PEAK OIL SCIENCE CURRICULUM

By Gail E. Tverberg

Part 1 – The Science of Oil and Peak Oil

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. It 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. 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!)

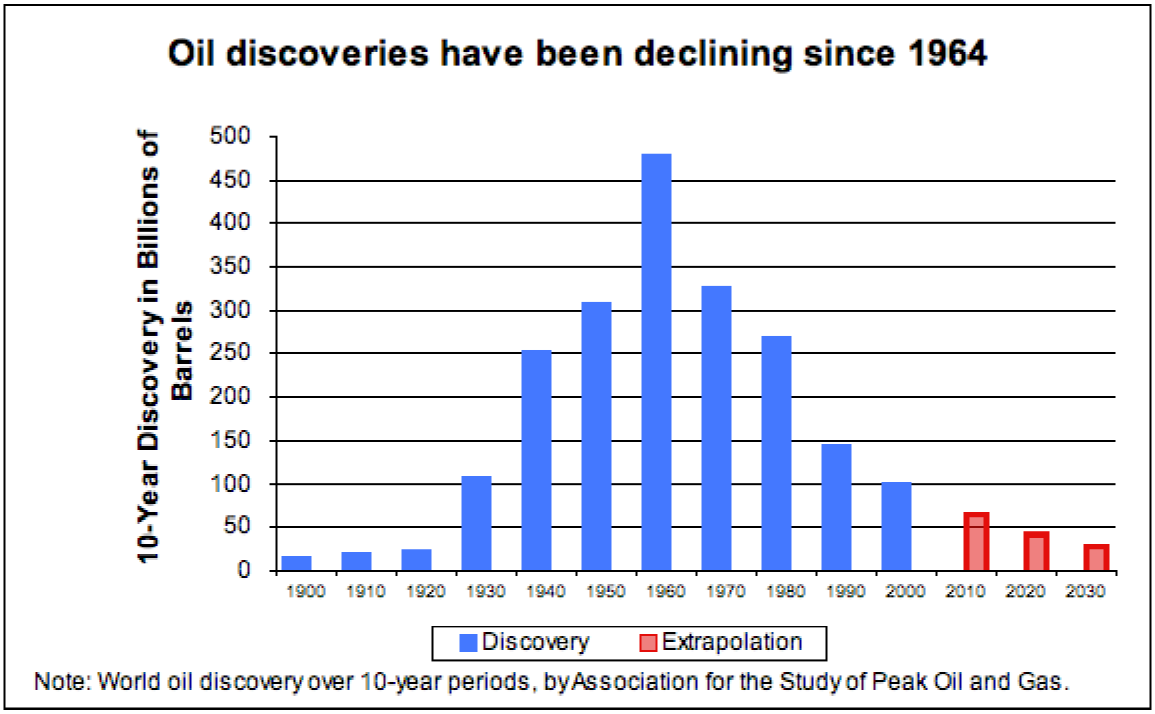

Figure 1

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.

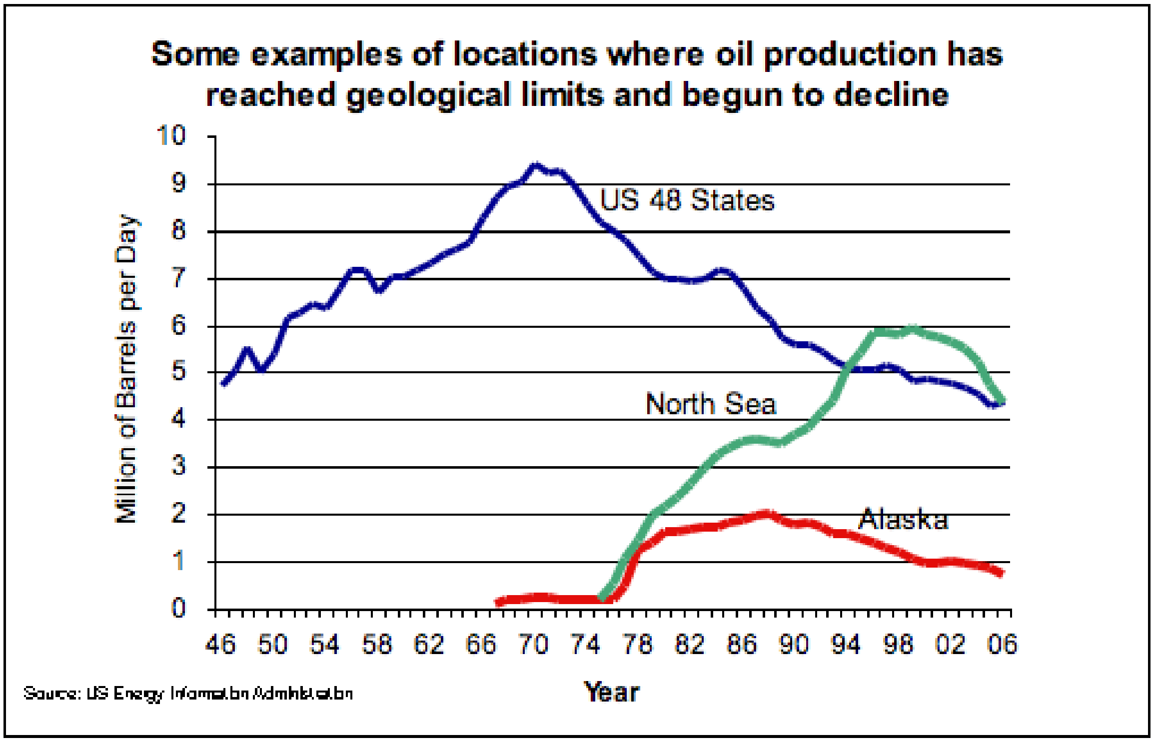

Figure 2

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_global_scenarios/two_energy_futures/two_energy_futures_25012008.html)

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?content=20080125_144737_464&page=1)

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.

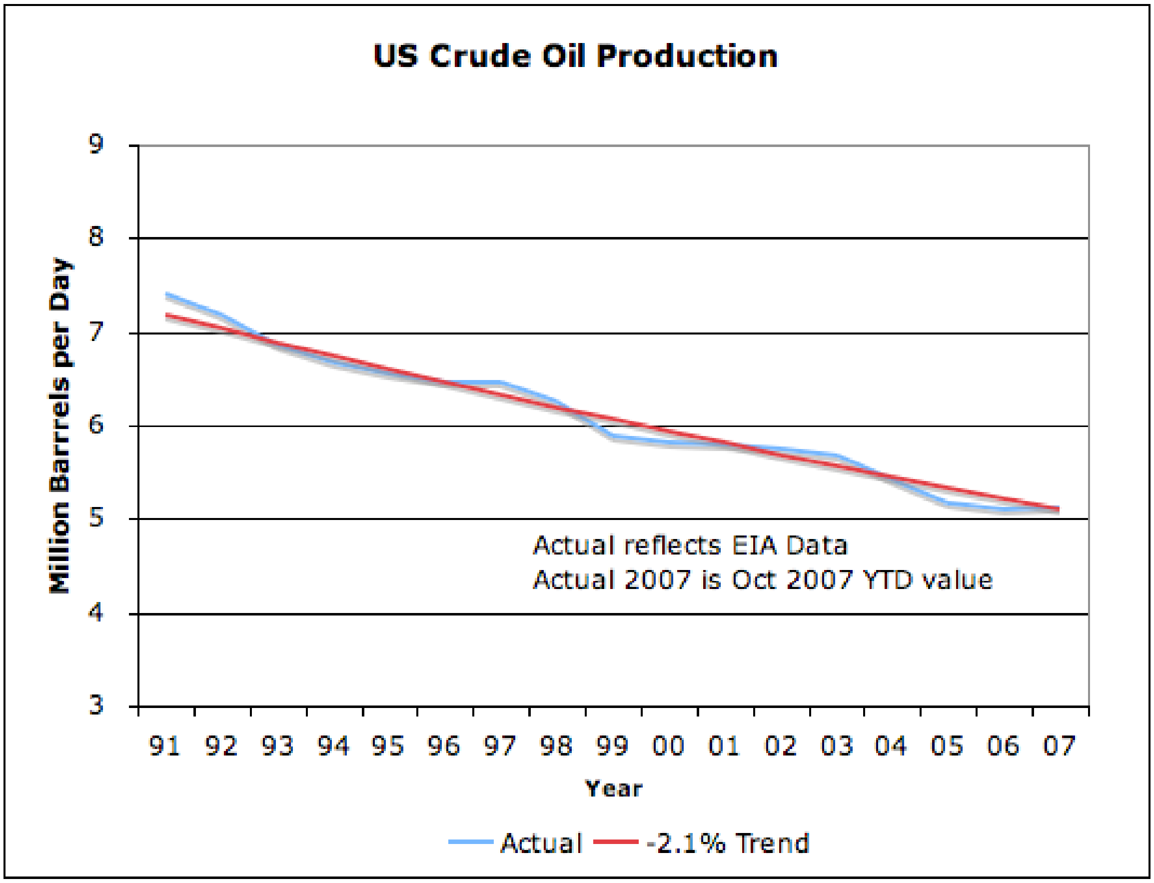

Figure 3

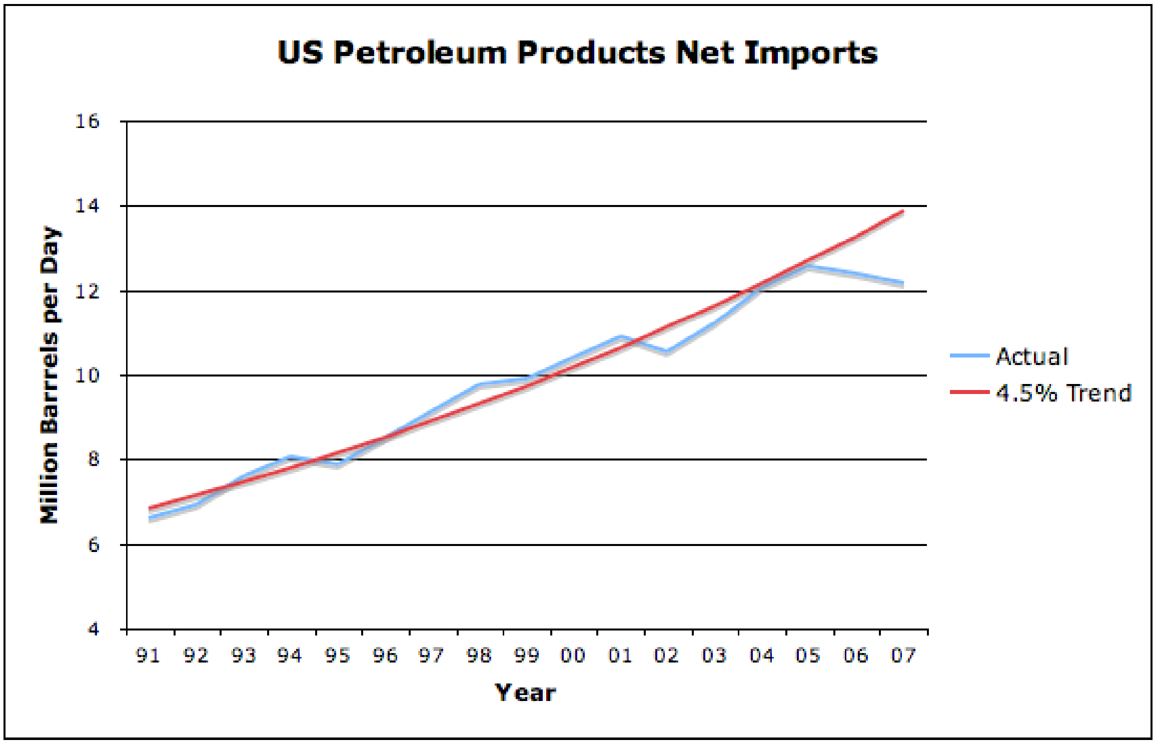

Figure 4

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)

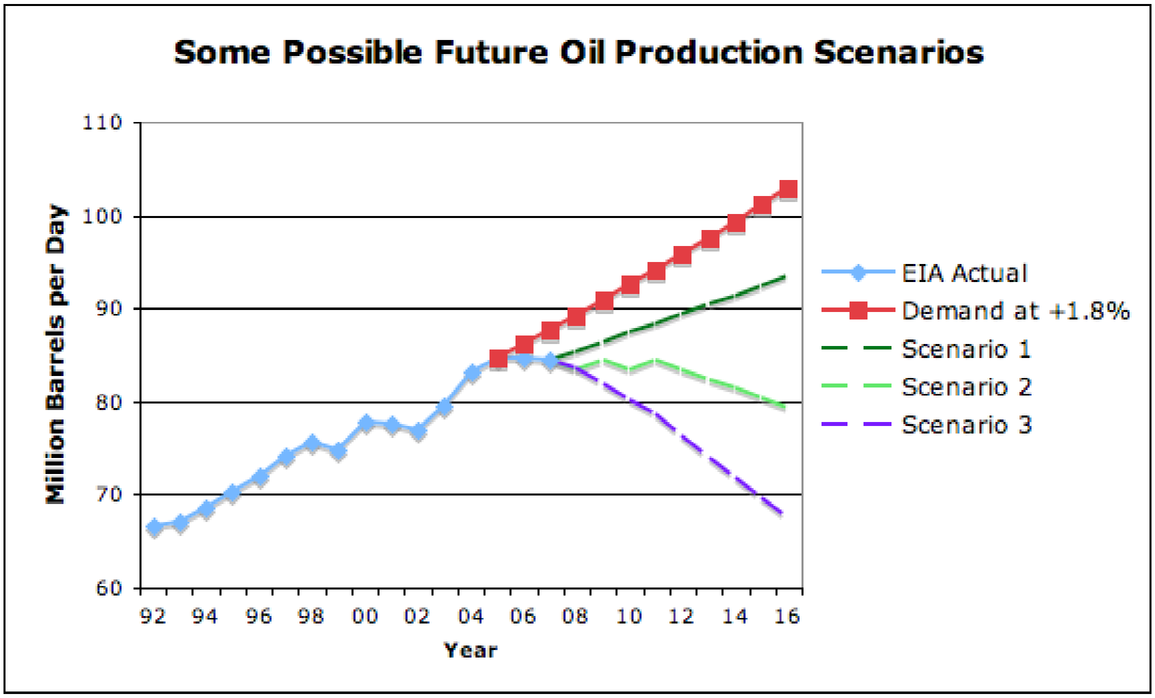

Figure 5

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.

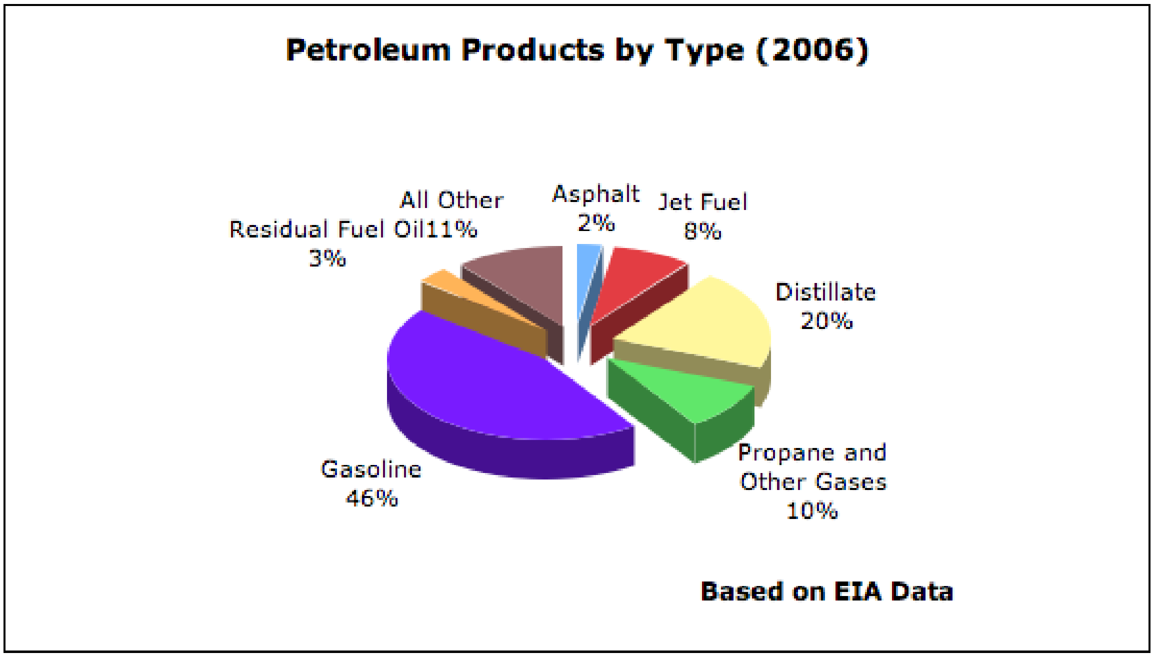

Figure 6

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.

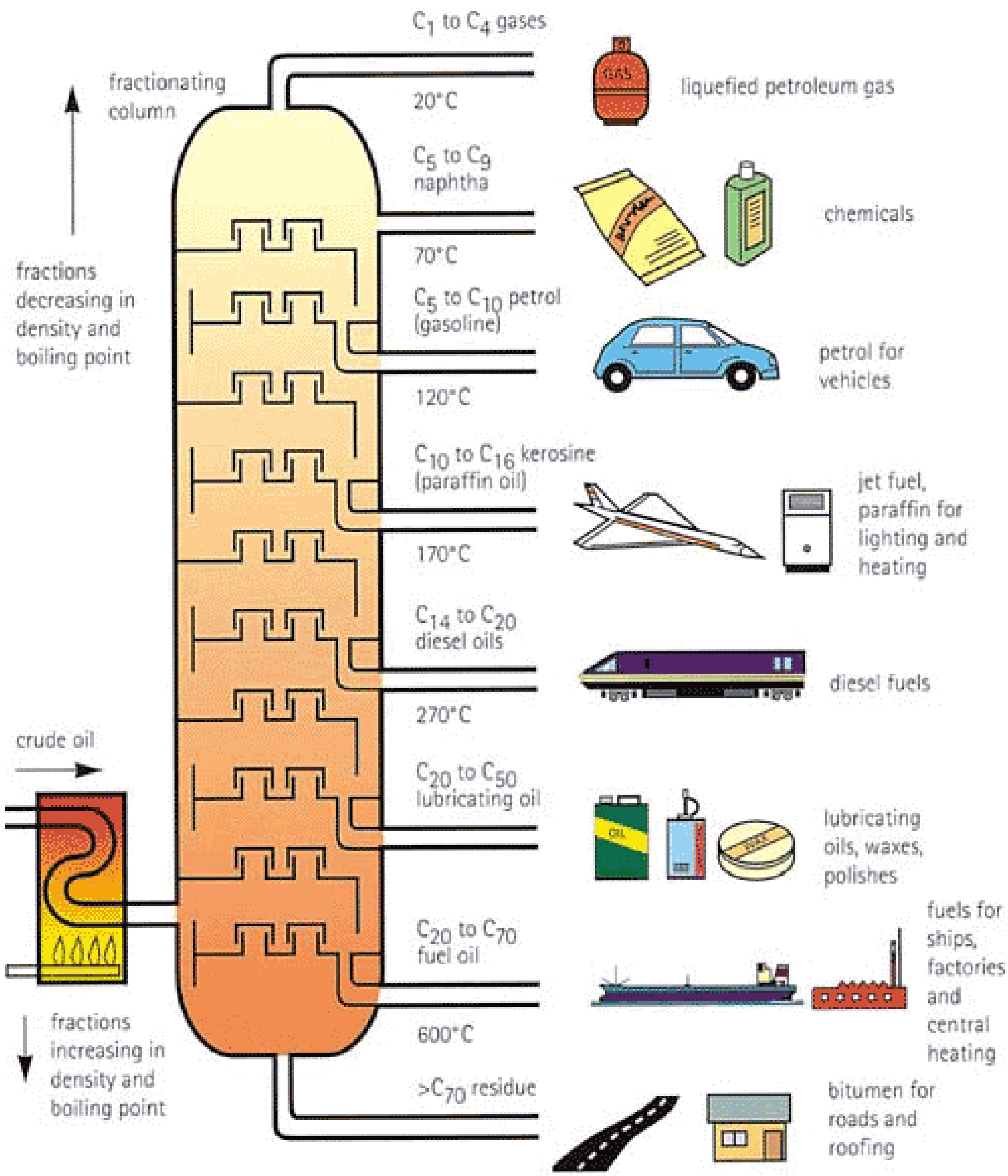

Figure 7. Fractional Distillation (Diagram by The Institute of Petroleum, UK)

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.

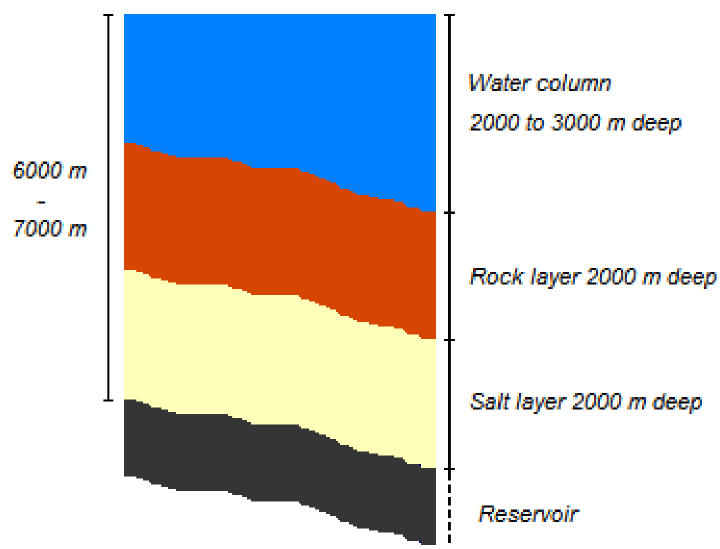

Figure 8 Tupi Layers (The Oil Drum)

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

Part 2 – Oil as a Liquid Fuel and Expected Peak Impacts

1. Why is petroleum so highly valued?

The main reason that petroleum is highly valued is *for its energy content*. If petroleum is burned, it can do *work* that makes our lives easier. For example it can be used to power an automobile or an airplane. We eat food to give us energy that allows us to do work of various kinds. In many ways, petroleum is the equivalent of food for many types of mechanical objects. For example, petroleum allows us to drive a car, and to do the work of transporting our luggage and ourselves. If we didn't have petroleum, we would have to do the work ourselves – walk and carry our own luggage.

Another reason petroleum is valued is for all the things that can be created from the petroleum itself, without burning it. Final products include fabrics, plastics, drugs, herbicides, insecticides, and much more. At some point, we may decide oil is too valuable to burn. These products are very valuable, and it would be difficult to find replacements.

2. What is the relationship between energy use and standard of living?

There is a close tie between energy use and standard of living. Energy use gives us mechanical slaves that can do much work that we could do ourselves, but would take much longer. For example, mechanical equipment is used to plant and harvest crops, and to wash and package the food. Trucks are used to transport food to market. We could do many of these steps ourselves, by digging in the ground, picking the crops ourselves, and walking to market with the produce, but it would take much more of our own physical work.

Many economists dismiss the close tie between energy and standard of living. They say that energy costs are only a small portion of total costs, so energy is not very important. This reasoning is not correct. If there is a shortage of petroleum, it is in some ways analogous to a shortage of food. The real problem is not that we have to pay more; it is that we have to get along with less. If our diet were reduced from 2,000 calories a day to 1,900, it would make a difference to our lives. If the economy suddenly experiences a shortfall in petroleum products, fewer goods can be transported to market, and someone will have to do without a product or service that they would otherwise have had.

Robert Ayers and Benjamin Warr showed the close relationship between energy use and standard of living, disproving the standard belief of economists. In particular, they showed that there is a very strong tie between energy use, including the more efficient use of energy, and economic growth.
http://www.iea.org/Textbase/work/2004/eewp/Ayres-paper1.pdf

3. Why is petroleum more highly valued than other forms of energy?

There are many reasons:

a. Its abundance. Petroleum is the largest energy source for the United States, comprising 40% of our energy use. Coal and natural gas are each a little over half as big (23%). The new alternatives are tiny in comparison.

b. The fact that it is a liquid. Liquids are easy to transport and store. Imagine filling your fuel tank with coal!

c. Its high level of concentration. Those of us who have done cooking or counted calories know that oils have a lot more calories for the same volume than other foods. It is the same way with fuel. Gasoline has 115,000 Btu per gallon, or in terms we are more familiar with, 29,000 calories (of the type you eat in food – actually *kilocalories*) per gallon. Ethanol, which is equivalent to alcohol in alcoholic beverages, has only two-thirds as many calories (that is, energy) per gallon.

d. Its low price. The reason oil has historically been inexpensive is that it takes a relatively small amount of resources to extract oil. In the early days of production, it took roughly the energy of one barrel of oil, plus a few other inputs (human labor and iron ore) to extract 100 barrels of oil. Even recently, it has taken as little as the equivalent as 15 barrels of oil (plus human labor and a few other inputs) to produce 100 barrels of oil.

e. Very favorable energy balance. This is just the flip side of Item d, oil's low price. If it only takes one barrel of oil to produce 100 barrels of oil, a small investment can create a huge amount of energy. Even if it takes 15 barrels of oil to produce 100 barrels of oil, there is still a very favorable return. This extra energy benefits society in many ways. It gives us the extra energy we need to build roads and malls and better our lifestyle.

f. Built Infrastructure. Nearly all of the cars, trucks, airplanes, and farm equipment currently in use were designed to burn oil products. While theoretically they could be replaced, this is a huge sunk cost. It would require technical innovation, a large investment of fuel and other resources, plus a timeframe of thirty or more years to convert to a new base.

g. Non-intermittent supply. At least historically, the supply of oil has been there, so that we could depend on it. We didn't have to worry whether the wind was blowing, or a cloud was covering the sun.

4. **What are the petroleum's disadvantages?**

a. Not renewable. The supply is depleting. Decline may begin within a few years.

b. Not environmentally friendly. There are problems in three different areas:

Global warming gases. Oil is only 80% as bad as coal in terms of the amount of carbon dioxide formed per unit of energy, but 40% worse than natural gas. Because we use so much oil, total carbon dioxide is more from oil than from coal or natural gas.

Air pollution. Smog, airborne particulate matter, and some carcinogens are the indirect result of the burning of petroleum.

Local environmental damage. Spills. Pollution problems particularly for Canadian oil sands, where much water is required for extraction. http://www.commondreams.org/archive/2008/01/10/6304/

5. **How are oil and gasoline priced?**

Oil is priced based on supply and demand. If there is not sufficient oil for everyone who wants it, the price increases until some would-be buyers are priced out of the market or an alternative appears. Additionally, the price must be high enough to cover the cost of extraction of even recently discovered oil. If the price drops too low, or it the likelihood of profit is too low because of punitive taxation, oil companies will discontinue their attempts to produce more oil.

Prices tend to "shoot up" if there is a shortage oil or gasoline, because people are unwilling to go without, and substitutes are very limited. A rough estimate is that 1% shortfall in supply will result in a 17% increase in gasoline prices, and a 2% shortfall will result in a 33% increase in prices. (This is based on a shot-term price elasticity of demand of .06. See http://www.cbo.gov/ftpdocs/88xx/doc8893/01-14-GasolinePrices.pdf)

The price of gasoline is fairly closely related to the price of oil, plus the additional costs involved. One US Energy Information Administration government website shows this relationship:

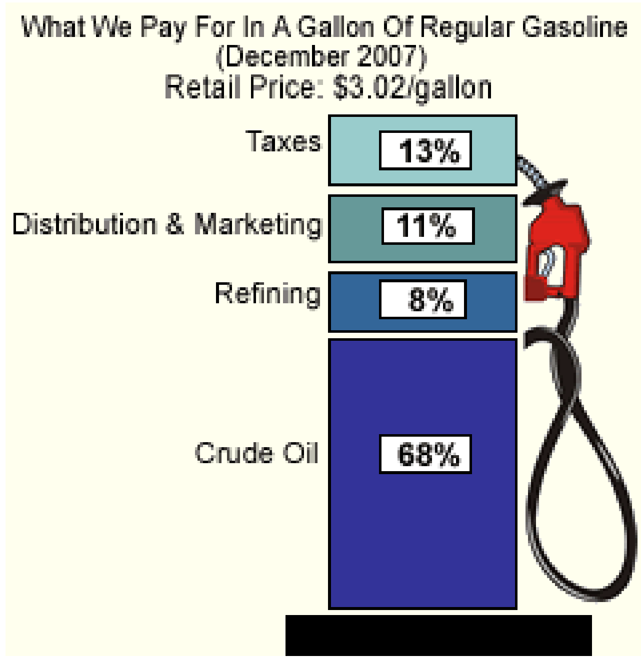

Figure 6

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6. **How does corn-based ethanol compare to petroleum as a solution to our energy needs?**

Corn-based ethanol is a **very poor substitute** for petroleum. Actually, it is only, at best, a substitute for gasoline. Other petroleum products, such as diesel, lubricating oil, and asphalt require different types of substitutes.

The major problems with ethanol from corn are

a. Not scalable. A very large amount of land is required to produce a small amount of fuel. In 2007, over 20% of America's corn was devoted to ethanol, but this provided only the energy equivalent of 3% of our gasoline use (or 1.1% of our petroleum use). More than doubling this will be very difficult.

b. Causes food prices increases. Competition of corn for land raises food prices. We end up paying a second time for corn ethanol through higher food prices.

c. Causes fertilizer shortages. Corn uses a lot of fertilizer. Fertilizer is made from natural gas and mostly imported. Fertilizer prices are now double what they were a year ago. The situation may get worse in future years and lead to shortages of fertilizer for food crops.

d. Environmental impacts as bad as gasoline (or worse). There are problems in several areas. Ethanol produces more *global warming gasses* than ethanol, according to recent studies. Older studies say that ethanol might produce slightly less global warming gasses than gasoline, but even this is not much help.
http://www.rsc.org/chemistryworld/News/2007/September/21090701.asp
http://www.independent.co.uk/environment/climate-change/biofuels-make-climate-change-worse-scientific-study-concludes-779811.html

A Stanford study says that *air pollution* is also worse than with gasoline. Ozone, which causes smog, is likely to be worse with ethanol than gasoline. Ethanol decreases some carcinogens, but increases others. http://news-service.stanford.edu/news/2007/april18/ethanol-041807.html

The planting of corn also has negative environmental impacts, including aquifer depletion, topsoil erosion, and fertilizer runoff. These are especially problems if expansion of corn acreage means that corn is planted in hilly or arid locations where it would not usually be planted.

e. Energy intensive. Nearly as much energy must be used to make ethanol as is gotten back in return, so we are mostly recycling scarce fuels. Ethanol is not like petroleum, which has a positive energy balance to benefit our standard of living. If corn ethanol replaces petroleum, the impact on standard of living is likely to be negative. (See Item 3e)

f. Poor fit with petroleum system. At most 10% ethanol can be used in gasoline, without causing corrosion, unless autos are especially modified. Ethanol cannot be transported by pipeline, so costly and complex special arrangements must be made.

g. Less energy per gallon than oil. Ethanol has only about two-thirds the energy (calories) of gasoline. Summer gasoline price run-up. Adding ethanol to gasoline makes gasoline evaporate at lower temperatures. To counter this, the fraction of gasoline that evaporates most easily (molecules with 4 or 5 carbon atoms, rather than 6 to 10 carbon molecules) must be removed from the gasoline mixture. Removing this portion of the gasoline reduces supply in the summer, and increases prices.

h. Drought sensitive. Supply depends on good weather in growing regions.
http://collinpeterson.house.gov/PDF/ethanol.pdf

i. Expensive. Requires subsidies to be cost-competitive. Subsidies raise tax levels. Even with subsidies, ethanol's cost is often higher than that of gasoline.

7. **Why is ethanol so popular?**

The primary reason ethanol is popular is because it makes legislators look like they are doing something about reducing imports of gasoline. People do not realize that the benefit is tiny at best, and offset by many other problems.

The use of corn ethanol was expanded before people had a chance to learn its real-world problems. Many continue to support it because they believe it will be a "bridge" to better second generation fuels, such as cellulosic ethanol.

Corn ethanol also provides income to investors in biofuel refineries and jobs in rural areas. The offsetting costs of subsidies and higher food prices are far enough removed that people are not aware of them.

Car manufacturers like ethanol also because of a loophole that allows them to get credit for cars with higher mileage than they really have. Because of this, car manufacturers can build more gas-guzzlers than they would otherwise and still meet mileage requirements.

Ethanol's use was expanded in 2005 and 2006 because clean air laws required the use of an additive called an "oxygenate". The previous oxygenate, MTBE, had been found to be unsatisfactory. A number of people have raised the question as to whether oxygenates are really needed any more. Engines manufactured since 1994 have substantially reduced tailpipe emissions, so that an oxygenate may not to be needed.
http://www.foxnews.com/story/0,2933,104259,00.html

8. **What other possibilities are there as a replacement for oil as a liquid fuel?**

Some other biofuel possibilities include the following:

a. Biodiesel from rapeseed. This is equivalent to what we in the US would call "canola oil". Use of farmland for nonfood items is likely to drive up food costs. Heavy user of fertilizer. Has somewhat better energy balance than corn-ethanol. Mostly produced in Europe.

b. Cellulosic ethanol. Can be made experimentally, but isn't yet commercially viable. Would be made from non-food bio-products such as wood, switchgrass, and corn stalks. Likely to be more energy efficient than corn ethanol, and cause less pressure on land use. Most methods are not economic at this time, but one approach claims better success.

   Larger potential volume than corn ethanol, but still would not replace more than 20% of petroleum use. Cellulosic ethanol will compete with electricity generation for the use of the same biomass. Some analyses indicate that cellulosic ethanol is not the best use for biomass. http://www.coskataenergy.com/process.html
   http://www.technologyreview.com/Energy/19842/ (Requires free registration)

c. Biodiesel from left-over oil. Can be made from leftover vegetable oil or from animal fat. Energy efficient, but total volume likely to be small.

d. Ethanol from sugar cane. Not cost efficient in US; Brazil makes low-cost product with much hand labor. Brazilian product is very energy efficient, but has human rights issues for laborers. Relatively small amount available for export. Would be another source of imported fuel.

e. Biodiesel from palm oil. Also made from other tree fruits. Often grown on forest land that has been cleared for this purpose, so has very adverse environmental impacts. Often competes with food use for oil. Would be another source of imported fuel.

f. Biodiesel from algae. Under investigation, but no one has found a way to do this in a commercially viable way yet. Requires little land use.

Besides biofuel approaches, there are also fossil fuel approaches:

a. Coal to liquid. Process to convert coal to a petroleum substitute was developed many years ago. Method is quite energy intensive. Has much worse carbon dioxide impact than petroleum. Probably less expensive than most biofuels. Several plants now being planned.

b. Natural gas to liquid. It is theoretically possible to convert natural gas to a liquid fuel, but the process is very expensive and not much used. Cars can also be adapted to run on compressed natural gas. Natural gas solutions may work in some parts of the world, but supply is not adequate in North America, and imports are very limited.

9. How about solutions such as wind turbines, solar voltaic panels, battery operated cars, and hydrogen powered cars?

None of these are liquid fuels. They don't directly solve our need for something to keep are current fleet of vehicles and other devices using petroleum products operating. It is possible that over the very long term they can be part of the solution, but they cannot keep our current fleet on the road and our airplanes in the air.

Wind turbines and solar voltaic panels really relate to our need for better sources of *electricity*. Electrical supply is likely also to be a problem in the future, but we have not attempted to address the electrical supply issue in this document.

Battery-powered cars are a worthwhile idea, but there are some obstacles that need to be overcome. http://www.evworld.com/

a. Common materials. Batteries that require rare minerals will not scale up to the volume needed for millions of cars. If we do not require too long a range, more options may be available. It is possible that ultra-capacitors will be part of the solution. http://www.nrel.gov/vehiclesandfuels/energystorage/ultracapacitors.html

b. Long time frame. Even if technology were fully perfected today, it would still take 15 to 20 years to get factories built and the current fleet of cars replaced. Peak oil may delay this further.

c. Electricity issues. We assume that adequate excess electricity will be available to charge the cars 20 or 30 years from now, but that may not be the case. It would be ideal if a way could be found to use solar power to charge the cars. http://www.theoildrum.com/node/3316 http://jalopnik.com/335956/austrailian-solar-bus-is-mighty-green-mighty-ugly

Hydrogen powered cars seem to be much farther in the future than battery powered cars. Hydrogen is not a fuel source; it is more like a battery. Somehow, we would have to produce the huge amount of energy that would be necessary to separate the hydrogen from the compounds in which it is found. Besides having to build new cars, we would have to build a new pipeline network, a new set of filling stations, and the infrastructure to make this work. The whole process would be extremely expensive and likely require over 30 years.

10. Will biofuels and the other alternatives be sufficient to compensate for the petroleum shortage?

No, not based on what we know today. If nothing else, there will be a time-gap before the transition to alternatives can be made. There are a lot of alternatives under consideration, but none, by itself, seems likely to solve our need for a liquid fuel substitute in the timeframe in which it is needed.

Conservation will need to be an important part of the solution to our liquid fuel shortage. Better use of what we have, like carpooling, is one possibility. Another is electrified rail transportation. Streetcars were used years ago in many places, and could be built again, without developing new technology. Existing rail systems could be enhanced to permit more freight to be transported by rail. In some cases, sails can be added to boats to reduce fuel needs. If need be, personal vehicles can be made much smaller than we drive today, perhaps akin to golf carts or electric bicycles. http://en.wikipedia.org/wiki/Tram

11. Besides higher oil prices, what types of impacts can we expect from peak oil?

Increasing food prices. One reason is that oil is used in planting, harvesting, packaging, and transporting food. Another reason is that growing corn for ethanol will compete with other uses of land, and drive food prices up. Also, if there are fertilizer shortages, yields may be lower.

More defaults on loans can be expected, as food and petroleum prices increase. Families will have less money left over to pay mortgages and credit card debt.

Pre-peak impacts. Increases in oil and food prices are likely to begin even before peak hits, and seem to be happening already. All that is needed is a gap between oil supply and demand (see Part 1, Figure 5), not an actual decline. Ethanol-induced land shortages also contribute to the food price increases. Higher oil and food prices may be contributing to current US financial problems.

Reduced discretionary spending. People will spend less on things like restaurant food and out-of-town vacations.

Reduced economic growth or actual decline appears likely.

12. **What are the implications of the likely shortfall in oil production on career opportunities?**

Careers in fields that are very petroleum-dependent may not be good choices. For example, there will likely be fewer airline pilots in 2040 than there are today.

If there is less petroleum, people are likely to be interested in having stores nearby that they can walk to. Thus, there may be an opportunity for starting a small store in your own neighborhood, or developing a neighborhood clinic.

Recycled products, especially those using petroleum inputs, are also likely to become more important. There may be careers in buying and selling these products.

There is clearly a need for more scientist and engineers in many energy-related fields. We need to find better ways to extract the oil that is available, and we need to develop more fuel-efficient vehicles. We need to find more and better petroleum alternatives, and to find ways to scale up these alternatives to the quantities needed as replacements for petroleum products.

13. Are there any actions we should take?

These are several ideas:

a. When buying a car, purchase the smallest, most fuel-efficient model you can find.

b. Consider sharing rides with someone else who is commuting in the same general direction, or take public transportation.

c. Make greater use of work-at-home programs and distance learning programs. Or live in a dorm.

d. Move closer to work or school.

e. When distances are short, walk or ride a bicycle, rather than drive.

f. Use recycling, especially for petroleum-based products like plastic. Other recycling is also helpful from a general energy-saving perspective, but not necessarily from a petroleum-saving perspective.

g. Avoid fruits and vegetables that have been flown to the United States from around the world. These tend to be quite expensive.

h. Reduce trips taken to distant locations, whether by air or automobile.

One idea, which looks at the shortfall in a different way, is to reduce meat consumption by eating smaller portions of meat or by substituting beans for meat in some meals. We are currently using biofuels as a substitute for petroleum, and this puts huge pressure on the food supply. By eating less meat, a person can help reduce pressure on the food supply.

Animals eat several times as many calories in grain products as they produce in meat calories. By eating less meat, fewer acres of grains need to be planted to meet our food needs. We also reduce production of global warming gasses, because animals, particularly cows, are big contributors to these gasses.

Another idea is to get involved with campus groups or political groups to try to solve some of the problems in the years ahead. It is likely to be a difficult adjustment, but working together we are likely to be able to accomplish more than we can as individuals.

Part 2 – Discussion Questions

1. US oil consumption is about 25 barrels per year for each person in the United States. There are 42 gallons in a barrel, and each gallon contains on averages 34,800 (kilo) calories (gasoline has less, asphalt has more). How many (kilo) calories does this equate to? (Answer: 36,540,000)

   If we had food equivalent to this many calories, how many people could be fed with this many calories, assuming people, on average, eat 2,000 (kilo) calories a day? (Answer: 50)

   What does this relationship say about the likelihood that we will be able to grow enough crops to turn into biofuels to meet our current petroleum usage?

2. If oil rationing were imposed, and the amount of gasoline you could purchase were limited to half of what you are currently using today, how would that change your driving / commuting?

3. If you were the president of the United States, and needed to impose rationing, in what order would you rank the following in priority.

    a. Military
    b. Farmers
    c. Chemical feedstock use
    d. Transportation of food
    e. Mining of coal and uranium
    f. Transportation of non-food items
    g. Railroad and bus fuel
    h. Air travel
    i. Emergency services (ambulance, police)
    j. People with jobs
    k. People without jobs (retired, students)

4. There have been numerous governmental studies about peak oil. It is clear from public comments that Alan Greenspan is a believer in peak oil, as is former President Clinton. President Bush and Dick Cheney worked in the oil industry before their election.

    Do you think that President George W. Bush is aware of peak oil? If so, how do you think it has affected Bush's presidency? How long do you think that they have been aware of peak oil? Do you think it has had any impact on their policies? Why haven't they said anything about peak oil?
    http://search.doe.gov/search?output=xml_no_dtd&sort=date%3AD%3AL%3Ad1&ie=UTF-8&client=default_frontend&y=6&oe=UTF-8&proxystylesheet=default_frontend&x=14&q=Peak+Oil&x=0&y=0
    http://www.peakoil.net/Articles2005/Westervelt_EnergyTrends__TN.pdf
    http://www.straight.com/article/clinton-raises-alarm-about-oil-depletion-0?#
    http://online.wsj.com/article/SB119763743685729349.html (Greenspan)
    http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf

5. One of the reasons that there has been little said about peak oil is that economists keep saying that peak should not be no problem; in a free market economy, substitutes will be found.

    Name three substitutes for food.

How does your answer to the substitutes for food question suggest that economic theory may be incorrect in with respect to replacements for liquid fuels?

6. If biofuels, at least at this point, seem to have as many environmental problems as oil, would it make sense to concentrate our efforts on enhanced oil recovery? How about coal to liquid?

For further reading – Relates to both Part 1 and Part 2:

A number of links are given in the reading material. In addition, some websites that may be of interest are

www.TheOilDrum.com - Discussion about energy and our future, including peak oil. Many articles written for the site, plus news items related to energy, and discussion about the various items. I write as "Gail the Actuary" for this site. A list of my articles can be found at http://www.theoildrum.com/user/Gail+the+Actuary/stories

www.EnergyBulletin.net - Peak oil related news items. No discussion.

Association for the Study of Peak Oil and Gas - USA http://www.aspo-usa.com/ Has a good weekly newsletter, and an annual conference.

Educational website about oil and gas, how it is formed, and production ins and outs http://www.ukooa.co.uk/education/storyofoil/index.cfm

"Peaking of World Oil Production: Impacts, Mitigation, and Risk Management" by Robert Hirsch, Roger Bezdek, and Robert Wendling. Analysis of peak oil and mitigation options prepared for the US Department of Energy in early 2005. http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf

Rear Admiral Hyman Rickover's 1957 speech talking about the expected future decline in fossil fuel resources and the need to tell the younger generation. http://www.theoildrum.com/node/2724

Myths of Biofuels - Talk by David Fridley - Free video for download - http://www.sfbayoil.org/sfoa/myths/index.html

Peak Oil and the Fate of Humanity – Series of downloadable presentations – Canadian http://www.peakoilandhumanity.com/chapter_choice.htm