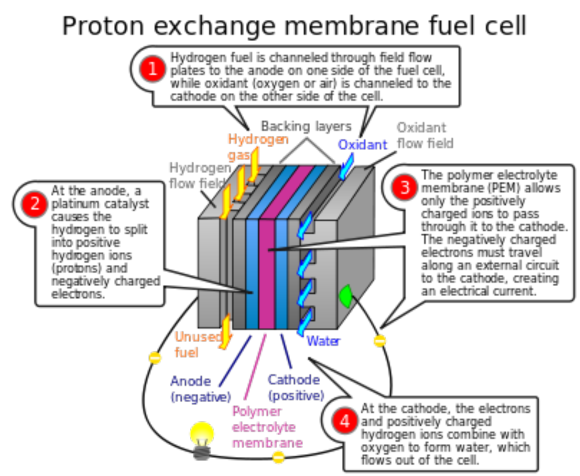
- Many of the major rivers of the world have already been dammed in multiple places and are close to or at capacity
- This being said, there is still considerable hydroelectric potential left (global hydropower could maybe triple or quadruple, but could not fulfill all our current energy demand)
- Dam breach/failure; optimizing a reservoir for hydropower and/or drought avoidance enhances risk of flooding or structural failure
- Economic, ecological and sediment consequences; sediment accumulates in the reservoir, downstream ecology and communities need enough water flow
- Power generation is climate/weather dependent
- Evaporation rates from reservoirs can be rather rapid
- In low latitude environments, reservoirs can release large quantities of methane
- Unintended consequences – Quebec hydropower altering the salinity of Hudson Bay; causing problematic ecological consequences
- Hydroelectric construction can also be very politically/socially costly – over 1 million people were displaced by Three Gorges Dam



Fuel cell technology

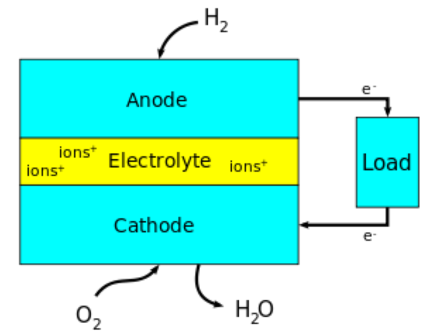
- Premise is to harness energy from the combination of hydrogen or hydrocarbons and oxygen
- All fuel cells consist of an anode, a cathode and an electrolyte
- Hydrogen is attracted to anode and made to dissociate into proton and electron, oxygen is drawn to cathode and electrolyte facilitates the formation of water
- Fuel cells require a constant source of fuel
- Still a largely experimental energy source
- Total fuel cell production as of last month is over 2 GW (fuelcellenergy.com); will likely continue to be a rather small contributor for some time
- Some exhibition fuel cell cars have been built
- Could be a partial solution to transportation sector, as well as more stationary energy needs



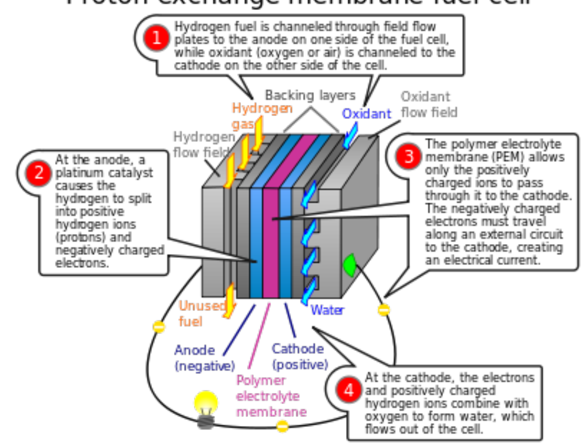


Challenges and limitations to fuel cell technology

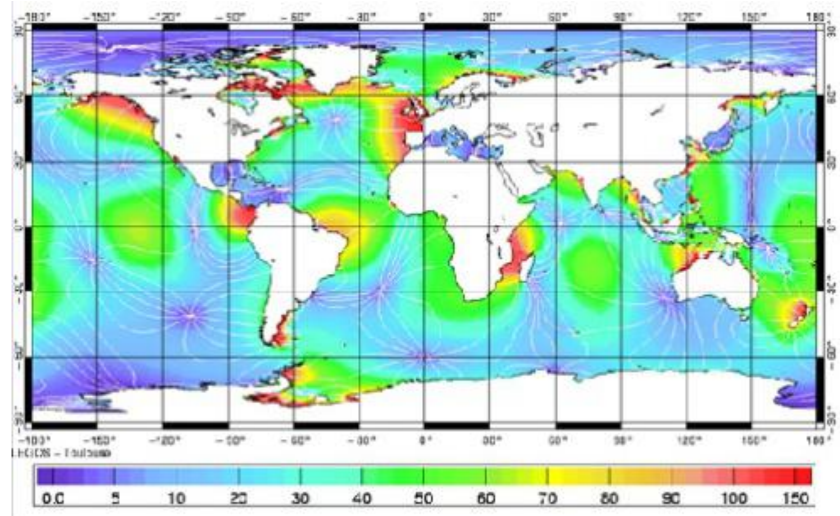
- hydrogen gas by itself is not common in nature (hydrogen is usually bound to something else)
- In order to supply hydrogen energy source, often other energy sources must be used to split a compound (often water) and harness the hydrogen; when done with fossil fuels, the GHG impact can be problematic
- Hydrogen gas is somewhat volatile and must be dealt with carefully
- Water vapor is still a greenhouse gas!; so while a fuel cell may have zero carbon emission, it's almost impossible for it to have zero GHG emissions
- This being said, depending on efficiency (which tends to be fairly high), the GWP per kwh may be relatively low
- The major challenge is finding a process to produce a large quantity of hydrogen with a low energy footprint



Proton exchange membrane fuel cell

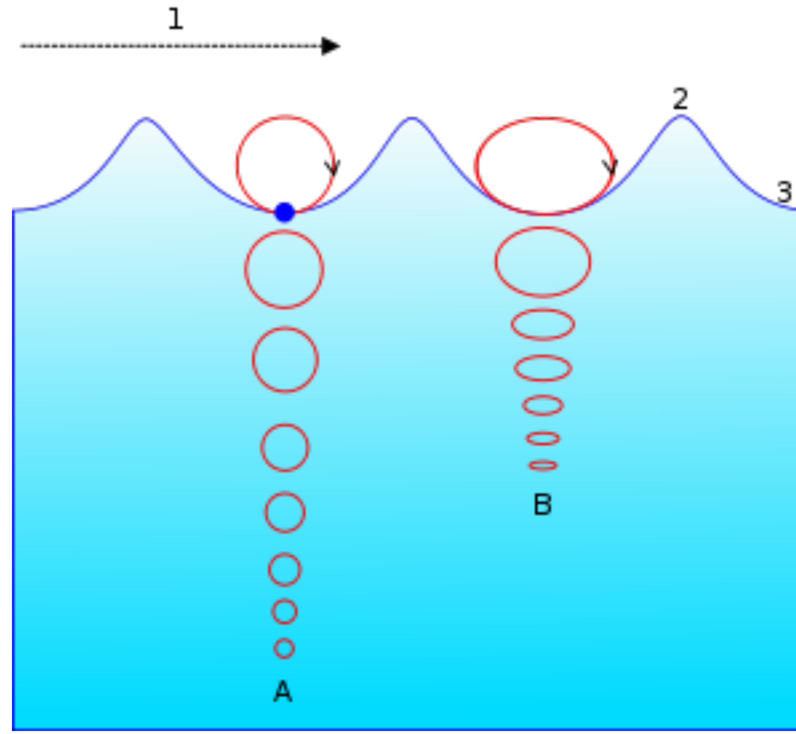


Tidal Power



- Can be thought of as a specialized form of hydroelectric energy
- Kinetic (tidal stream) or potential (tidal barrage) energy of moving water during tidal cycle is used to produce electricity
- Is only viable in areas where tidal amplitude is rather large
- Is somewhat more reliable than wind, solar or wave energy
- Generally projects are relatively small scale – projects in the Bay of Fundy, the English Channel, the East River
- Challenges: ecological and corrosion
- Some 200 MW plants in operation (in France and South Korea) and some much larger plants proposed, but this still represents a very small portion of our total energy demand
- Potentially up to 150 TWh of electricity generating potential, but arguably that's rather optimistic and might have significant knock on consequences
- Realistically, tidal power is likely to remain a small contributor to energy mix

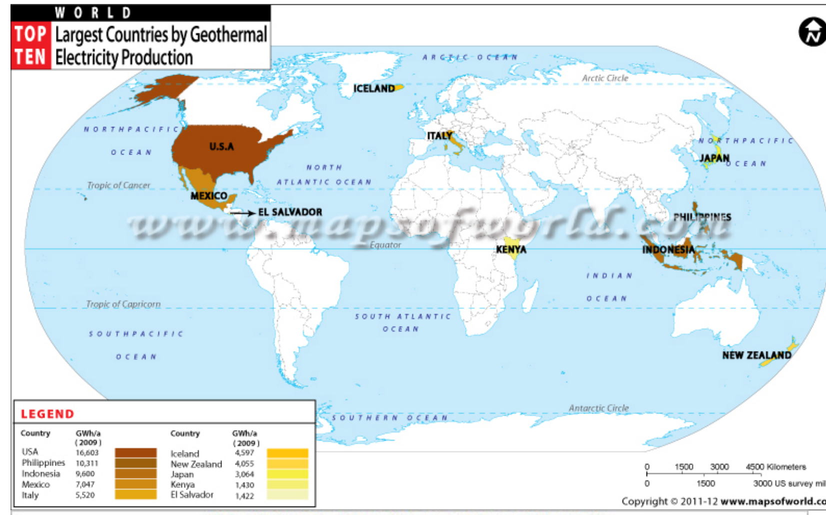
Wave energy



- Floating, flexible devices called wave energy converters used to harness the kinetic energy of the waves and tides and converts that energy to electricity; energy is sent back to shore via submarine cables
- Wave power is proportional to the square of the height of the waves
- Large project began near the coast of Portugal in 2008
- Globally, there is tremendous energy in the waves of the ocean, but getting enough to shore to support our energy demand is very challenging
- Low energy density
- Inconsistent production
- This is likely to only be a marginal contributor to the world energy portfolio

"conventional" geothermal

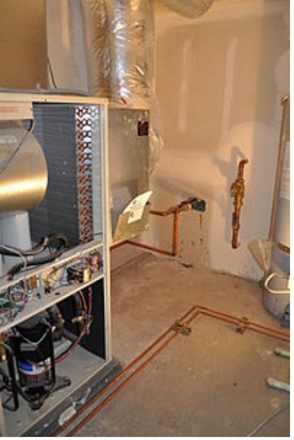
- Extract thermal energy from naturally occurring geothermal environments where magma near the surface heats the surface water
- Thermal energy from the radioactive decay of minerals and from upper mantle convection bringing warm material to the surface
- Around 11 GW geothermal energy per year
- Primarily used for electricity and heating
- Theoretically, geothermal energy resources could supply all of our demand for electricity, but proven geothermal reserves are far less adequate
- Geothermal energy typically restricted to areas near tectonic boundaries with naturally occurring geothermal features
- The US, Philippines and Indonesia are the global frontrunners in geothermal energy production
- The largest proportional production and consumption (about 65%) is in Iceland, where geothermal energy accounts for
- Flash steam plants (dramatically lower water pressure to produce steam) and binary cycle geothermal plants (only moderately warm water can be used to heat a secondary fluid with a lower boiling temperature) to boil and produce a type of steam to drive a turbine and produce electricity
- Not expected to grow significantly (although very modest growth in some limited areas is more possible) as a source of renewable energy



Worldwide Geothermal per Capita

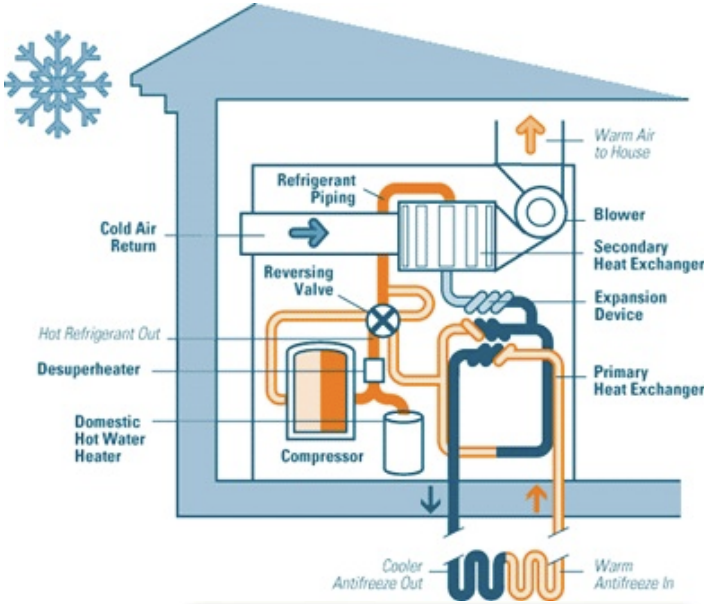
	2010 Capacity MW	Population Millions	kW/capita	Rank	Relative to USA
Iceland	575	0.3	1.806	1	181
New Zealand	628	4	0.143	2	14.3
Costa Rica	166	4	0.039	3	3.9
El Salvador	204	6	0.033	4	3.3
Philippines	1,904	92	0.021	5	2.1
Nicaragua	88	6	0.015	6	1.5
Italy	843	61	0.014	7	1.4
USA	3,086	309	0.010	8	1.0
Mexico	958	112	0.009	9	0.9
Indonesia	1,197	238	0.005	10	0.5
Japan	536	128	0.004	11	0.4
Kenya	167	43	0.004	12	0.4
Turkey	94	75	0.001	13	0.1

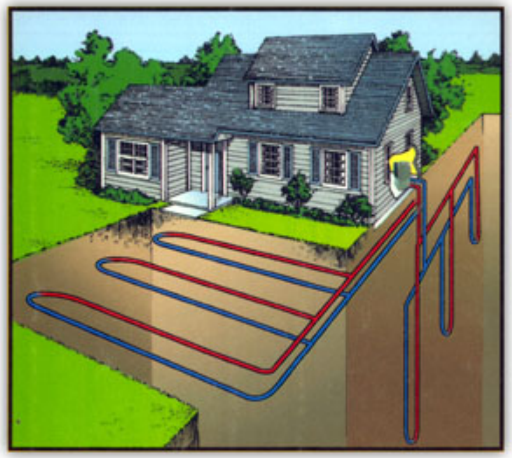
Note: Actual population used to calculate kW/capita.



Groundsource geothermal

- While geothermal energy is most concentrated near tectonic plate boundaries, a more limited geothermal energy can be used anywhere
- Pretty much anywhere in the world, the temperature about 6 meters below the surface is close to constant around the region’s average temperature (and seasonal temperature changes are minimized)
- Can be used for HVAC anywhere in the world
- That temperature modified air can be piped into homes in existence now all year round, thereby dramatically reducing heating costs and energy expenditure, and effectively eliminating cooling costs and energy expenditure
- Different techniques – direct exchange, ground source heat exchanger, different well designs and depths
- Both conventional and groundsource geothermal use energy to run pumps/exchanger
- About 100,000 installations in the US



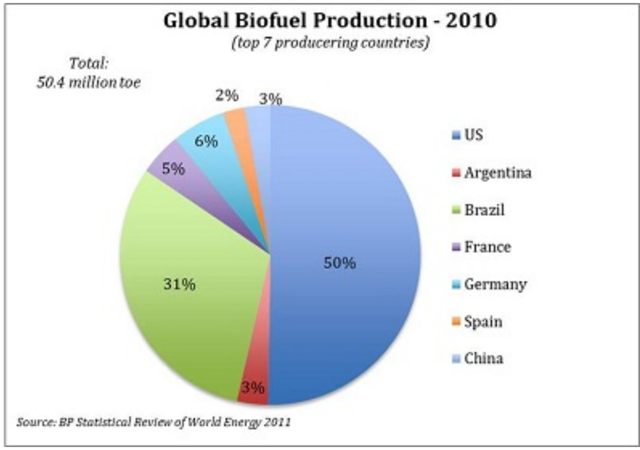


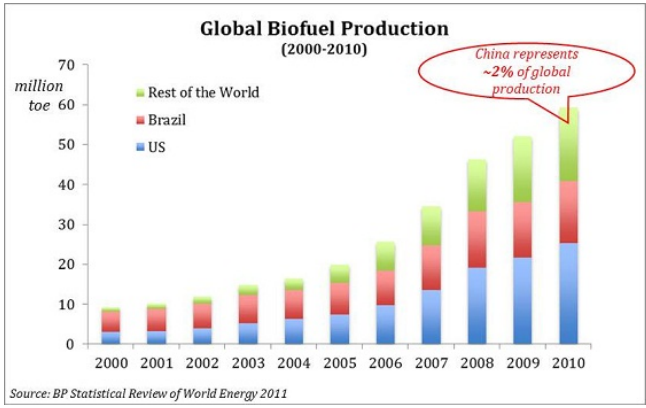
Geothermal potential, challenges and limitations

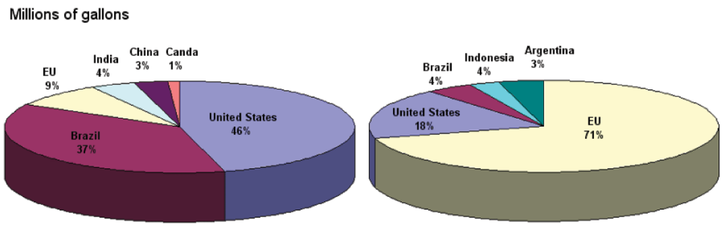
- Both types of geothermal energy require some form of energy input in order to extract/exchange heat from source to use
- Ground source is OK for heating and cooling, but not as efficient for electricity production
- Conventional geothermal is good for HVAC and electricity production, but can only be employed in very geographically limited areas
- Total potential is limited and can only deliver a small fraction of our total global energy demand
- For ground-source HVAC housing installation, large up-front cost, but energy savings over time (as compared to standard fossil fuel heating/cooling)
- Ground-source installation may be complicated in crowded areas with a great deal of subsurface infrastructure

Crop biofuels

- The growth of crops that can be cultivated for their oils which can be substituted for gasoline
- Rapidly growing fuel source – now about 60 million tons of oil equivalent (now something like 600 ish TWh/year)
- In principle biofuels can be made from a wide assortment of plants
- In the US, starch based corn ethanol is most commonly used
- In Brazil, sugarcane based ethanol is the dominant form of biofuel
- Germany is the leader in biodiesel production
- But waste cooking oil and vegetable oil can also be used as a fuel substitute for gasoline
- Palm oil, jatropha, rapeseed oil also used as sources
- Broadly speaking, the primary “refined” biofuel products are ethanol and biodiesel, but ethanol is more dominant
- In principle, cellulosic derivative material could have the best energy savings when considering the full life cycle of the food production
- the conversion of cellulosic material to ethanol is not yet done at a large scale and there are still some technical challenges







World Ethanol Production
14.1 million gallons

World Biodiesel Production
2.5 million gallons

Source: FAPRI 2008 U.S. and World Agricultural Outlook.

Algal biofuels

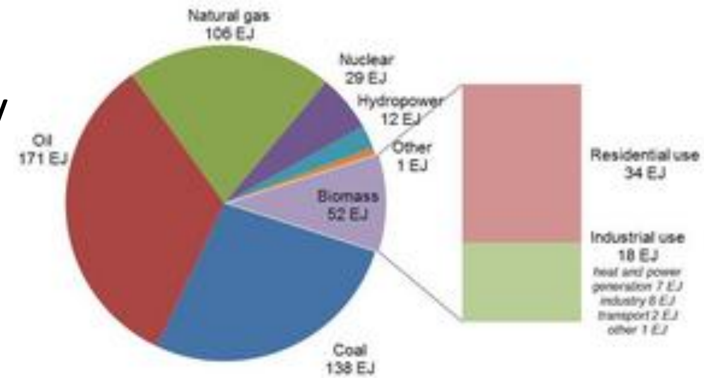
- The oily/lipid part of certain species of algae can be harvested to produce an assortment of liquid biofuels (including ethanol, biodiesel, biobutanol, biogasoline, jet fuel, natural gas/ methane (via pyrolysis and anaerobic digestion), vegetable oil fuels)
- Refinement process somewhat similar to fossil fuels needed to convert raw algae into liquid fuel
- Advantages include smaller impact on water resources than “conventional” biofuels, higher energy yields per unit area (on the order of 10-100 fold better yield per unit area), can use ocean water or wastewater
- Don’t compete for land area with agriculture
- Major downside – cost; not yet cost competitive for large scale production and substitution
- There are now a number of cars that can run on various types of biofuels, and a good number of Brazilian public transit vehicles that can run on sugarcane ethanol
- Since 2011, there have been some long haul, commercial flights run on biofuels or biofuel/fossil fuel mixes (including several transAtlantic flights) – some of these flights have been based on jatropha and other non-algal biofuels, but some have been algae driven

Biofuel challenges and limitations

- Crop biofuels compete for cropland with food crops – potentially leading to food and energy price shocks (2008)
- Corn ethanol has almost no GHG benefit because of the energy/carbon intensity of corn cultivation
- Brazilian sugarcane ethanol production is much more efficient (but can't be done in the midlatitudes)
- Cellulosic ethanol is not yet operational on a wide scale, but has a lot of theoretical potential
- Algal biofuel production is also not yet operational on a large scale, but could potentially substitute for a large portion of the energy demand in the transportation sector, and perhaps more broadly
- Subject to political whims and funding challenges

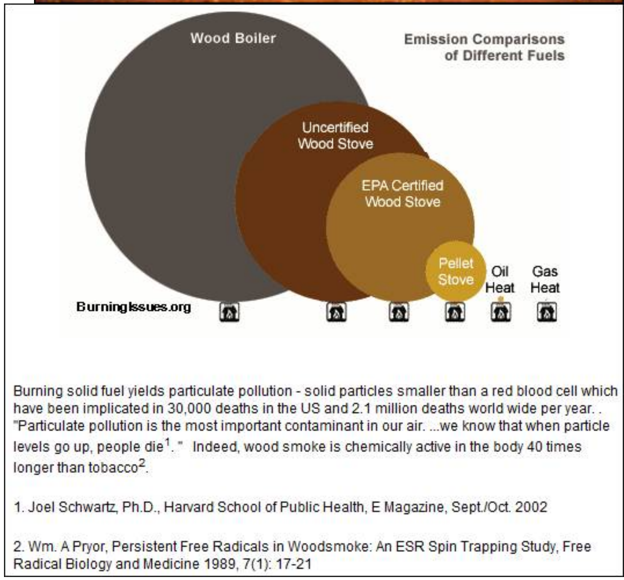
More traditional biomass fuels

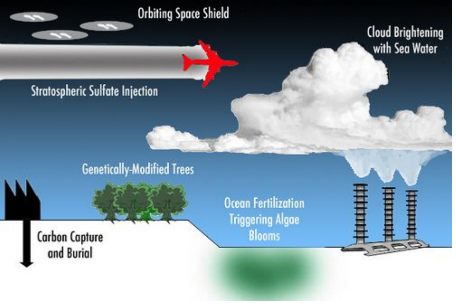
- Advanced/refined biofuels are part of a larger narrative on biomass fuels, which account for around 10% of the world's energy production/ consumption
- "biomass burning" includes all types of biomass burn to produce energy or heat
- Intentional, controlled wood fires, leaf fires, dung fires, to cook or heat
- Intentional fires to clear land and promote soil fertility or reduce extreme fire risk
- Unintentional fires
- Biomass burning does produce a fair amount of both CO_2 and methane, but accounts for a large share of energy consumption, especially in the developing world
- If biomass burning is done in an incinerator and the material is burned completely, then the comparative greenhouse gas emissions will be reduced



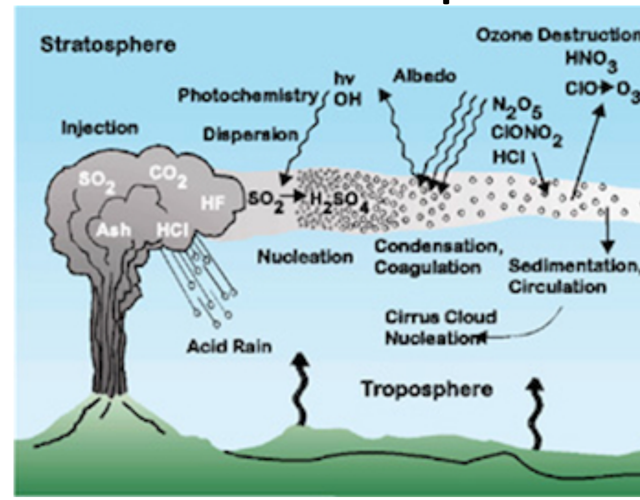
Potential, challenges and limitations of biomass

- If living quarters are poorly ventilated, biomass burning indoors can have problematic health impacts; releases a lot of toxins and particulates which can cause or exacerbate respiratory and/or cardiovascular/ cardiopulmonary issues
- Similar issues can occur at a wider scale when biomass burning is industrialized in a wood chip or dung burning plant
- GHG benefit may be somewhat limited depending on the efficiency of the burn
- Deforestation is the result of unsustainable biomass burning (which has the secondary effect of removing the carbon sink that trees supply)
- Many people in the developing world don't have many alternatives
- Although solid biofuel burning could be expanded globally, the potential consequences for health and the environment are likely to be rather problematic





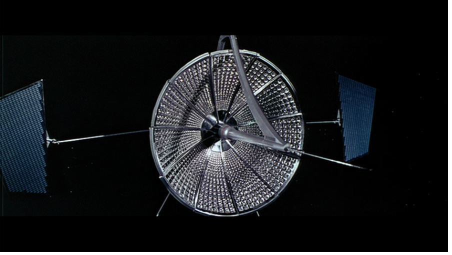
Geoengineering – sulfates in the stratosphere



- Put huge quantities of sulfate (SO_2) into the stratosphere to serve as aerosols with negative radiative forcing (increasing planetary albedo)
- Likely to be very costly with unexpected and potentially quite problematic consequences
- Chemically, the possibility of acid rain (although some research suggests that the impact of the acid deposition may not be that pronounced – still debatable)
- Also sulfates enable the destruction of ozone by chlorofluorocarbons
- But a host of other climate and ecological implications as well
- Alan Robock does a lot of work in this area
- Do we have the moral authority to do this?

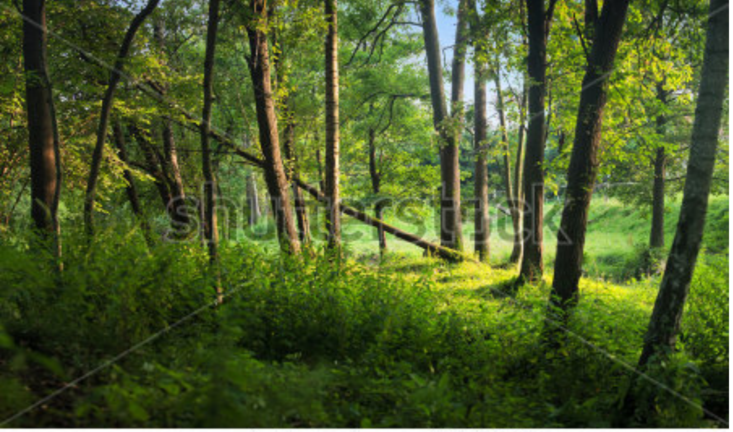
Benefits	Risks
1. Cool Planet	1. Drought in Africa and Asia
2. Reduce or reverse sea ice melting	2. Continued ocean acidification from CO_2
3. Reduce or reverse land ice sheet melting	3. Ozone depletion
4. Reduce or reverse sea level rise	4. No more blue skies
5. Increase plant productivity	5. Less solar power
6. Increase terrestrial CO2 sink	6. Environmental impact of implementation
	7. Rapid warming if stopped
	8. Cannot stop effects quickly
	9. Human error
	10. Unexpected consequences
	11. Commercial control
	12. Military use of technology
	13. Conflicts with current treaties
	14. Whose hand on the thermostat?
	15. Ruin terrestrial optical astronomy
	16. Moral hazard—the prospect of it working would reduce drive for mitigation
	17. Moral authority—do we have the right to do this?

Some potential implications



Geoengineering – space mirrors

- Put large mirrors in space to effectively increase planetary albedo
- Likely to be incredibly costly (at a minimum, many hundreds of billions of dollars – quite possibly many trillion)
- Highly uncertain outcome
- Unintended consequences – in order for an array of mirrors to occupy an area large enough to reduce solar energy significantly, what impact does this have on local energy, sunlight, climate, biology, etc.?



Geo "engineering" – forestation

- Perhaps one of the most sensible/practical approaches to the carbon problem is to simply plant more trees/reforest to absorb more CO_2 via photosynthesis
- Trees take time to grow
- Land couldn't be used for other purposes
- Photosynthesis is a carbon sink, but dark forests have a low albedo

Replacement

- Some social science research shows that energy “replacement” is generally not achieved
- Wishful thinking that we can directly replace fossil fuel usage with alternatives
- But history shows a tendency towards Jevon’s paradox; as renewables increase, reduction in fossil fuels is relatively minimal – we just use more energy, period (from fossil fuels as well as from renewable resources)
- Similar to traffic problem (more roads tend to lead to more development, more cars and at least as much traffic in the long run)
- We need to find ways to reduce our energy demand
- We need to stop incentivizing fossil fuel use and start subsidizing alternatives more seriously
- We need to find a way to do CCS – when you consider the whole life cycle of energy production, almost none of the “alternatives” is completely green