EENS 1110	Physical Geology
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Energy Resources

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Energy

Energy is the capacity to do work and is required for life processes. An energy resource is something that can produce heat, power life, move objects, or produce electricity. Matter that stores energy is called a fuel. Human energy consumption has grown steadily .throughout human history. Early humans had modest energy requirements, mostly food and fuel for fires to cook and keep warm. In today's society, humans consume as much as 110 times as much energy per person as early humans. Most of the energy we use today come from fossil fuels (stored solar energy). But fossils fuels have a disadvantage in that they are non-renewable on a human time scale, and cause other potentially harmful effects on the environment. In any event, the exploitation of all energy sources (with the possible exception of direct solar energy used for heating), ultimately rely on materials on planet Earth.

Some of the questions we want to answer in this discussion are:

1. What sources of Energy are available?
2. How do the energy sources rely on resources available on Earth?
3. Which energy sources are renewable on a human time scale?
4. Since fossil fuels (oil, natural gas, coal) are our main source of energy, how are they formed, how do we find them and exploit them?
5. What is the future for our energy needs?

Energy Sources

There are 5 fundamental sources of energy:

1. Nuclear fusion in the Sun (solar energy)
2. Gravity generated by the Earth & Moon.
3. Nuclear fission reactions.
4. Energy in the interior of the Earth.
5. Energy stored in chemical bonds.

Solar Energy

Solar Energy arrives from the Sun by electromagnetic radiation. It can be used directly for heat and converted to electricity for other uses. It is a nearly unlimited source, it is renewable, and largely, non-polluting.

Gravity Generated by the Earth & Moon.

Gravitational pull of the Moon on the Earth causes tides. Tidal flow can be harnessed to drive turbines. This is also a nearly unlimited source of energy and is largely non-polluting.

Combining both both solar energy and gravity provides other useful sources of energy. Solar radiation heats air and evaporates water. Gravity causes cooler air to sink and condense water vapor. Gravity then pulls condensed water back to Earth, where it flows downhill. The circulation of the atmosphere by the process is what we call the wind. Energy can be extracted from the wind using windmills. Water flowing downhill has a result of gravity can also be harnessed for energy to drive turbines and generate electricity. This is called hydroelectric energy. This sources of energy are mostly renewable, but only locally, and are generally non-polluting.

Nuclear Fission Reactions

Radioactive Uranium is concentrated and made into fuel rods that generate large amounts of heat as a result of radioactive decay. This heat is used to turn water into steam. Expansion of the steam can then be used to drive a turbine and generate electricity. Once proposed as a cheap, clean, and safe way to generate energy, Nuclear power has come under some disfavor. Costs of making sure nuclear power plants are clean and safe and the problem of disposing of radioactive wastes, which are unsafe, as well as questions about the safety of the plants under human care, have contributed to this disfavor.

Energy in the Interior of the Earth

Decay of radioactive elements has produced heat throughout Earth history. It is this heat that causes the temperature to increase with depth in the Earth and is responsible for melting of mantle rocks to form magmas. Magmas can carry the heat upward into the crust. Groundwater circulating in the vicinity of igneous intrusions carries the heat back toward the surface. If this hot water can be tapped, it can be used directly to heat homes, or if trapped at great depth under pressure it can be turned into steam which will expand and drive a turbine to generate electricity.

Energy Stored in Chemical Bonds

Energy stored in chemical bonds drives chemical reactions. When the reactions take place this energy is either released or absorbed. If it is absorbed, it is stored in the chemical bond for later use. If it is released, it can produce useful heat energy. electricity, and light.

Hydrogen Fuel Cells are one example: A chemical reaction occurs wherein Hydrogen reacts with Oxygen in an electrolyte bath to produce H_2O, and releases electricity and heat. The reaction is non-polluting, but currently has problems, such as safely storing and distributing compressed hydrogen gas, and producing hydrogen efficiently.

Biomass Energy is an other example. It involves burning (a chemical reaction) of wood, or other organic byproducts. Such organic material is produced by photosynthesis, a chemical process which derives energy from the Sun and stores that energy until the material is burned.

Fossil Fuels - Biomass energy that is buried within the Earth where it is stored until humans extract and burn it to release the energy. Among these sources are petroleum (Oil & natural gas), oil shale, tar sands, and coal. All of which will be one of the primary topics of our discussion here.

Geology and Energy Resources

Exploitation for human use of nearly all of the energy sources listed above, requires geologic knowledge.

While using direct solar energy to heat water and homes does not require geologic knowledge, the making of solar cells does, because the material to make such cells requires knowledge of specific mineral deposits. Chemicals to produce wires (iron, copper, gold), batteries, (Li, Cd, Ni), and electric motors (Fe, Cu, Rare Earth Elements) all must be extracted from the Earth using geologic knowledge.

Hydroelectric energy requires geologic knowledge in order to make sure that dams are built in areas where they will not collapse and harm human populations.

Finding fossil fuels and geothermal energy certainly requires geologic knowledge.

Nuclear energy requires geologists to find deposits of uranium to generate the fuels, geologists to find sites for nuclear power plants that will not fall apart due to such things as earthquakes, landslides, floods, or volcanic eruptions, and requires geologists to help determine safe storage sites for nuclear waste products.

Again, here will concentrate on the fossil fuels.

Fossil Fuels

The origin of fossil fuels, and biomass energy in general, starts with ***photosynthesis***. Photosynthesis is the most important chemical reaction to us as human beings, because without it, we could not exist. Photosynthesis is the reaction that combines water and carbon dioxide from the Earth and its atmosphere with solar energy to form organic molecules that make up plants and oxygen essential for respiration. Because all life forms depend on plants for nourishment, either directly or indirectly, photosynthesis is the basis for life on Earth. The chemical reaction is so important, that everyone should know it (**Hint**).

$$nCO_2 + nH_2O + \text{Energy} \longrightarrow C_nH_{2n}O_n + nO_2$$

Carbon Dioxide, Water (from atmosphere); Solar Energy; Simple Sugar (Plant matter); Oxygen to atmosphere

Note that if the reaction runs in reverse, it produces energy. Thus when oxygen is added to organic material, either through decay by reaction with oxygen in the atmosphere, or by adding oxygen directly by burning, energy is produced, and water and carbon dioxide return to the Earth or its atmosphere.

Petroleum

To produce a fossil fuel, the organic matter must be rapidly buried in the Earth so that it does not oxidize (react with oxygen in the atmosphere). Then a series of slow chemical reactions occur which turn the organic molecules into hydrocarbons- Oil and Natural Gas, together called Petroleum. ***Hydrocarbons*** are complex organic molecules that consist of chains of hydrogen and carbon.

Petroleum (oil and natural gas) consists of many different such hydrocarbons, but the most important of these are a group known as the paraffins. ***Paraffins*** have the general chemical formula:

$$C_nH_{2n+2}$$

As the value of n in the formula increases, the following compounds are produced:

n	Formula	Compound	Use
1	CH_4	methane	Natural Gas
2	C_2H_6	ethane	
3	C_3H_8	propane	
4	C_4H_{10}	butane	
5	C_5H_{12}	pentane	Gasoline
6	C_6H_{14}	hexane	
7	C_7H_{16}	heptane	
8	C_8H_{18}	octane	
9	C_9H_{20}	nonane	
>9	various	various	Lubricating Oils, Plastics

When we extract petroleum containing these compounds and add oxygen to it, either in furnaces, stoves, or carburetors the following reaction takes place:

$$\underset{\text{Hydrocarbon}}{C_nH_{2n+2}} + \underset{\text{Oxygen}}{\frac{3n+1}{2}O_2} \longrightarrow \underset{\text{Carbon Dioxide}}{nCO_2} + \underset{\text{Water}}{(n+1)H_2O} + \text{Energy}$$

Formation of Petroleum

The process of petroleum formation involves several steps:

- Organic matter from organisms must be produced in great abundance.
- This organic matter must be buried rapidly before oxidation takes place.
- Slow chemical reactions transform the organic material into the hydrocarbons found in petroleum.

The organic matter that eventually becomes petroleum is derived from photosynthetic microscopic organisms, like plankton and bacteria, originally deposited along with clays in the oceans. The resulting rocks are usually black shales that form the petroleum source rock. As the black shale is buried to depths of 2 to 4 km it is heated. This heating breaks the organic material down into waxy kerogen. Continued heating breaks down the kerogen with different compounds forming in different temperatures ranges -

Oil and gas – 90° to 160°C.
Gas only – 160° to 250°C.
Graphite – >250°C.

If temperatures get higher than the petroleum forming window (90 to 150 °C) then only graphite forms, which is not a useful hydrocarbon. Thus oil is not formed during metamorphism and older rocks that have been heated will also lose their oil forming potential.

Most oil and gas is not found in the source rock. Although black shales (oil shales) are found, it is difficult to extract the oil from such rock. Nature, however, does separate the oil and gas. As a result of compaction of the sediments containing the petroleum, the oil and natural gas are forced out and migrate into a reservoir rock.

Petroleum Reservoirs

Reservoir rock contains pore space between the mineral grains (this is called ***porosity***). It is within this pore space that fluids are stored. Sands and sandstones are the best reservoir rocks because of the pore space left around the rounded sand grains. Highly fractured rock of also a good reservoir rock, because the fractures provide lots of open space. Limestone, if it has often been partially dissolved, also has high porosity.

Another essential property of reservoir rock is that it must have good permeability. ***Permeability*** is the degree of interconnections between the pores. Low permeability means that the fluids cannot easily get into or out of the pore spaces. Highly cemented sandstones, unweatherd limestones, and unfractured rock have low permeability.

Since oil and natural gas have a density lower than that of water, the petroleum migrates upward. It would continue upward and seep out at the surface where it would oxidize, if it were not for some kind of trap that keeps it in the Earth until it is extracted.

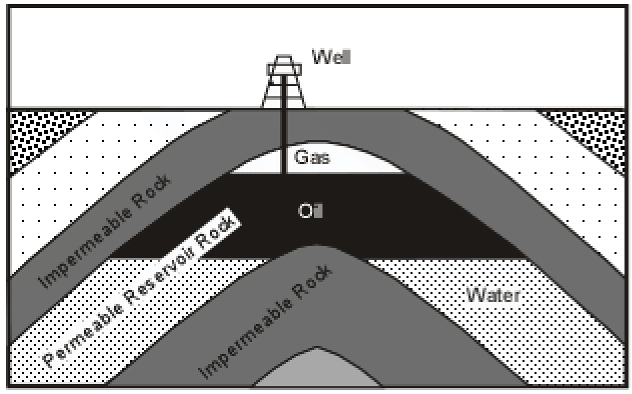
Oil Traps

An oil or gas reserve requires trapping in the reservoir. A trap is a geological configuration that holds oil and gas. It must be overlain by impermeable rock called a seal or caprock, which prevents the petroleum from migrating to the surface. Exploration for petroleum reservoirs requires geologists to find trap and seal configurations where petroleum may be found.

Oil traps can be divided into those that form as a result of geologic structures like folds and faults, called ***structural traps***, and those that form as a result of stratigraphic relationships between rock units, called ***stratigraphic traps***. If petroleum has migrated into a reservoir formed by one of these traps, note that the petroleum, like groundwater, will occur in the pore spaces of the rock. Natural gas will occur above the oil, which in turn will overly water in the pore spaces of the reservoir. This occurs because the density of natural gas is lower than that of oil, which is lower than that of water.

Structural Traps

- Anticlines - If a permeable reservoir rocks like a sandstone or limestone is sandwiched between impermeable rock layers like shales or mudstones, and the rocks are folded into an anticline, petroleum can migrate upward in the permeable reservoir rocks, and will occur in the hinge region of the anticline.

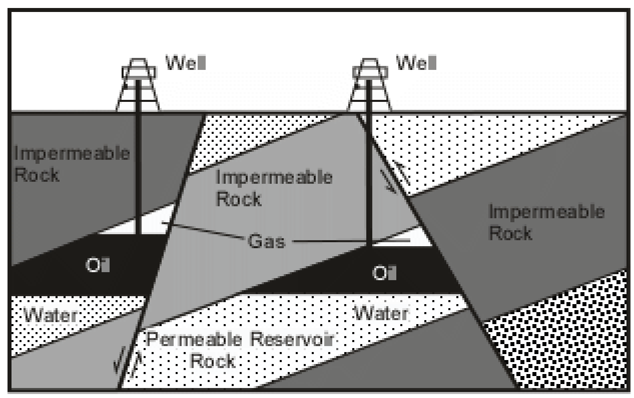


  Since anticlines in the subsurface can often be found by observing the orientation of rocks on the surface, anticlinal traps were among the first to be exploited by petroleum geologists.

  Note that synclines will not form an oil trap (Why?).

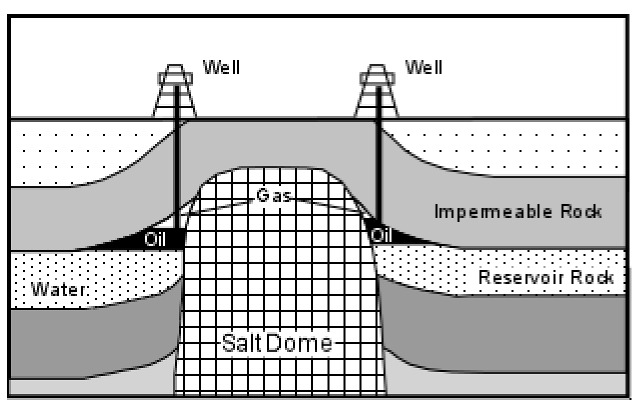
- Fault Traps

  If faulting can juxtapose permeable and impermeable rocks so that the permeable rocks always have impermeable rocks above them, then an oil trap can form. Note that both normal faults and reverse faults can form this type of oil trap.



  Since faults are often exposed at the Earth's surface, the locations of such traps can often be found from surface exploration.

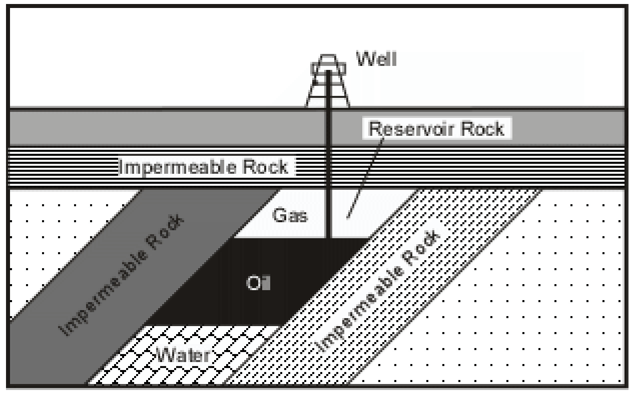
- Salt Domes - During the Jurassic Period, the Gulf of Mexico was a restricted basin. This resulted in high evaporation rates & deposition of a thick layer of salt on the bottom of the basin. The salt was eventually covered with clastic sediments. But salt has a lower density than most sediments and is more ductile than most sedimentary rocks.



  Because of its low density, the salt moved upward through the sedimentary rocks as salt domes. The intrusion of the salt deforms the sedimentary strata along its margins, folding it upward to create oil traps. Because some salt domes get close to the surface, surface sediments overlying the salt dome are often domed upward, making the locations of the subsurface salt and possible oil traps easy to locate.

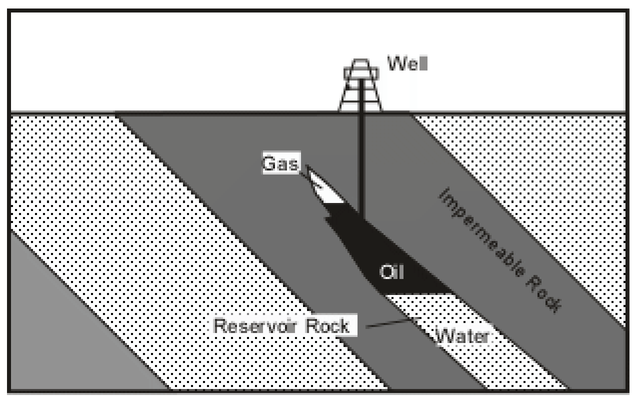
Stratigraphic Traps

- Unconformities - An angular unconformity might form a suitable oil trap if the layers above the unconformity are impermeable rocks and permeable rocks layer are sandwiched between impermeable layers in the inclined strata below the unconformity.



This type of trap is more difficult to locate because the unconformity may not be exposed at the Earth's surface. Locating possible traps like this usually requires subsurface exploration techniques, like drilling exploratory wells or using seismic waves to see what the structure looks like.

- Lens Traps
Layers of sand often form lens like bodies that pinch out. If the rocks surrounding these lenses of sand are impermeable and deformation has produced inclined strata, oil and natural gas can migrate into the sand bodies and will be trapped by the impermeable rocks.



This kind of trap is also difficult to locate from the surface, and requires subsurface exploration techniques.

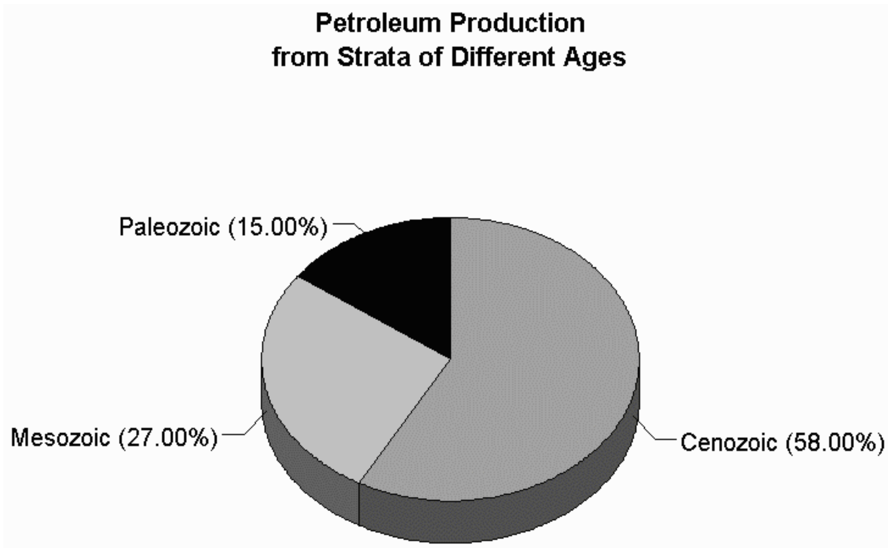
Petroleum Distribution

As we have seen, in order to form a petroleum reserve, the development of 4 features is necessary :

1. Formation of a source rock.
2. Formation of a migration pathway so that the petroleum can move upwards
3. Filling a suitable reservoir rock with petroleum.
4. Development of an oil trap to prevent the oil from migrating out of the reservoir.

Because these features must develop in the specified order, development of an oil reserve is geologically rare. As a result, petroleum reserves reserves are geographically limited. The largest known reserves are currently in the Persian Gulf (see figure 14.15 in your text)..

Although the distribution of petroleum reserves is widespread, the ages of the petroleum and the reservoirs is somewhat limited. Since older rocks have had more time to erode or metamorphose, most reservoirs of petroleum occur in younger rocks. Most petroleum is produced from rocks of Cenozoic age, with less produced from rocks of Mesozoic and Paleozoic age**.**



Petroleum Exploration and Production

The first petroleum reservoirs exploited by humans were found as a result of seeps on the surface. The 1st oil well was drilled in Titusville, PA., in 1859. Oil wells eased petroleum recovery and initiated an oil boom, and within years, 1,000s of oil wells had been drilled. It was soon realized that a systematic approach to oil exploration was essential to prevent drilling dry holes.

First step is to make geologic maps of sedimentary rocks and structures. Based on surface mapping and drill holes, geologic cross sections are made and such cross-sections often reveal structures and potential reservoir rocks that could then be drilled.

Geophysical techniques were soon developed in order to see beneath the surface and find reservoirs that could not be detected from the surface. The most useful technique is seismic reflection profiling which can be done on both land in at sea. This technique involves generating seismic waves from either small explosions on land or air guns in the water. The seismic waves reflect back to surface from different rock interfaces below the surface and these reflected waves are then detected by receivers called geophones. By moving the source and the receivers along the surface, and tracing the pulse of each seismic wave, a cross section can be constructed that reveals potential reservoir rocks. These sections are correlated with drill holes where the geology is known, to produce a detailed picture of the subsurface. (see figure 14.12 in your text).

Once potential reservoir rocks are located, drilling from the surface attempts to tap into the reservoirs. A diamond rotary bit pulverizes rock to drill the hole. High-density drilling mud is then pumped in to cool the drill bit and lift the rock cuttings. The heavy mud also helps to prevent blowouts.As the bit advances, the open borehole deepens. Drill pipe is added by a drill derrick, a tower that stands above the surface. Some derricks are mounted on offshore platforms and many of these platforms can drill many holes in many directions.

When a petroleum reservoir is encountered, drilling ceases and steel casing is inserted to line the hole and prevent collapse. After the casing has been emplaced, the well is pumped to recover the oil and gas.

Primary recovery uses the reservoir pressure and pumping to extract the oil, but his is usually inefficient; and enables recovery of only about 30% of the oil. Secondary recovery methods are then used to extract as much of the rest as possible. Secondary recover involves pumping in fluids, like steam or CO_2 to help push the oil out. Sometimes hydrofracturing using high pressure or explosives, can be used to artificially increase permeability and allow for more efficient extraction.

Oil Shale and Tar Sands

- *Oil shale* is shale that contains abundant organic matter that has not decomposed completely to produce petroleum. Oil can be extracted from oil shales, but they must be heated to high enough temperatures to drive the oil out. Since this process requires a lot of energy, exploitation of oil shales is not currently cost-effective, but may become so as other sources of petroleum become depleted. Known deposits of oil shale are extensive.

- ***Tar Sands*** are sandstones that have thick accumulations of viscous oil in their pore spaces. Extraction of this oil also requires heating the rock and is therefore energy intensive and not currently cost effective.

Coal

Coal is a sedimentary/metamorphic rock produced in swamps where there is a large-scale accumulation of organic matter from plants. As the plants die they accumulate to first become peat. Compaction of the peat due to burial drives off volatile components like water and methane, eventually producing a black- colored organic- rich coal called ***lignite***. Further compaction and heating results in a more carbon- rich coal called ***bituminous coal***. If the rock becomes metamorphosed, a high grade coal called ***anthracite*** is produced. However, if temperatures and pressures become extremely high, all of the carbon is converted to graphite. Graphite will burn only at high temperatures and is therefore not useful as an energy source. Anthracite coal produces the most energy when burned, with less energy produced by bituminous coal and lignite.

Coal is found in beds called ***seams*,** usually ranging in thickness from 0.5 to 3m, although some seams reach 30 m. The major coal producing period in geologic history was during the Carboniferous and Permian Periods, the continents were apparently located near the equator and covered by shallow seas. This type of environment favored the growth of vegetation and rapid burial to produce coal.

Known reserves of coal far exceed those of other fossil fuels, and may be our best bet for an energy source of the future. Still, burning of the lower grades of coal, like lignite and bituminous coal produces large amounts of waste products, like SO_2 and soot, that pollute the atmosphere. This problem needs to be overcome before we can further exploit this source of energy.

Mining of coal is still a problem from an aesthetic point of view. Seams near the surface are often strip mined and backfilled, leaving temporary scars on the landscape. Deep coal seams have to be mined through tunnels, which often collapse, catch fire, or explode as a result of ignition of coal dust or methane released from the coal. Coal miners often suffer from black-lung disease from years of breathing coal dust.

Energy for the Future

Currently, society relies mostly on fossil fuels for energy (39% natural gas, 24% natural gas, 23% Coal, 8 % nuclear, and 6% other). Since fossil fuels are non-renewable sources of energy, at least in human lifetimes), we need to ask how much longer society can rely on this source. Further, what are the options for the future?

Non-Renewable Resources

First we look at the reserves of various non-renewable energy resources. Look at figure 14.28b in your text. Note that Uranium (for nuclear energy) and Coal appear to be most plentiful, while Tar sands and oil shale are currently not economical. The current known oil reserves will likely run out sometime between 2050 and 2150.

Currently we are consuming oil at a rate 3 times that of the discovery of new resources. Even in terms of 4,000 years of human history, the oil age will be very short lasting only 150 to 200 years.

Coal reserves could last for about 300 years if we can cope with the associated pollution. Natural Gas is cleaner and can probably last for another 200 years. Nuclear seems like a good bet in terms of available resources, but can it be made cheap, clean, and safe? Will the recent problems with nuclear reactors during the March 11, 2011 earthquake have an effect on the future of nuclear energy?

Tar Sands and Oil Shale will require research to find more efficient way to extract, the resource, but will likely be necessary to replace oil in the short term.

Renewable Resources

Wind power is limited to areas with high consistent winds, and so is limited to very specific areas. The wind mills are not aesthetically pleasing to look at at, make a lot of noise and kill large numbers of birds, all problems that would need to be overcome to expand this resource.

As for hydroelectric resources, they will not likely increase, since most rivers are already dammed and there are few places left where new hydroelectric facilities could be built.

Geothermal energy is limited to areas of known thermal activity (mainly recently active volcanic areas). It is a great local resource, but will never play a major role as an energy resource.

Solar energy is a huge source, but requires other resources (Li, Rare Earth Elements) to exploit. Many of these problems might be overcome with new research and the development of new technologies.

Hydrogen Fuel Cells are another promising resources with plenty of supply, but needs further research and technological development.

Future energy resources have huge environmental, political and economic implications that could change the world order. Still, the geologic aspects of energy resources will play a large role.

Questions on this material that could be asked on an exam.

1. What are the five sources of energy available to us? Give some examples of each source?
2. Even though the fossil fuels are considered an energy source based on energy stored in chemical bonds, in reality, where did that energy originate?
3. Which energy sources are considered renewable on a human time scale?
4. What is photosynthesis and why is it important?
5. Name and describe 5 types of oil traps.
6. Why is petroleum mainly produced out of rocks with relatively young geologic ages?
7. What are the problems associated with the recovery of energy from oil shales, tar sands, and coal?
8. What are the different grades of coal? Which of these grades produce the most and least amount of energy when burned?
9. If we run out of oil, what energy sources hold the most promise for the future of our society?

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