Lab #1
<u>Conventional Energy Sources</u>

Introduction

We encourage you in this lab to work with a partner when looking up information in the reading or online. Please discuss and compare your answers and ask your TA for help if needed!

In class this semester, we are discussing global warming and energy. In today's lab, we will learn about some conventional energy sources currently used or planned for use in the near future, once we either run out of fossil fuels or stop using them voluntarily.

Please read through the following passage. Where a paragraph contains information asked about in the worksheet, an indicator as to the worksheet question number will appear at the end of the paragraph (though the entire text should be read in order to provide definitions and context for your answers).

Fossil Fuels

There is currently some dispute over "Peak Oil," a concept first introduced by geoscientist M. King Hubbert when he was working for the Shell Oil Company in the 1950's The amount of oil in the Earth's crust that we are able to recover is finite. Experts from oil companies and oil-producing countries have attempted to forecast the supply and demand for oil in the coming decades, but there is a great deal of uncertainty in their predictions. (**Q1**)

Starting from the supply side of the problem, we have several types of oil to consider:

Proven Oil Reserves

This includes oil already extracted from the ground as well as oil that is very likely (95% or better) to be extracted from known reservoirs underground.

Likely Oil Reserves

This includes oil that has about a 50% chance of being extracted, and that uncertainty is either due to uncertainty about the size of the reservoir or uncertainty about our ability to extract the oil from the reservoir. Oil fields such as the

Arctic National Wildlife Refuge and many deep sea fields fall into this category.

<u>Speculative Oil Reserves</u>

This includes oil that has less than 10% chance of being extracted in the future, and it is not generally considered as part of the analysis of total supply.

<u>Unconventional Oil Reserves</u>

This includes oil that could be extracted from oil sands or shales or through conversion of natural gas or coal. Oil shales in Canada and the Rocky Mountain West in the United States fall into this category.

Though in theory, the amount of oil in proven and likely oil reserves should be easy to calculate based on data that could be provided by the companies and/or countries extracting oil from each location, in practice, reliable information is difficult to come by.

Oil companies may want to underestimate the amount of their reserves in order to make oil seem scarce and thus drive up the price. On the other hand, some companies may have incentive to overestimate their resources in order to look more attractive to potential buyers or to drive up their stock price on global exchanges. Governments also have an incentive to overstate reserves in order to promote economic stability or (for producer countries) to increase their perceived worth and bargaining power in international negotiations. (**<u>Q2</u>**, **<u>Q3</u>**)

At this time, reliable estimates of proven and likely oil reserves are somewhere between 800 and 1200 billion barrels.

Unconventional sources of oil could potentially produce four to ten times as much oil as currently exists in our conventional oil reserves, but this oil is much more difficult to extract. Usually, wells have to be dug deeper or the oil has to be separated or purified, both of which are energy-intensive processes. At the limit, imagine the amount of energy it takes to extract one barrel of oil, purify it, clean up the waste products and transport it to its desired destination.

What if the amount of energy to do this is equal to a barrel of oil or more? Then it isn't worth the trouble from an economic standpoint and so while the oil may be there in the ground, it doesn't "count" as part of our oil reserves since it is too much trouble to extract. (**Q4**)

On the demand side, the data is much easier to come by since such figures are routinely reported by various economic agencies with no incentive to mislead (and, in fact, great incentive to be accurate). The oil consumption of the United States is currently around 8 billion barrels per year and while high, it is not growing very quickly (about 1% per year on average). The oil consumption of developing nations like China is smaller, currently around 2.6 billion barrels per year, but it is growing quickly (about 7% per year on average).

If we project these numbers forward, it is fairly easy to figure out, based on various assumptions, how long the oil will last. Just divide the total reserves by the average rate of consumption, which is currently 33 billion barrels per year. The answer you get is somewhere in the neighborhood of 20 to 40 years if you just go by proven and likely reserves, depending upon how much demand is projected to grow (or shrink) in that time.

There has been some debate politically over whether or not the United States should extract oil from the Arctic National Wildlife Refuge (ANWR). At this time, our best estimate of recoverable oil from the ANWR is around 10 billion barrels, which amounts to about 10% of the total estimated amount of undiscovered oil reserves in the United States. The actual amount of oil present there could be as much as 50% higher or lower depending upon various assumptions about the geology of the formation.

If we assume the optimistic case, and if we begin the extraction process now, the field would be open for production in about 10 years, peaking around the year 2030, and at that time, its production would amount to around 2% of our annual consumption of oil in the United States. These numbers tell us that whether we drill or refuse to drill in the ANWR, the impact on "peak oil" will be minimal. (**Q5**)

The term "peak oil" comes from the fact that of the 800-1200 billion barrels of recoverable oil in the world, it won't all come out of the ground in the same way. As oil reservoirs dry up, it becomes substantially more difficult to extract oil from a given well and so while the oil is there, it comes out of the ground more slowly. So there may be 1200 billion barrels of oil in the ground, but as that number shrinks, the amount of oil we can get out of the ground will shrink each successive year.

What offsets the shrinking rate of production is new discoveries and new fields open that will extract oil at high rates. As the number of discoveries tapers off (and there is debate over how quickly that will happen or has happened), the amount of oil produced in a year will peak and then start a slow decline as it becomes more and more difficult to extract remaining reserves from their underground reservoirs.

Regardless of when this may happen, there is near-universal agreement that it will happen, if not this decade then in 20-30 years or perhaps even a few hundred years if we can make the unconventional oil sources feasible. So there is great incentive to explore alternative energy sources, whether you agree with aggressive oil exploration to expand reserves or not.

<u>Based on this introductory passage on "Peak Oil,", please answer the associated questions on your worksheet before proceeding</u>.

<u>Nuclear Fission</u>

In the discussion above about oil production and consumption, we ignored the concept of global climate change as well as other problems (such as oil spills off the coast of Alaska or in the Gulf of Mexico). As we are discussing in lecture this semester, consumption of fossil fuels like oil, coal and natural gas is a major source of Carbon Dioxide in our atmosphere, not to mention other pollutants. Many scientists feel that fossil fuel usage should be curtailed for this reason alone. So whether you feel that fossil fuel usage should end sooner because of the threat of global warming or later because of dwindling reserves, if we are going to continue using energy, we need to find other sources.

To introduce you to the basics of Nuclear Fission, I will ask you to read through a brief summary of the subject on Wikipedia, accessible in your browser at the following address: http://en.wikipedia.org/wiki/Nuclear_power As you read this article, please answer the associated questions on your worksheet. (**<u>Q6 through Q13</u>**)

Nuclear Fusion

Fusion reactors work by using light nuclei, such as Hydrogen (or isotopes of Hydrogen, which are Deuterium and Tritium), and combining the nuclei at very high temperatures so they form more complex nuclei like Helium or Lithium. The end result is a nucleus with less mass than the initial components in the reaction, and the lost mass is converted into energy, usually at a much higher rate than what is found in a typical fission reaction.

Hydrogen has a single proton for a nucleus. Deuterium is an isotope of Hydrogen with a proton and a neutron in its nucleus. Tritium is an isotope of Hydrogen with a proton and two neutrons in its nucleus, and Tritium is unstable, with a radioactive half-life of about 12 years. In order for nuclei such as these to fuse together, a fusion reactor must have extremely high temperatures. This is because fusion can only occur if the original nuclei can be forced very close together. (**Q14**)

Normally, two positively charged nuclei will repel each other due to the electric force, and this repulsion increases dramatically as the nuclei get closer together. However, if temperatures are high enough, the nuclei will be moving so quickly that they will approach to very close distances before the electric force can bring them to a stop. (**Q15**)

When this happens, the attractive (but short range) nuclear strong force will bind them together to make a new, larger nucleus. Often, this new nucleus has less total mass than the original nuclei it was constructed from, and this mass that is lost is converted into energy during the reaction. That energy comes off either as light (photons) or as kinetic energy of the resultant particles. This energy is eventually converted into thermal energy which can heat water to power a boiler or steam turbine and so on.

The most common reaction used today in experimental fusion reactors is the combination of Deuterium and Tritium, or the D-T reaction:

$$^{2}D + {}^{3}T \longrightarrow {}^{4}He + n$$

Deuterium and Tritium have an advantage for us that they are easier to fuse than ordinary Hydrogen, thanks to the presence of the additional neutrons in the nuclei. The neutrons provide more attractive strong force but no extra positive charge for the repulsive electric force. In this reaction that total mass of the input (^{2}D and ^{3}T) is a little greater than the mass of the output (^{4}He and a neutron), and that mass difference is converted into energy. (**Q16**)

To put the released energy into context, suppose we have one gallon of gasoline. The amount of energy released chemically by burning the gasoline is around 1 billion Joules. That's roughly the amount of energy used by an average household during a day. Suppose we fill a 1-gallon milk jug with a enough of a mix of Deuterium and Hydrogen so that it weighs the same as the gallon of gas. The amount of energy this mix would produce in a fusion reactor is about one million times greater, enough to power an average household for 3000 years!

Because of the essentially limitless abundance of Hydrogen fuel on the Earth (in water) and the enormous amounts of energy available via nuclear fusion, there is a great deal of interest in the scientific community in making commercial fusion reactors viable. First, there are a few problems we will need to overcome.

Confinement

Because of the extremely high temperatures required for fusion to work, ordinary containers are not practical. Any solid we try to use to confine the D-T mixture as it heats up would quickly melt, allowing the plasma to escape. One way around this is called inertial confinement. In this method, the D-T mixture is machined into a solid fuel pellet, and this pellet is then placed on a target at the center of a device that can fire many high energy laser beams into the pellet.

The pellet heats up quickly and explodes outward, but for a tiny fraction of a second, it has the necessary temperature and density for some fusion to occur. This is a similar sort of technology used in a Hydrogen bomb but on a much smaller scale. In a reactor, we would cycle pellets into an ignition chamber many times each second to get a series of controlled bursts and a constant supply of energy. This type of process is similar to using a fuel injector to spray gasoline into a piston chamber, then igniting it with a spark plug, creating a series of tiny explosions to power a car's engine. (**Q17**)

I recommend you read more about the National Ignition Facility at http://lasers.llnl.gov . (**Q18**)

Another method is magnetic confinement. Since the D-T mixture must be heated to extremely high temperatures, the electrons will be stripped from the atoms, creating a gas of positively charged nuclei and negatively charged free electrons. Charged particles cannot cross magnetic field lines easily, a fact that enables the Earth's magnetic field to protect us from the solar wind, a constant stream of high energy charged particles coming from the Sun.

Using a hollow donut-shaped device called a tokamak, we can generate a magnetic field in a continuous ring and confine the plasma within this ring as we heat it up. Thus, the plasma does not actually come into contact with the walls of the chamber. Unfortunately, once fusion begins occurring within the plasma, the plasma will heat up thanks to the extra energy, and that creates instabilities which may allow the plasma to escape confinement. (**Q19**)

For more information and some images/videos of this kind of reactor, visit the website of ITER (International Thermonuclear Experimental Reactor) at http://www.iter.org. (**Q20**, **Q21**)

Energy Accounting

Another problem that must be overcome is inefficiency. When designing a fusion reactor, we must consider both the amount of energy put into the process to make the reaction occur and also the amount of energy that we can successfully extract from the plasma once the fusion has occurred. The ratio of output energy divided by input energy is called the Q-value. (**Q22**)

For the input energy, we consider first the amount of energy it takes to construct the reactor. If the reactor can handle billions of reactions, then this may not be a big deal in the long run, but if the reactor or parts of it must be replaced every so often, then the amount of energy invested in construction materials for every reaction can become significant.

Next, we must consider the amount of energy it takes to acquire the fuel. Perhaps we get the Hydrogen or the D-T mixture from splitting apart water molecules, and that takes energy. Then we must consider the energy to heat up the gas, keep the magnetic fields powered and keep the plasma confined (or to fire the lasers and manufacture the pellet in an inertial confinement reactor).

For the output energy, we hope to harvest as much of it as we can, but there is always some energy lost due to inefficiencies. So in practice, while a gallon of D-T mixture could theoretically provide enough energy to power a household for 3000 years, we might only be able to extract 10% of that energy from each reaction with the rest being lost as waste heat or other means.

In order for a fusion reactor to be commercially viable, the fusion process must have a Q-value greater than 1; otherwise, there is no point going through the fusion process. The purpose of our experimental reactors is, in part, to find an efficient process for manufacturing the fuel, igniting fusion and extracting energy from the process. If we can get a Q-value of 20 or more in an experimental reactor, then we should be able to build viable commercial reactors using the same process. The two experimental reactors mentioned previously (ITER and NIF) are both expected to achieve Q-values of at least 1 for the D-T fusion process. (**Q23**)

Nuclear Waste

Looking again at the D-T reaction, notice that the output products are Helium and a neutron. The Helium nucleus is not harmful and is not considered nuclear waste, but the neutron is potentially harmful. First of all, whether we use inertial confinement or magnetic confinement, the neutron has no charge and so cannot be contained. Thus, while fusion reactions are going on, the walls of the chamber will be bombarded with neutrons.

When ordinary atoms like Carbon or Silicon or Iron are bombarded with neutrons, these neutrons are absorbed into the nuclei, often converting them into highly radioactive and dangerous isotopes. This causes the structure to break down, resulting in replacement costs and radioactive waste. It is possible in theory to blanket the fusion reaction with Lithium, which when bombarded will break apart into Tritium and Helium. Then the Tritium (which is expensive to manufacture due to its short half-life) can be used for another reaction, eliminating the fuel cost. (**Q24**)

Such reactors are expensive and require a lot of energy to maintain operations, so the energy must be extracted from the reactions efficiently. An alternative is to use a fusion reaction that doesn't produce neutrons, such as a combination of simple Hydrogen with Boron-11, which produces 3 Helium-4 nuclei as output, along with energy, but it requires higher temperatures.

And higher temperatures mean a less efficient process. So we must choose whether to deal with the problem of excess neutrons at low temperatures or the inefficiency associated with high temperature reactions. With each generation of experimental reactor, we are approaching a level of efficiency that will make nuclear fusion feasible, but most experts project that the soonest possible date for a commercial reactor is the year 2050 based on current research trends.

Nuclear fusion does hold promise for the future as a way out of our dependence on Carbon-based fossil fuels, but it is still not a reality. In the meantime, if the goal is to reduce or eliminate fossil fuel usage, we will have to consider other alternative sources of energy.

Worksheet

Please turn now to the worksheet for this lab and answer the questions there about nuclear fusion based on the introductory reading you have just completed.

Conclusion

This week's lab is qualitative. The purpose is to give you a chance to go deeper into topics we only have time to touch on in lecture. In qualitative labs, there will be no essay assignment included. When you have finished answering the questions on your worksheet, you are finished with the lab.

Lab #1 Worksheet

Name:
Home TA:

<u>Part 1 (Peak Oil)</u>

From the introductory passage on Peak Oil, answer the following questions in the space provided.

1. Who first modeled the future of oil production and introduced the concept of peak oil?

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2. Briefly explain one reason why some oil reserves may be underestimated.

3. Briefly explain two reasons why some oil reserves may be overestimated.

4. Explain why, even though a barrel of oil may be present in an unconventional source such as oil shales in the Western United States, we would not count it as part of our overall oil reserves?

5. Explain why the decision on whether or not to extract oil from the Arctic National Wildlife Refuge (ANWR) has very little impact on the overall issue of peak oil.

Part 2 (Nuclear Fission)

From the Wikipedia article on Nuclear Power, answer the following questions:

6. Currently, nuclear power (from fission reactors) provides what percentage of the electricity consumed in the United States? See section 5 - Installed capacity and electricity production.

________%

7. Based on the pie chart in the right hand column next to the table of contents, what are the five main sources of fuel the world uses for energy?

____________________, ____________________, ____________________,

_____________________, ____________________

8. From section 3, entitled “Nuclear Power Station,” answer: Describe how electrical energy is generated in a nuclear fission power plant (this is the very last part).

9. From section 4 on “Life Cycle”, the authors perform a calculation for the lifetime of Uranium as an energy source. According to 2011 calculations, the amount of Uranium in our reserves is enough to last us for at least how many years?

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10. From section 4.3 on “Nuclear Waste,” and in particular 4.3.4 “Waste Disposal,” describe where most nuclear waste is stored from nuclear power plant operations.

11. What are two reasons cited in the next section (4.4 “Reprocessing”) why reprocessing of nuclear waste into usable fuel is not currently a common practice?

12. Moving on to section 12, “The Debate on Nuclear Power”, list five reasons proponents favor the expansion of nuclear fission power?

1. ____________________

2. ____________________

3. ____________________

4. ____________________

5. ____________________

13. List five reasons critics oppose the expansion of nuclear fission power.

1. ____________________

2. ____________________

3. ____________________

4. ____________________

5. ____________________

Part 3 (Nuclear Fusion)

From the introductory passage in the lab handout on Nuclear Fusion, answer the following questions in the space provided.

14. Explain what Deuterium and Tritium are.

15. Explain why high temperatures are necessary in order to achieve nuclear fusion.

16. Explain why it is easier to fuse Deuterium and Tritium as opposed to simple Hydrogen.

17. In your own words, briefly describe the inertial confinement method for nuclear fusion.

18. At the website for the National Ignition Facility (http://lasers.llnl.gov, look under Education –> How Lasers Work and read this short article. Next, the video to watch is now on youtube rather than the NIF website, so navigate to http://www.youtube.com and search for "How NIF works". Watch the five-minute video and draw a simple sketch of how fusion in the target is ignited by lasers. Use appropriate labels.

19. In your own words, briefly describe the magnetic confinement method for nuclear fusion.

20. Visit the website for the experimental magnetically confined fusion reaction at http://www.iter.org. On the top toolbar, there is a Science menu. On that menu, select "What is Fusion" and briefly explain how fusion generates energy:

21. Under the Science menu at http://www.iter.org, select "ITER Goals" and answer: The current record Q-value for a fusion is 0.67. If the ITER works as envisioned, what will be its Q-value?

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22. Explain what is the Q-value for a fusion reactor?

23. Suppose a reactor has a Q-value of 20. If 1 million Joules of energy are used to create a fusion reaction, how much energy would be output from the reactor in the form of useful energy such as electricity?

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24. From the reading on nuclear fusion in the lab handout, explain how nuclear fusion reactions may generate radioactive nuclear waste.