The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Science 1101 Part 1: The Science of Oil and Peak Oil

Posted by Gail the Actuary on February 5, 2008 - 5:24pm
Topic: Supply/Production
Tags: curriculum, education, ethanol, oil, oil reserves, peak oil, refineries, tupi [list all tags]

In this article, I provide Peak Oil science curriculum suitable for introductory college science classes, advanced high school classes, and adult seminars. The material requires a little background in high school chemistry, but otherwise does not have any pre-requisites. There is sufficient material for a two to four session unit on peak oil.

The written material is divided into Part 1: The Science of Oil and Peak Oil (in this article) and Part 2: Oil as a Liquid Fuel and Expected Peak Oil Impacts (found at this link). There are also discussion questions at the end of Parts 1 and 2, and numerous links to other references. A PDF version which contains both Part 1 and Part 2 can be found at this link.

Last week, I posted an earlier version of proposed peak oil curriculum. Many of the comments related to things I had left out or hadn't explained adequately. After considering the comments, I decided that folks were right, and added some more material. Since the post was already fairly long, I broke it into two parts. I also reorganized sections to make a more logical flow. The earlier version can be found at this link.

The current version incorporates changes based both on comments to this post, and on comments to the previous post. On a rapidly changing topic such as peak oil, there is no real consensus on some issues. I have tried to pick a reasonable interpretation. If readers have questions or comments, I can be reached at gailtverberg (at) comcast (dot) net.

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1. What is petroleum?

Petroleum (also called oil) is a viscous liquid that is found beneath the earth's surface that is refined to make fuels, plastics and other goods. Oil is not found in large pools. Instead, it is generally trapped in the pores of sandstone or other porous rocks. It is often found with natural gas, which is formed under similar conditions.

Petroleum is not a single compound. Instead, it consists of a mixture of hydrocarbon chains of different lengths, ranging from about C_5H_{12} to $C_{42}H_{86}$. It also contains some associated hydrocarbon gasses, with 1 to 4 carbon molecules. When petroleum is burned, the hydrocarbon chains plus oxygen are transformed into CO_2 (carbon dioxide) and H_2O (water), and energy is released. Carbon dioxide is one of the major gasses implicated in global warming.

2. How was petroleum formed?

Petroleum was formed millions of years ago from the remains of small plants and animals that lived in seas or lakes. These plants and animals died and fell to the bottom of the sea. Gradually, layers of silt and sediment covered their remains, causing great heat and pressure to build up.

Under this heat and pressure, a chemical reaction took place, transforming the hydrogen and carbon from the decaying plants and animals into the mixture of hydrocarbons that we know as petroleum. This petroleum is found in only a relatively small number of places in the world, where conditions were precisely right for its formation.

3. Is new petroleum now being formed?

Not in any measurable quantity. Once we use up the petroleum that was formed millions of years ago, it will be gone for good.

4. Aren't we continuing to discover more and more oil every year?

No. Once we started looking for oil, we found more and more oil for a while, but then new discoveries started to drop off, as more and more of the world was explored. This is shown in Figure 1, below. We are continuing to discover oil, but the quantity discovered now is much smaller than it was years ago, and much smaller than we are now using. (In all of these charts, the amount of oil is measured in barrels. A barrel is equal to 42 gallons or 158.984 liters. The total quantity is huge!)

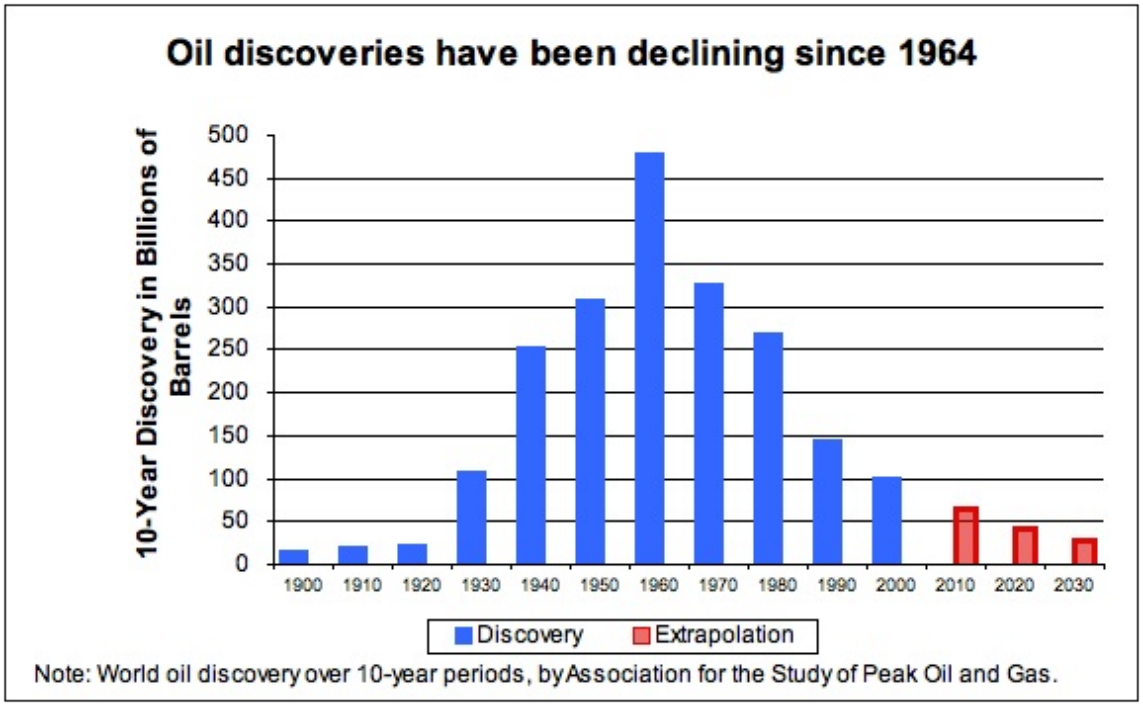

Figure 1

We often read in the news about finding new fields, but these fields tend to be smaller and harder to reach than those discovered in the past. We are now so concerned about finding oil that even small discoveries are reported as news.

Figure 1 does not include oils that are not liquids, like the Canadian oil sands. There are large quantities of these, but extraction is extremely slow. It is doubtful that they will ever become a significant share of world oil production.

5. How is petroleum extracted from the ground?

Petroleum is generally extracted by drilling oil wells in areas where there is some reason to believe oil might be located. When oil is first found, it often comes from the ground very quickly, under great pressure. Gradually, the oil comes out more and more slowly. This happens partly because the oil pressure drops, and partly because the oil that is extracted from the ground tends to be mixed with more and more water, as more oil is removed from the ground. Many US oil wells produce more than 99% water.

In some places, such as the Canadian oil sands, a very viscous form of oil is found. This is mined, rather than extracted using oil wells. Production of such oil tends to be very slow and expensive.

6. Is all of the oil in a given area removed by the use of oil wells?

No. As noted in Item 1, oil is generally found trapped in the pores of porous rock such as sandstone or limestone. The rock is somewhat like a hard sponge, with a goey liquid trapped inside. This oil is very difficult to get out of the rock. If wells are used to collect the oil that seeps out of its own accord, typically only 10% to 30% of the oil originally in the rock can be removed.

Various methods of enhanced oil recovery have been developed to increase the percentage of oil that can be removed. One approach uses water injection to increase the pressure in the well. In another approach, carbon dioxide or some other gas is injected, to force some of the trapped oil out. In one newer process, microbes are used to break up the oil droplets into smaller pieces, so that they can more easily be removed. One method under development uses an underground fire to heat the oil, so that it will become more liquid and drain out of the rock (Microbial Method: http://www.titanoilrecovery.com/ Water injection: http://en.wikipedia.org/wiki/Water_injection_(oil_production) Underground fire: http://www.theoildrum.com/node/2907)

Usually, even with enhanced oil recovery, not more than 50% of the oil originally in place can be removed. Often the percentage is quite a bit less than 50%. Some of the newer enhanced oil recovery methods offer the possibility that this percentage may be raised in the years ahead.

7. Can an oil company produce a constant amount of oil in a given location?

No, it generally doesn't happen this way. When a single oil well is drilled, production very often quickly reaches a peak, and then tapers off over a several-year period, as oil pressure drops and the amount of water produced increases.

When we look at production from all of the wells in a given geographic area, production generally increases for several years, as more and more oil wells are drilled. One by one, wells begin to decline, and new wells are drilled. Eventually, there are not enough new places to drill additional wells, and overall production starts to decline. (See Figure 2, below.)

US oil production for the 48 states excluding Alaska and Hawaii reached its peak in 1970. Once energy companies realized that production was declining in the US 48 states, they looked for new locations where oil might be extracted. Alaska had oil, but it was difficult to transport oil out of Alaska without a pipeline. The necessary pipeline was completed in 1977. Production reached its peak in 19888, and has been declining since then.

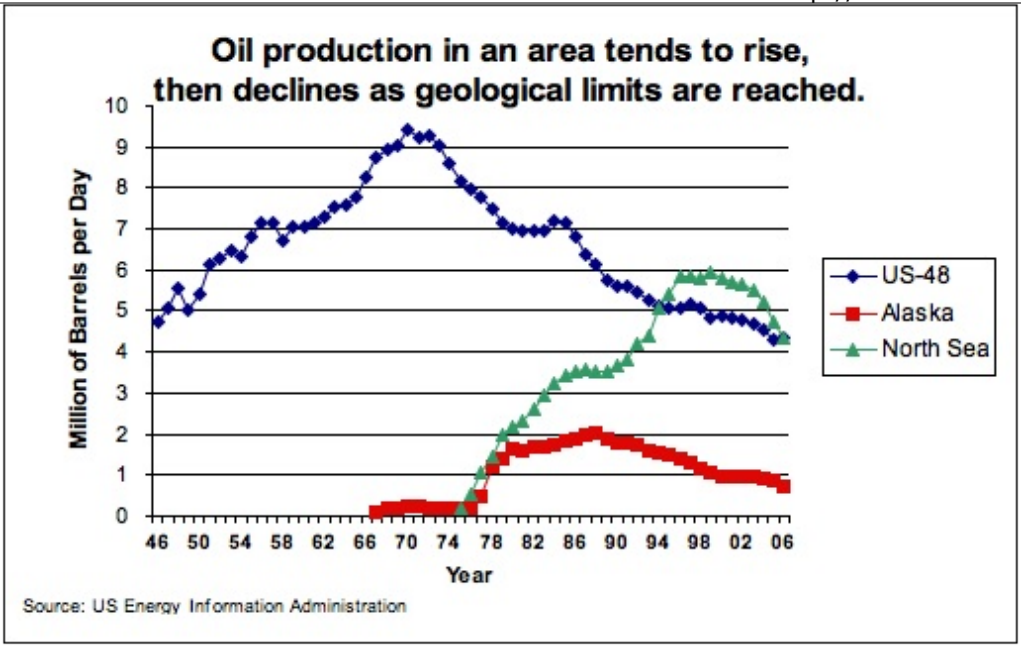

Figure 2

Oil production was also begun in the North Sea, near Norway and Great Britain, but this too soon reached a peak. North Sea oil production has been declining since 1999. All of these declines have taken place in spite of new technology and improvements in oil recovery methods.

Oil is also produced in many other parts of the world, but oil recoveries are starting to decline in many of these areas as well. At this point, much of the world's "easy to produce" oil has been removed. New oil production tends to be in difficult areas, like deep-sea locations.

8. Will world oil production reach a peak and begin to decline? If so, when?

Since oil is a finite resource, we know that production must eventually decline. There is considerable disagreement as to when this decline in production will occur.

The US General Accountability Office (GAO) released a report in March 2007 titled, "Uncertainty about Future Oil Supply Makes It Important to Develop a Strategy for Addressing a Peak and Decline in Oil Production." This report indicates that decline is likely to begin sometime between now and 2040. The United States Association for the Study of Peak Oil indicates that the peak and decline is expected to occur prior to 2015.

Even oil companies are beginning to talk about the possibility of future production falling short of demand. This wouldn't necessarily be a decline; it might be a plateau or slight increase. Shell Oil says, "After 2015, easily accessible supplies of oil and gas probably will no longer keep up with demand."

(GAO Report: http://www.gao.gov/new.items/d07283.pdf Shell Oil statement: http://www.shell.com/home/content/aboutshell-en/our_strategy/shell_globa... National Petroleum Council 2007 report "Facing the Hard Truths about Energy" http://www.npchardtruthsreport.org/ Canadian Business article: http://www.canadianbusiness.com/columnists/jeff_sanford/article.jsp?cont...)

9. How are estimates of the date of peak production made?

There are a variety of methods. In 1956, M. King Hubbert correctly forecast that oil production for the United States was likely to reach a peak and decline about 1970. Estimates from that time period put the peak in world production at about 2000. Because of efficiency increases and energy conservation efforts that were put in place during our previous energy crises, growth in oil usage slowed and the date of the peak was pushed back. http://www.hubbertpeak.com/hubbert/1956/1956.pdf

Besides using techniques similar to Hubbert's, estimates now consider additional types of information, including new projects being planned and decline rates on existing fields. Another consideration is the fact that it been very difficult to increase oil production in the past few years. Oil production since 2005 has been flat, in spite of increasing prices. Oil companies are having difficulty finding more oil reserves to replace those used by extraction of oil during the year.

The organizations with the highest estimates tend to put greatest reliance on published reserve estimates of the major oil exporting nations. These amounts are not audited. There is increasing evidence, including Google satellite information, that these amounts are inflated. Exporting nations look more powerful if they report high numbers, so there is a temptation to report optimistic amounts. http://www.theoildrum.com/node/3574#more

10. Can outside factors make a difference in future production?

If every country had infinite resources, and chose to put them all into oil production, it is likely that oil production would be higher than it is. In the real world, that is not the way it is, though.

One limitation is the supply of trained geologists and engineers. The energy field has been stagnant for many years. Many people trained for the oil and gas have left the field, because of frequent boom and bust cycles. Of those remaining, a disproportionate number are near retirement age.

There are also limitations on physical infrastructure. There is a limited number of drilling rigs, especially those needed for the very deep-sea locations now being explored. The forces of supply and demand drive up costs for these rigs, making projects more expensive. Other infrastructure items are in similarly short supply. Companies do not have infinite budgets, and can't use equipment that is not available, so projects get pushed back.

Another factor is the influence of foreign governments and of government sponsored oil companies around the world. One estimate is that only 7% of the world's oil reserves are in countries that allow "International Oil Companies" (companies like ExxonMobil, Chevron, and Total) free reign.

Wars and civil disorder can affect production. The production of Iraq and Nigeria have clearly been affected by fighting of various types.

One factor that has the potential to help future supply, or at least soften the down slope, is technological advances. For example, some of the newer enhanced oil recovery methods may have promise. Putting them to work on old fields could be done, but it would not necessarily easy. In many cases, oil rights would need to be obtained from current owners, and new wells drilled. This would be expensive.

11. How certain are future petroleum imports?

Not very. Oil imports comprise about two-thirds of US petroleum use. The amount of future

world production is uncertain, and the portion available for import is even more uncertain. Oil exporting countries want to keep their own populations happy. This often means increasing use of oil within the country, at the expense of exports. Also, if it becomes clear that there will be a shortfall in world production, exporting countries may decide to hoard the oil they have, saving it for the future when it is likely to sell for an even higher price.

Another concern is a possible drop in the value of the dollar, because of difficulties within the US financial system, or because of balance of payment problems. If the value of the dollar should decline, oil will be much more expensive, so it will be difficult to buy as much.

Figure 3 below shows US crude oil production. It has been decreasing at about 2.1% peer year.

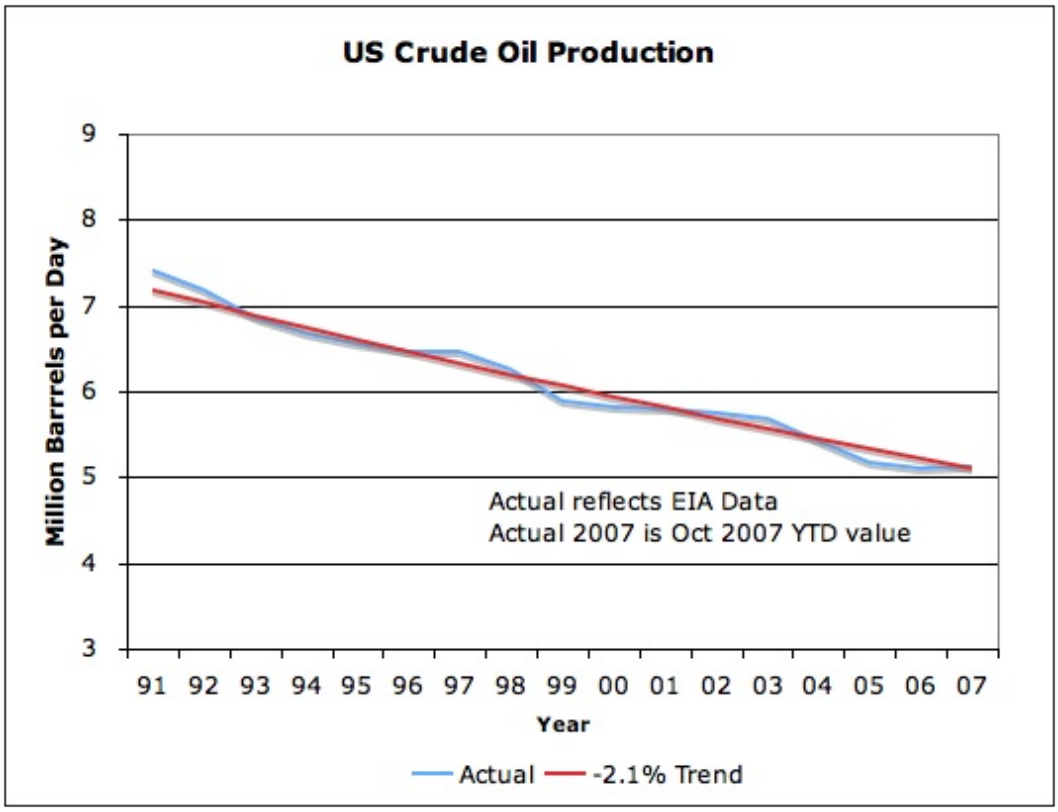

Figure 3

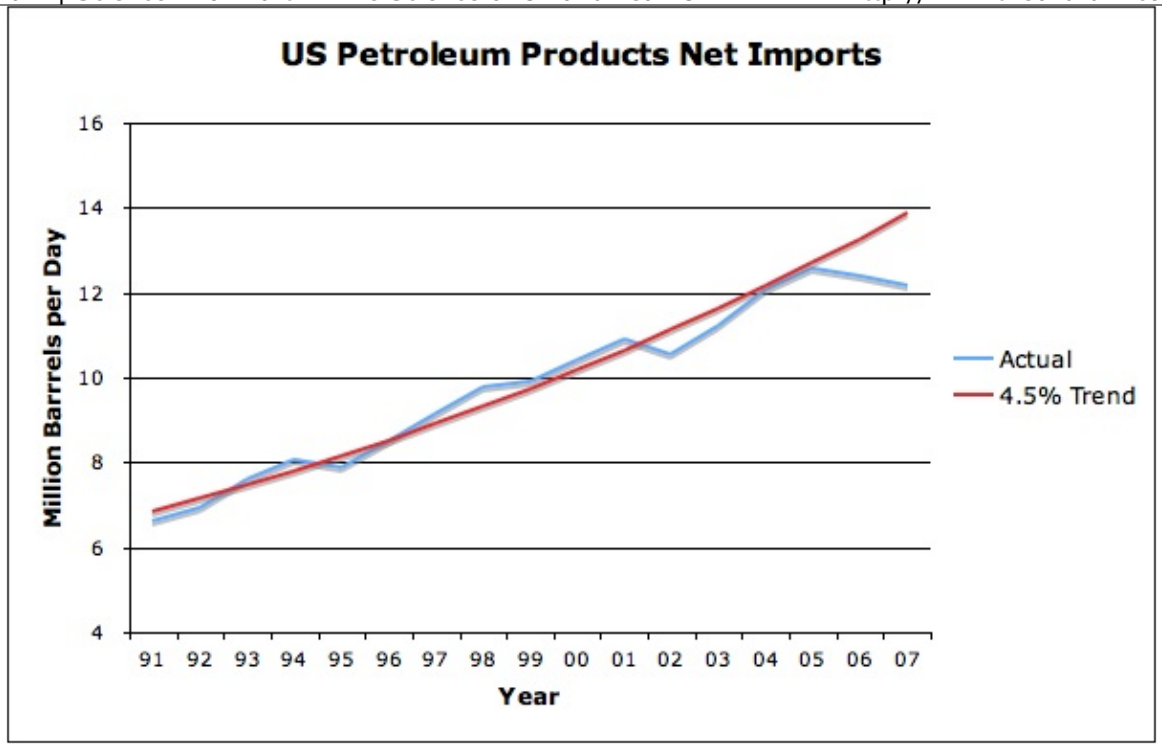

Figure 4

Figure 4 shows US imports of oil and finished products, like gasoline. These were rising at about 4.5% a year, but declined in 2006 and 2007. World oil production has been flat since 2005. (See Figure 5, below). With no increase in world production, it has been harder for the US to find oil to import, and the price of what we have been able to find has been higher.

12. Does the date of the peak matter?

We have already reached the point where oil is in short supply. Because of this, we need to find ways to conserve, and to find alternative energy sources. The actions we need to take are pretty much the same, whether the peak in the world's oil production is now, or in 2040.

Also, any governmental action taken to change our oil usage, or to find alternatives, is likely to take many years to implement. For example, if manufacturers start making cars more fuel efficient, it will take many years before all of the old fuel-inefficient cars can be replaced. For this reason, we need to start taking action well before the peak.

(See "Peaking of World Oil Production: Impacts, Mitigation, and Risk Management" by Robert Hirsch, Roger Bezdek, and Robert Wendling for US Department of Energy (2005) http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf)

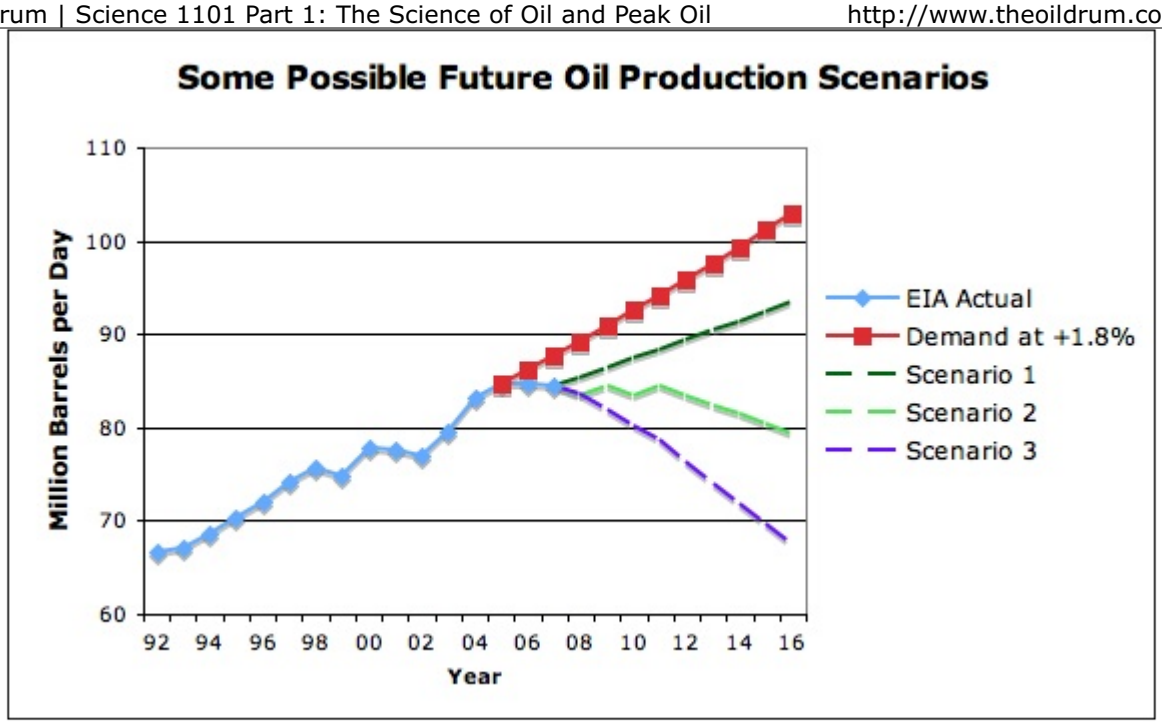

Figure 5

The blue line Figure 5 shows recent oil production trends. Oil production has been on a plateau for three years, since 2005. The line "Demand at +1.8%" gives an idea of how much oil the world would like to use, if it is actually available, at a reasonable (2005) price. It assumes 1.8% per year growth. Scenarios 1, 2, and 3, give three (of many) possible directions future oil production may follow. Even if a fairly optimistic scenario like Scenario 1 occurs, there is likely to be a significant gap between demand and supply.

13. What is petroleum used for?

The vast majority of oil is used as fuel, of one type or another. Figure 6, below, shows that largest share (46%) of US oil usage is for gasoline. The next biggest slice is "distillate", with 20%. Distillate includes diesel fuel (used in trucks and many types of equipment) and home heating oil (used primarily in the Northeast). Petroleum is also used as jet fuel, and as fuel for boats, so it provides the vast majority of the transportation fuel used in the United States. It also provides asphalt for our roads, and lubricating oils for engines.

The "All Other" category is quite small on the graph, but includes most of the chemical uses for petroleum. Products made using petroleum as a feedstock include plastics, synthetic fabrics, dyes, pharmaceutical drugs, detergents, insecticides and herbicides, and many other products we use every day.

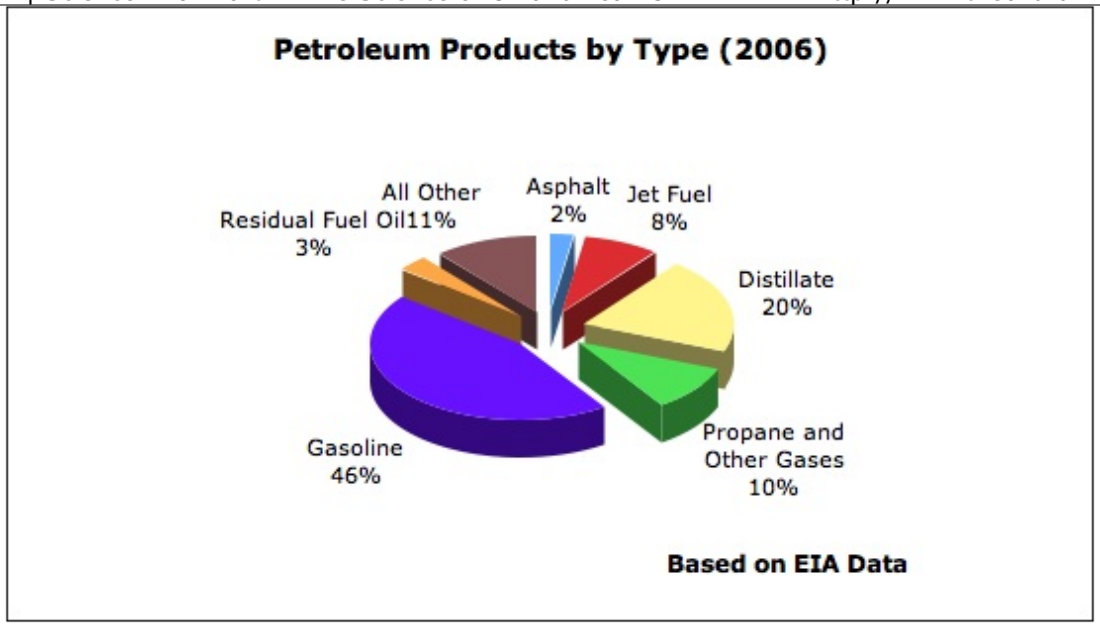

Figure 6

In some parts of the world, petroleum is used to produce electricity. In 2006, only about 2% of US power generation was from oil. http://www.theoildrum.com/files/Generation%20by%20State%20by%20Type.png

14. How is petroleum processed to obtain its major products?

Petroleum is sent to a refinery, where it is processed to remove impurities and to separate it into its component parts. As we noted earlier, petroleum is a mixture of different hydrocarbons ranging from about C_5H_{12} to $C_{42}H_{86}$. These hydrocarbons have different properties, including different boiling points and different viscosities. Very short chains, containing 1 to 4 carbon molecules, are gasses at room temperature. Chains with 5 to 10 carbon molecules are thin liquids that boil at low temperatures. The longest chains are asphalt or bitumen. Asphalt is very viscous and has a very high boiling point.

During refining, a process called fractional distillation is used to separate out the mixture into components. Petroleum is heated to a vapor, and then allowed to condense in a tower containing trays at different levels. Because the shorter hydrocarbon chains boil at lower temperatures than longer chains, this process can be used to separate petroleum into its component parts. The lighter the fraction, (that is, the fewer carbon molecules in the chain), the higher up it condenses.

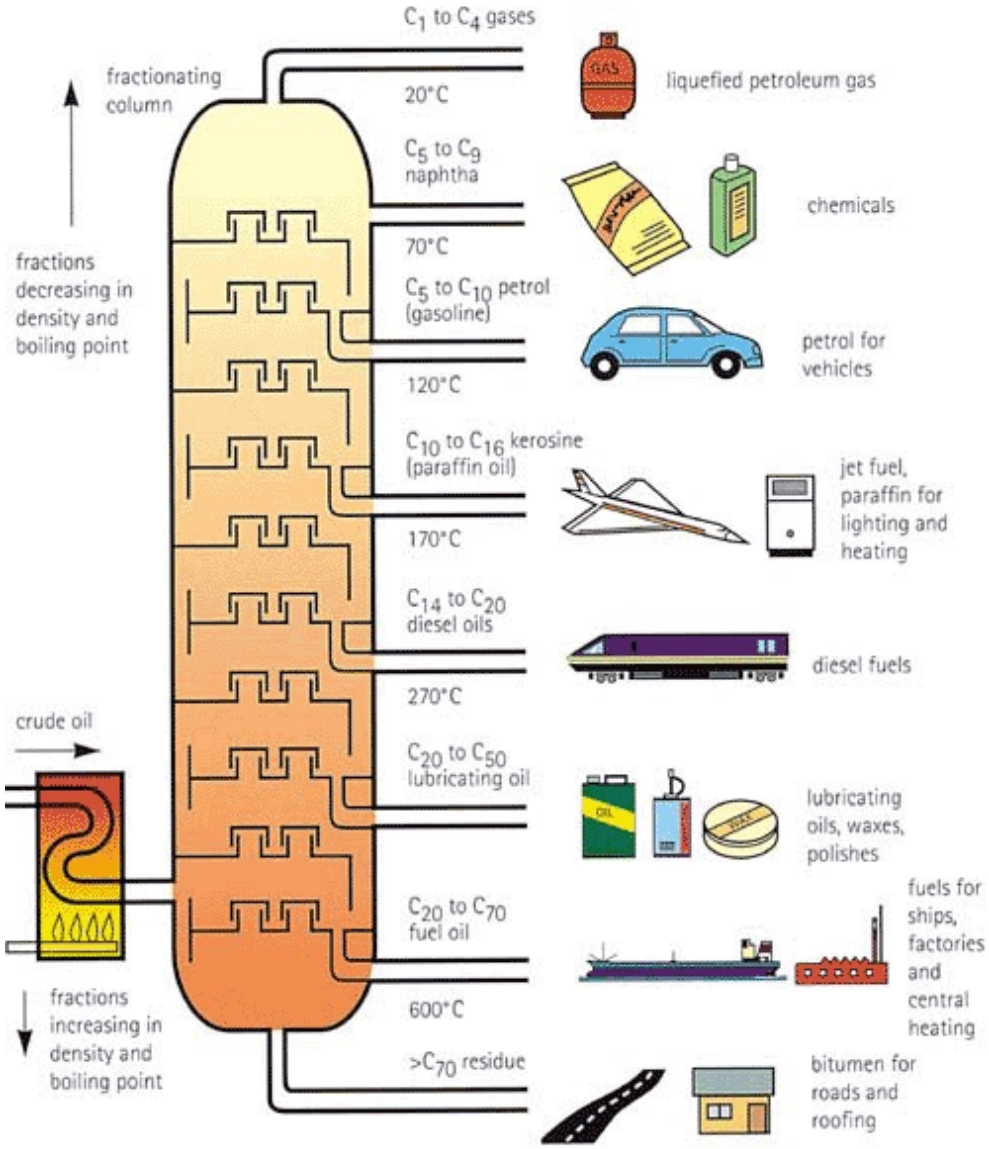

Figure 7. Fractional Distillation (Diagram by The Institute of Petroleum, UK)

For further discussion see "How Oil Refining Works" on HowStuffWorks.com (http://science.howstuffworks.com/oil-refining.htm)

15. Is petroleum from different locations the same?

No. Some petroleum is "light" – that is, composed mostly of the shorter chain hydrocarbons. Other petroleum is "heavy" – that is composed mostly of longer chain hydrocarbons. Some is even "very heavy". Oil also differs in the amount of impurities. The highest quality (and highest priced) crude oil is light oil, with few impurities. The lowest priced crude oil is heavy oil, with many impurities.

The reason that light oil is prized is because when fractional distillation is used, it yields a high proportion of gasoline and diesel fuel, and relatively little asphalt and other lower priced products. When fractional distillation is used on heavy oil, it tends to yield a high a proportion of asphalt and other low priced products. A process called "cracking" can be used to break very long molecules into shorter, more commercially valuable molecules, but this process is expensive, and requires

specialized equipment.

The amount and types of impurities in crude oil is also important in determining the selling price of crude oil. Special processes, available only in certain refineries, may be needed to remove certain types of impurities. In some cases, it is necessary to build a refinery especially for oil from a particular location, so as to have the proper equipment to remove the impurities from the oil.

Some of the oil that has not yet been extracted is oil with difficult to remove impurities. This oil was bypassed in the past as too difficult to process. Saudi Arabia has some oil that it is not extracting because a refinery has not yet been built to handle the impurities.

16. How is oil transported from place to place?

When crude oil is found in a location, it must be transported to a refinery for processing. There are two major ways this is done. One is by "oil tanker" (type of ship). The other is by pipeline. When oil is discovered in a remote location, new pipelines often must be built before production can begin so as to have a way of transporting the oil once it is extracted. This is costly, and may take several years.

Once the oil is refined, the refined products are again shipped by pipeline to a location near where they will be used. Trucks are generally used for transportation to the final customer.

It might be noted that each pipeline has both a maximum and a minimum flow rate. If production or use drops too much in an area, its pipeline may no longer be usable.

One exception to the use of pipelines for transport occurs for gasoline with ethanol. The gasoline base is shipped by pipeline, but ethanol cannot be shipped by pipeline, because it tends to absorb water. Ethanol must therefore be shipped by other means (railroad, barge, and /or truck) to a location near where the gasoline will be sold. There, ethanol is blended with the appropriate gasoline base to make gasoline. After it has been blended with the base, it is shipped by truck to the retail location where it is sold. This whole process is expensive and difficult to co-ordinate.

Part 1 - Discussion Questions

1. In 1957. Rear Admiral Hyman Rickover gave a speech in which he talked about the expected peak of oil and gas production in the first part of the 21st century, and the likely decline of coal toward the middle of the 21st century. He also talked about the need to tell young people, and to start planning for the difficult transition that likely lay ahead. http://www.theoildrum.com/node/2724

Why didn't people take his advice?

2. In 2007, there was considerable publicity about the Tupi field in Brazil. According to newspaper articles, Tupi may transform Brazil into a major oil exporter. When you read further, you find that the oil field is nearly 200 miles off shore, and is at record depths. Furthermore, the oil is found beneath layers of rock and salt.

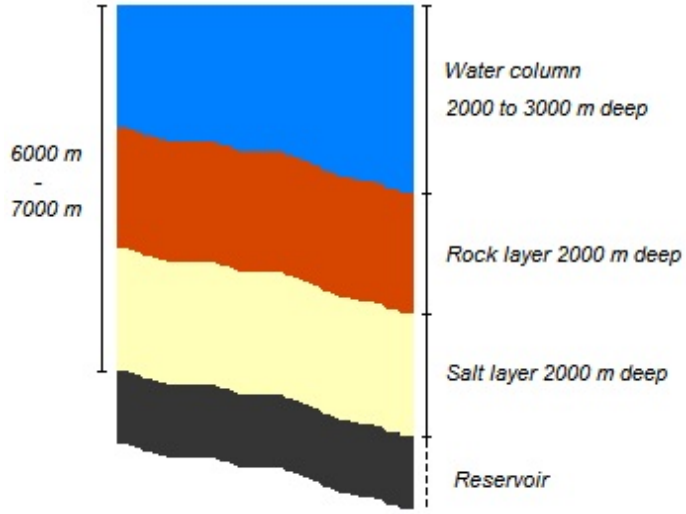

Figure 8 (The Oil Drum)

The salt is unstable to drill through. A problem with thermal shock is expected when oil is extracted because the temperature of the oil in the reservoir is expected to be nearly 100 degrees Celsius, while the water above the rock is expected to be 4 degrees Celsius. In order to extract the oil, new technology will need to be developed to drill this deep and to overcome the problems of the unstable salt layer and of thermal shock.

Also, some means of transporting the material extracted will be needed. Because natural gas will be included, the usual method would be a pipeline, but the distance will be a challenge. Therefore, the company is considering building a floating liquefied natural gas to liquid plant, so that tankers can transport both the oil and liquefied natural gas.

The expected oil production from Tupi is large relative to recent discoveries, but not large relative to the amount of oil we need to discover each year. At full development, Tupi is expected to produce 500,000 to 1 million barrels a day. This is equivalent to 2.4% to 4.8% of the United States' current daily oil usage, or 0.6% to 1.2% of world usage. Just to offset declines in existing fields, we need to discover 5 to 9 fields the size of Tupi each year.

a. What probability would you assign to this project actually succeeding?

b. The company hopes to have initial production by 2013. Given the technology and infrastructure issues, how likely does this seem? Would you be surprised by setbacks?

c. If this is the major discovery of the year, what does this tell you about other discoveries?

To read about Tupi (not needed for exercise)
http://www.theoildrum.com/node/3269
http://www.iht.com/articles/2008/01/11/business/oil.php
http://www.afxnews.com/about488/index.php?lg=en&c=00.00&story=2305842

http://www.theoildrum.com/files/TupiLayerSketch.png