Chapter 6

Oil

Chapter Objectives:

1. Discuss the historical and current issues in oil production and use.
2. Describe how oil is created in the ground and the structures in which oil can be found.
3. Describe how seismic data is acquired and processed.
4. Discuss the use of direct hydrocarbon indicators to determine viability of oil reserves.
5. Identify and describe 3 oil and gas production methods.
6. Discuss issues with the production of oil shale and tar sand deposits.
7. Discuss the environmental impact of oil exploration and production.
8. Discuss factors involved in resource prediction.

History

We are a country that runs on oil. From the gasoline in our cars to the plastic in our computers to the detergents that we put in our dishwashers, we rely on oil for our modern way of life. It cannot be understated just how strong of a role it plays in our economy and politics. It is used in tractors that plow and harvest food. It is used to power manufacturing plants and as feedstock in commercial goods. It powers all the trains and trucks that bring goods to market. It runs our cars, heats and cools our homes, and powers our electrical devices. Because of its ubiquitous nature in the marketplace, any small increase in the price of oil will cause a widespread increase in the price of living. This dependence of our economy, coupled with the fact that we import over 50% of our usage, means that oil is a primary consideration in international politics.

This situation has not always been so, even though ancient cultures knew of the existence of crude oil. Many years ago, oil and tar that had seeped out of the ground were used to seal boats and light lamps. Its scarcity severely limited its use, though. This all changed in 1859 when Edwin Drake struck oil at a depth of 69 feet in a well that he drilled in Pennsylvania. His success spurred wells to be drilled in other locations around the world that were thought to hold oil, creating enough of a supply that new uses, such as home heating, could be realized. These new uses spurred further production, which led to even newer uses and inventions. With the refinement of the gasoline-powered internal combustion engine in the 1880's and its subsequent use in a car, the die was cast. Oil had become a hot commodity, and its impact on the economy and politics grew very large.

Fig. 1: Edwin Drake

As documented in the Pulitzer Prize winning book "The Prize" by Daniel Yergin, oil has been behind many historical events. The U.S.'s naval blockade of oil headed to Japan from Indonesia in 1941 led directly to their attack on Pearl Harbor and our entry into World War II. Hitler's belief in the power of oil and his quest to acquire large resources of it caused him to fight two very unsuccessful campaigns in Northern Africa and Russia, which led to Germany's defeat in WWII. America's support of Israel in the Six Days War in 1967 and the Yom Kippur War in 1973 led to an OPEC embargo of the U.S., causing a steep increase in inflation and a collapse of the American auto market. Our support of the Shah of Iran furthered our troubles with inflation when the Islamic Revolution overthrew the Shah and increased the embargo of the

U.S. Even recently, our involvement in two wars in Iraq is a direct result of our attempts to keep control of a large supply of Mid East oil in the hands of people friendly to our interests.[1]

Current Usage

Our involvement in the political affairs of other countries is a direct result of our inability to meet our own needs for oil since the 1960’s. While domestic production of crude oil has decreased since that time, peaking in 1970 at 9.6 million barrels per day (Mbbl/d), our demand for oil has increased such that we now supply less than half of all of the oil that we use. Figure 2 shows a graph of our usage and production since the early 1960’s. The huge increase in demand during the 1960’s (from about 10 Mbbl/d to about 17 Mbbl/d) was due mostly to an American society that was moving to the suburbs and driving many more miles in large cars that got horrible gas mileage. During the 1970’s, demand leveled off and then plummeted as gasoline prices shot up from about $.25 per gallon to over a dollar per gallon. Since a low spot in the early 1980’s, oil demand increased steadily as prices stabilized while inflation continued to increase. When one accounts for inflation, the price of oil in the 1990’s was at all-time historical lows. During this time, the average mileage of passenger cars in America dropped, as more and more people purchased large SUV’s and trucks. Combined with the facts that the number of miles driven and the number of passenger cars increased, consumption increased at a steady pace.

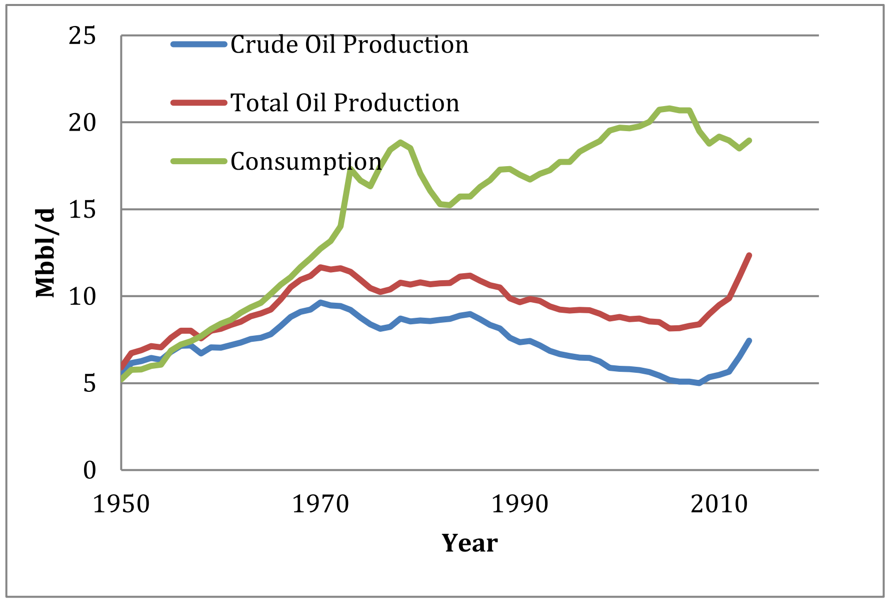


Fig. 2: Historical U.S. Oil Data (Data: DOE)[2]

In 2008, as we discussed in Chapter 1, this situation changed dramatically, mostly as a result of worldwide conditions. While we were increasing our usage of oil for driving, the rest of the world was doing the same thing. In China, an additional 1,000 cars each hour were being added to the cars on the road. When production worldwide could no longer keep up with this increasing demand, the price of oil began to skyrocket. Within a span of eight months, the price of oil went to over $140 per barrel. In the U.S., this led to pump prices of over $4 per gallon for gas. In light of this, the amount of oil consumed dropped worldwide, and after a short period of time, the price of oil plummeted back below $100 per barrel.

As Figure 2 shows, this jump caused some changes in the U.S., as our usage of oil has actually dropped since 2008. Currently, we use about 19.1 Mbbl/d in the U.S., which is 20.6% of the worldwide demand of 92.0 Mbbl/d. At the same time, we have begun to increase our production of oil, mostly from what were previously unconventional sources, both in terms of raw crude and natural gas liquids (discussed below). It is interesting to note that China's consumption has actually increased by 2.7 Mbbl/d during that same time period over which our consumption has dropped by 1.7 Mbbl/d. This situation can change rapidly, though, as recent overproduction by OPEC countries has driven prices down, which has resulted in an increase in our consumption. This overproduction is meant to halt U.S. production, which was causing competition problems for foreign producers.

Uses of Oil

When we think of crude oil, gasoline naturally pops right into our heads. For most people, the two are inseparable. There are good reasons for this connection in the U.S.: we use 45% of our crude oil to produce gasoline for use in our automobiles, and gasoline is a product that we deal with personally when we pump it into our cars. This demand is necessary for the ever-burgeoning number of cars on the roads and miles that they drive. There were over 246 million registered personal vehicles in the U.S. in 2013, which were driven, on average, almost 12,000 miles each year[4]. Of this number, 184 million consisted of passenger vehicles that got an average of 23.4 miles per gallon, which is up almost 8 miles per gallon over cars 30 years ago.

This figure is even more striking when you consider that the Bureau of Transportation Statistics redefined passenger vehicles and light-duty trucks/SUVs several years ago to passenger short wheel-base and passenger long wheel-base. Doing this pushed some light-duty trucks and SUVs down into the short wheel-base category, meaning that we went from 99 million light-duty trucks and SUVs in 2006 to 39 million long wheel-base passenger vehicles in 2007. Today, there are 40 million long wheel-base vehicles which get an average of 17.4 miles per gallon on the road, which is far better than the 12 miles per gallon they got almost 30 years ago. Even with the increase in prices, Americans are reticent to give up their large vehicles. In the last several years, a number of auto manufacturers have come out with hybrid versions of SUV's that get about 30-35 miles per gallon. While better than that of other large vehicles, it is still

behind that achievable by smaller vehicles, especially plug-in electric vehicles like the Chevy Volt that gets an equivalent of almost 100 miles per gallon when running on electricity.

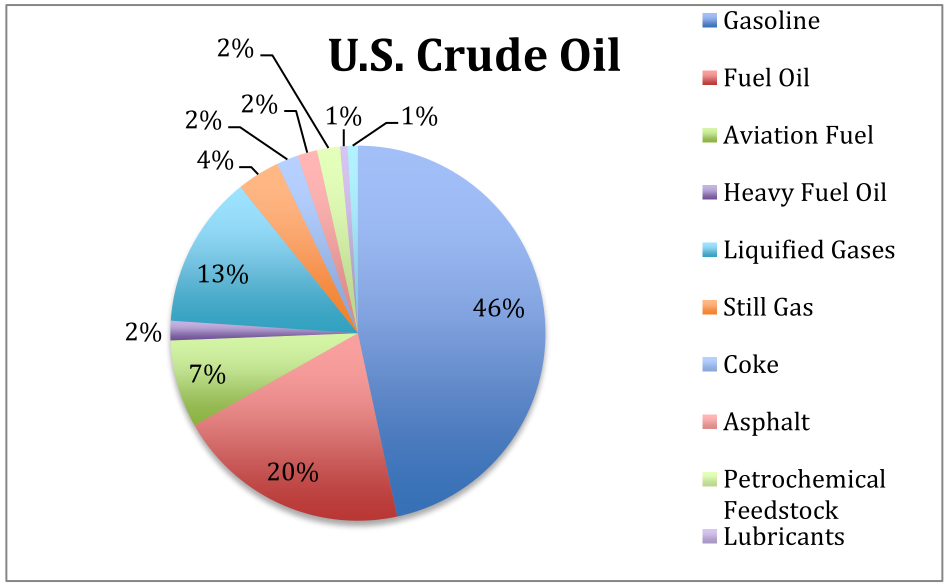


Fig. 3: breakdown of oil usage (DOE)[3]

Gasoline is not the only product that comes from crude oil, as Figure 3 shows. A little over one-fifth of the oil that we use goes toward making fuel oil that is used in industrial processes and to heat homes in the winter. Jet aircraft fly almost 6 billion miles in the U.S. each year, which accounts for almost 7% of the crude oil used. The remaining 27% of the crude oil goes to a number of uses such as asphalt for roads, coke for use in the metals industry, propane for use in cooking and heating, and waxes and lubricants for industrial processes. About 2% of the oil finds its way into petrochemical feedstocks, which are used to create plastics for many of the things that you find around you everyday. It is important that we keep these other uses in mind when we discuss the oil industry. Even if we find alternative methods for transportation and heating, our modern way of life still depends upon oil for many other uses.

As we discussed above, the U.S. is no longer able to supply its own needs for crude oil. This means that we must import oil from other countries, which leads to two misconceptions. The first of these is that the U.S. does not have that much oil. We are, in fact, the second largest producer of oil in the world. The other misconception has to do with the places from which our imported oil comes. When talking about oil imports, many people confuse OPEC, the Persian Gulf and Saudi Arabia. Figure 4 shows the breakdown of U.S. oil imports by country. OPEC currently contributes a little less than half of all of the imported oil to the U.S. However, a large portion of this is coming from countries that are not in the Middle East. Countries like Venezuela and Nigeria are also member of OPEC, and all of them, they supply a large amount of our imported oil. The OPEC members from the Persian Gulf supply only about 20% (about 2 million barrels of oil per day) of the total imports. Of this, a little over half, or about 1.2 million barrels per day, comes from Saudi Arabia. By comparison,

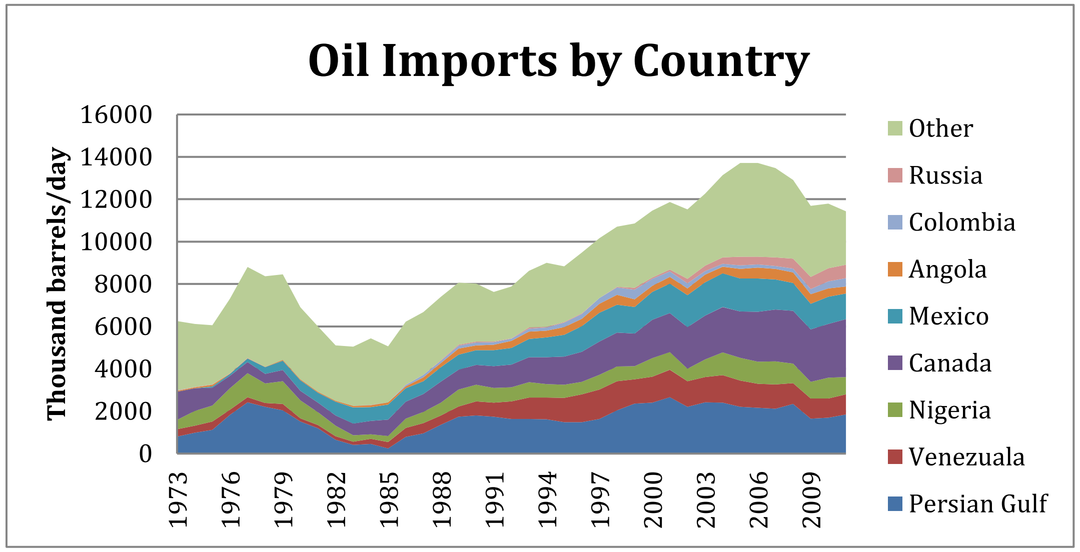
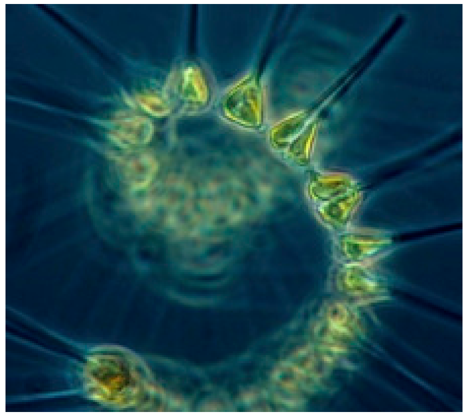


Fig. 4: U.S. oil imports by source (DOE)

both Mexico and Canada supply us with about .9 and 3.1 million barrels per day, respectively. However, we must remember that oil truly is a global market. If any one major exporting country decides to slow down the spigots to the countries to which it normally supplies oil, it will cause those countries to buy from other sources, which will increase the price of oil worldwide. Therefore, even countries from which we get very little oil (like Russia) can cause the price we pay to go up by merely reducing their output.

Oil Creation

In order to understand oil, we need to know a little bit about how it is created. Years ago, the popular image was that oil came from dinosaurs. In fact, the logo for one of the major oil companies in the Western U.S. is a brontosaurus (Sinclair Oil). We now know that this is not possible, as there is far more oil in the world than what could have come from large dinosaurs. The most likely scenario is that oil is the converted remains of countless numbers of microscopic phytoplankton and zooplankton that live in the ocean. These plants and animals have thrived in the oceans for billions of years feeding off of sunlight and each other. While some parts of their bodies are made of inorganic material (shells of calcium carbonate), they are comprised, like most living things, of organic materials containing hydrogen, oxygen, and carbon.



When these die, their remains fall to the bottom of the ocean, where some of them are consumed by bacteria, and some of them are covered with sediment. As time goes on, they become buried deeper in the ground as more and more sediment is piled onto the ocean bottom. In this anoxic environment, the decay of the organic material in the organisms is slowed tremendously or even stopped. Eventually, the temperature and pressure as the remains are buried deeper become so great that they are slowly converted into kerogen, which is a liquid-like hydrocarbon that is a precursor to oil and gas. At this phase, the remains become more mobile, as they can move between pores and cracks in the sediments/rock. With the addition of further pressure, the kerogen is converted into either crude oil or natural gas. The best estimates are that this occurs between 4 to 6 miles below the bottom of the ocean, and the rocks that it occurs in is known as **source rock**.

This is only half of the story since we are concerned with finding oil in quantities that are large enough to be produced economically. These new hydrocarbons are under tremendous pressure in the source rock. The oil, now being in liquid form, can migrate from its current location if there are openings in the rock above it through which it can move. If the sediment that was deposited after the plankton was round like sand, this will not be much of a problem, as there is a lot of connected pore space between sand grains. However, if finer, siltier deposits lie above the source rock, the oil will have a tough time migrating due to the small porosity and permeability of such sediments. The oil might still be able to migrate if there are faults in the sediments, like those caused by earthquakes, settling, and salt plumes that push their way up through the sediments.

If the oil can find a path through rock and sediment that leads all the way to the surface, it will seep or leak out of the ground. This is how ancient cultures found it. Oil companies also look for this type of oil seepage to determine possible new sites for exploration. They use low angle satellite photographs of the ocean to look for unaccounted oil slicks.

Fig. 5: anticlinal formation

For oil production to be profitable, though, the oil needs to be trapped in the ground. This means that the migrating oil has to encounter a rock layer(s) with no faults that is impermeable to flow through the rock matrix. In order for the oil to accumulate in quantities large enough to be produced profitably, the rock layers must also form a large trap. There are many types of traps, such as salt domes and fault-block traps. The easiest of these to understand is an anticlinal formation in which the rock layer forms a hill-like structure that has a caprock of shale or siltstone. Once the oil has flowed upward through the permeable layer to the top of the anticline, it is trapped by the siltstone and accumulates in the porous layer.

Exploration

The key to running a successful oil company is finding these large reservoirs of oil. Unfortunately, that is not a very easy task. Besides oil seeps, there are very few clues that a region has oil underneath it. Features, such as caprocks that are buried miles below the surface, do not really affect the surface features in any way that would give one a clue as to their existence below. Even if the existence of a reservoir features were found, one would need some way of determining that oil was actually trapped in the reservoir. Thus, we need to have ways of probing the interior of Earth to find both oil and rock features in which profitable supplies of it could be found.

Fig. 6: gravimeter

The first phase of oil exploration is determining whether a region has the type of rocks and features that would result in traps. Some of this can be done by geologists studying the surface features and rock types to determine what type of rocks might exist below. They are aided in this endeavor by some high tech equipment that gives very broad information about what might be below. Satellite photographs allow them to determine the local topography very accurately. Gravimetric readings made by extremely precise gravity meters give some indication of the existence of gravity anomalies in the ground that might originate from salt domes or igneous intrusions. They are also helped out with magnetic readings that can find the existence of magnetic anomalies that might be present do to the presence or absence of iron bearing sediments. In fact, it was geologists using magnetometers off the Yucatan Peninsula to find places to search for oil who found the magnetic anomalies that led to the discovery of the possible asteroid strike zone that caused the mass extinctions of dinosaurs at the end of the Jurassic Era.

All of this high tech equipment helps narrow down the range of prospective sites, but it does very little to determine the existence of hydrocarbons. For this, the only known tool that works with any degree of success is to actually drill a hole in the ground to see what is there. However, the cost of drilling a well can be on the order of several million dollars if it is done on land and several tens of millions of dollars if it is done offshore. Therefore, before drilling any holes in the ground, oil companies rely on a very old technology to give them some indication of the odds of finding oil: seismic surveying.

Fig. 7: high-pressure seismic air gun

The principle behind seismic surveying is the same as that used by bats for echolocation or doctors for ultrasound diagnostics. Sound waves are shot into the ground. Where the speed of sound or the density of the rock changes, echoes are generated that will travel back to the surface. Microphones laid out on the surface detect these echoes and transmit the information back to a recording device. Using some assumptions about the rock speeds, computers are able to add the echoes back together to give a picture of what the subsurface looks like.

The technology for this method is fairly old, although the computers are a recent addition in the last several decades. Originally, the sound waves were generated solely by dynamite blasts. Today, this is only used in very remote locations that do not allow for easy access by heavy equipment. On land, the most widely used sound source is a large truck with a special plate on the bottom that thumps and shakes the ground. These trucks require roads or paths that have been cleared of vegetation and are well connected to the ground in order to insure that the sound waves are transmitted. In offshore environments, the sound waves are generated by high-pressure air guns that open quickly, releasing huge air bubbles. The sound that is created is equivalent to many sticks of dynamite going off, which is transmitted through

Fig. 8: seismic surveying with recorder truck

the water, as well as going into the ground at the bottom of the water.

In both cases, the sound must be loud enough to travel between 4-12 miles through water, sediment, and rock and still be picked up by the microphones, as the sound must go all the way down and then back up. Along the way, these sound waves are reflecting off of all interfaces, which reduces the amount of energy that continues forward. It should be no surprise that the sound that does make it back to the surface is very low in intensity, requiring very specialized equipment to pick up the signals and interpret them. The microphones used are embedded in long cables that can stretch up to four miles in length. In a marine environment, these cables are towed behind boats on the end of gigantic reels. On terrestrial environments, these cables must be laid out by hand and the ends of the phones planted in the ground. This makes surveying in terrestrial environments much more expensive to get the same quality of data. In developing countries where laborers can be paid a pittance a day to move these phones, you are much more likely to find terrestrial surveying than in developed countries that require even minimum wage.

These data collection methods are often overlooked in tallying the environmental impact of using oil. Rural onshore data collection results in the cutting of paths and the downing of vegetation in order to allow access to thumper trucks and crews that lay out the miles long seismic cables that collect the data. Offshore methods rely on large blasts of sound every ten seconds are so that can do substantial damage to aquatic wildlife, especially mammals that rely on sound such as whales and dolphins. Swamps, which are somewhat midway between land and ocean, get possibly the greatest damage. In order to shoot seismic data in swampy environments, channels are dredged to allow boats to pass through the area while towing their microphone cables. These unnatural waterways open up the swamp to a host of problems, from invasive species to saltwater intrusion.

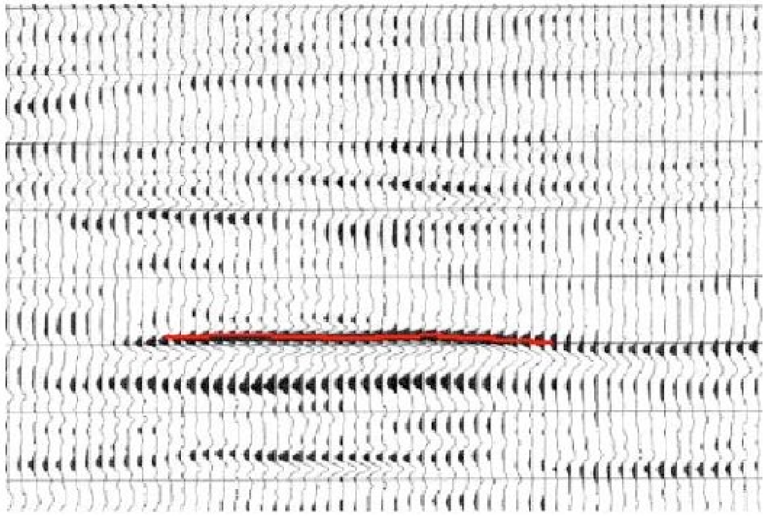


Fig. 9: seismic section from Gulf of Mexico

After the data is collected, it must be interpreted. Sophisticated and proprietary methods are used by oil companies to take the output from the microphones and try to figure out where each reflection originated. If the rock layers below the ground are not too complicated, these methods usually yield a fairly accurate picture of what the rock layers look like below the ground. If there is a lot of faulting, or if there are anomalous rock features such a salt domes nearby, these methods can lead to a mishmash of echoes that is very difficult to interpret. Figure 9 shows an example of this data from the deepwater area of the Gulf of Mexico where the layers are fairly well behaved. Each of the vertical lines in the picture corresponds to the theoretical signal that a microphone would receive for sound waves that went straight down into the earth and came right back up. To a trained geologist or geophysicist, this data can be interpreted to represent layers in the ground, as is shown with the red line. By looking at many different such seismic profiles in the region, layers can be mapped out over many square miles to see if the possibility of a trap formation exists.

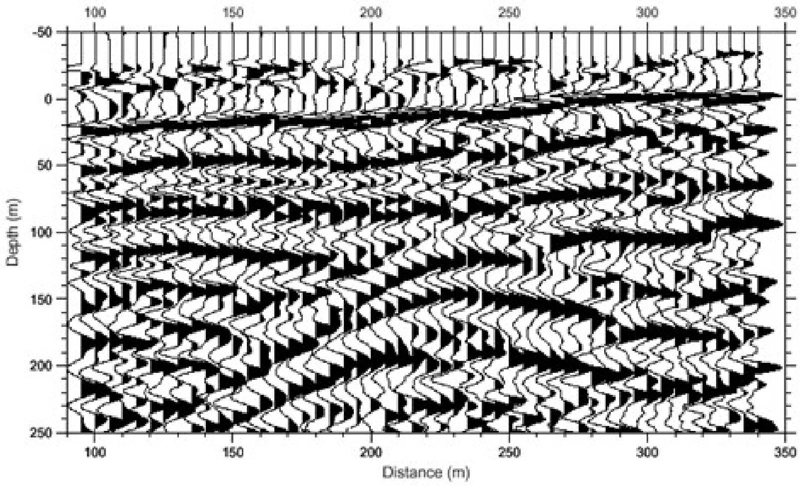


Fig. 10: USGS seismic reflection data

The interpretation of a possible trap, though, is just the beginning of the story. Before an oil company is going to spend a lot of money to determine if oil exists in the location, they will want to know what the odds of hitting it are. For this, oil companies have years and years of data where they have drilled wells to help them interpret the echoes that are in the seismic profile to determine the probabilities that oil is there. For example, some companies use a technique known as AvO (amplitude versus offset) to determine if oil or gas is in a reservoir. This technique compares the signatures of the echoes received at different angles (shots going straight down and coming straight up versus shots going at wide angles). If oil or gas is in the reservoir, there is normally a greater echo at large angles than there is at small angles. This is not always true, but there is a probability assigned to hydrocarbons being present based upon this technique, and this probability is factored into the equation of whether to drill

While some of the direct hydrocarbon indicator (DHI) techniques are fairly mature and well known, scientists and engineers are still working on new and refined methods that will provide more evidence of reservoirs. One exploration method that has received interest in recent years is called Controlled Source Electromagnetics (CSEM). This technique has been used for almost a century to study the deep lithosphere, but with changes in technology that have increased precision while reducing costs, it has started to be used as a DHI technique. Current attempts use a multitude of inexpensive EM sensors that are released from a boat to sink to the bottom of the ocean. With the ocean floor covered sufficiently with these sensors, a low frequency EM source is then towed behind a boat over the area. As these low frequency waves pass through the ground, they change the EM signature coming from Earth depending upon the resistivity of the different layers of rock, which can be effected by the presence or absence of hydrocarbons in those layers. These changes are detected by the sensors, which signal this information to the boat. Maps created from the data from the different detectors show where the hydrocarbons are or are not. In recent years, companies have begun to work on using this technique on land, but it is still early in the process of development.

Mineral Rights

It is after this interpretation of the data that a decision must be made as to whether to drill or not. The ability to drill in a location depends upon who owns the mineral rights to the land. These rights should not be confused with the actual ownership of the land. It is possible for a person to own the land and not own the rights to extract the mineral wealth below the land. The oil company will rarely, if ever, own the mineral rights to the land. If private individual or company owns them, then the oil firm will contract with them in order drill their test hole (they will have also contracted with the property owner to shoot the seismic data on their land). These contracts usually consist of a sum of money plus a percentage of the royalties from the oil that is pumped from the land.

If the mineral rights are owned by the government, then a much different procedure is followed. Each individual state has its own methods for handling drilling on their lands. Usually, these methods involve a bidding process with some entity of the state. Based upon who has the highest bid, the state will enter into negotiations with that company as to the length of the rights to the land and the royalties to be paid.

If the federal government owns the mineral rights, then the oil company will have to deal with the Department of Interior. For mineral rights that are on land, the company will deal with the Bureau of Land Management. If the land is offshore beyond the state territorial waters (these are normally within three miles of shore), then the company will deal with the Bureau of Ocean Energy Management (formerly the Minerals Management Service). Several times a year, the mineral rights to parcels of federal land are put on the auction block for people to bid upon. Using their interpretation of the data and what they think the rights are worth (and also using what they think other companies think the rights are worth), oil companies will submit sealed bids to the BOEM. At the appointed deadlines, the bids are opened, and the company that has the highest bids will receive the rights to drill on the land for a time that depends upon whether they do drill and set up an operating oil facility. Until they put an operating facility on the property, they must pay a yearly rent to keep the lease. If they do draw oil from the land, then they must pay the government a royalty on the value of the oil. This entire process brings in revenues to the federal government. In 2011, the Office of Natural Resources Revenue took in over $11 billion from oil and gas leases and royalties[5].

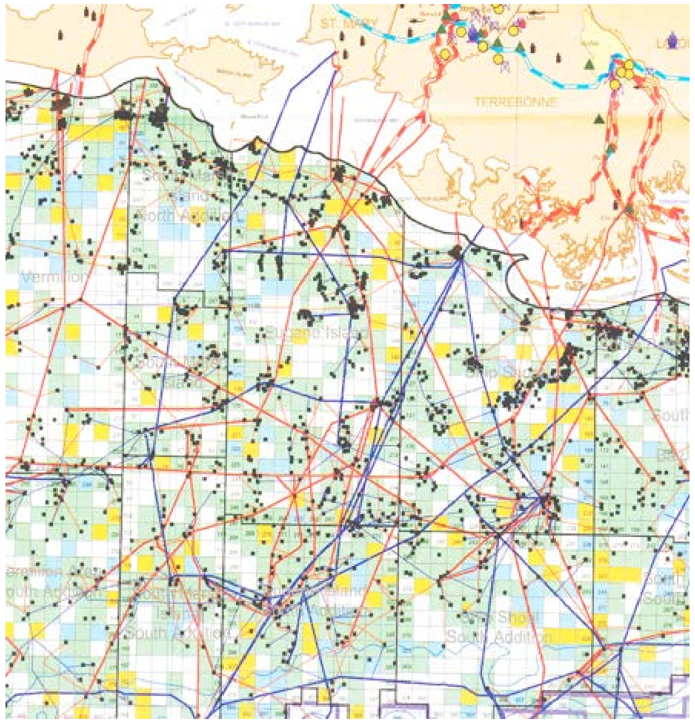


Fig. 11: lease sale map GOM

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Production

If the test drill finds oil, then the question becomes one of profitability. Depending upon the quality of the seismic data and data recorded in the test well, there might be a need to drill additional test holes to verify the size of the reservoir and the quality of the rock. These wells that are drilled are truly technological marvels. The reservoirs can be anywhere from about 3,000 feet to 5 miles deep. The well that is drilled down to these depths is only about a foot or two wide. It seems almost implausible that someone could drill a hole down to these depths through so much rock with any sort of accuracy pushing on a metal drill bit that is on the end of such a small diameter pipe. Yet, somehow they do, even though the process is expensive and time consuming.

The pipe comes in short sections that screw into one another to create a longer piece of pipe. As the drill goes down deeper, more pipes are added onto the end. The entire time, a very thick, viscous material called drilling mud is pumped through the pipe and comes up the outside of it. The purpose of this mud, along with casings that are placed outside of the pipe, is to prevent the well from blowing out. Remember, the fluids in the rock are under tremendous pressure that would force them up through any small crack in the rock above. The drilling mud has to seal these cracks and prevent the pressure from being able to blow the fluids up the pipe. This can create problems when you run into over-pressurized reservoirs, such as what occurred on the Deepwater Horizons in May of 2010. As the drill goes deeper, you normally pump mud that is more dense and viscous. You do not want to pump this mud in initially, as it would make it hard to drill through. But when you encounter a highly pressurized system, you need to have changed to higher density mud beforehand, or you will risk a blowout. In the case of the Deepwater Horizons well, the mud was too thin, the casings were not up to what they should have been, and the blowout preventer failed due to a dead battery. The result was over 4 million barrels of oil that leaked into the Gulf of Mexico over the next three months.

Once all testing has been done and the reservoir is deemed worthy of production, the oil company must decide how best to produce the area. Oil can be pulled from the rock with one of three different techniques. The cheapest of these is to merely put a pump in the well and suck the oil out of the rock. This primary method works very well if the rock is very porous, permeable and stable, and the oil is not very viscous. Even under these conditions, it does have some limitations. As oil is removed from the rock near where the well punctures it, more oil has to be pulled from the larger surrounding area to replace it. As time goes on, this becomes harder to do. Furthermore, as oil is removed from the rock, pressure is relieved within the reservoir. If the rock matrix is not able to hold up the surrounding rock without this oil pressure, then it will begin to settle, which will cut down on the rocks permeability and possibly shut off the flow of oil. This method, while cheapest, only allows for about 15-20% of the oil in the reservoir to be removed.

A secondary method for removing the oil is to help the pump out by forcing the oil toward the pump by pushing it from the surrounding area with water. This is achieved by drilling injection wells into the rock layer at positions that fall outside of the range where the oil exists. High-pressure water is pumped into these holes, which forces the water to the wells that are pumping the oil out. Besides helping to push the oil toward the hole(s), this method has the added advantage of maintaining high fluid pressures within the rock. This helps to insure that the rock matrix does not settle and reduce permeability. Using this technique, another 15-20% of the oil can be recovered from the reservoir.

Oil's surface tension makes it stick to the rock, much like it sticks to the fibers of your clothing if you spill it on yourself. Both of the methods mentioned above leave some of the oil in the reservoir because of this. A tertiary method for removing the oil is to use a surfactant to "scrub" the oil from the rock. To do this, the steam of carbon dioxide is sent through the injection wells instead of water to help loosen the oil from the rock as it pushes it to the production wells. While this method is a bit more expensive than secondary techniques, it can remove an additional 10% of the oil in the reservoir. This means that a combination of all three of these techniques can result in 40-50% of all of the oil in the reservoir being removed.

Refinement

Once the oil gets to the surface, it undergoes a small amount of processing to prepare it for its trip to the refinery. For instance, water that has come up with the oil is separated from it and injected back into the ground. After the oil has had enough contaminants removed and has achieved the proper viscosity, it is usually piped either directly to the refinery or to a large staging facility from whence it will be shipped to a refinery. The placement of the pipeline depends upon the locale of the well. If it is in an offshore environment, the pipeline will be run along the bottom of the ocean. Onshore locations in warm climates allow the pipeline to be buried in the ground away from view, although in some developing countries, it is run above the ground. Colder climates that have permafrost, such as the North Slope region of Alaska, require that the pipe be run above ground to keep the warm oil from heating the ground, resulting in slumping and breakage of the pipe. Of course, this comes with other challenges to the environment (Figure 13).

Fig. 12: Trans-Alaska pipeline (image: Luca Galuzzi)

Fig. 13: Alaskan pipeline shot by hunter (BBC)

At the refinery, the oil is separated into its various light and heavy components by distillation in a fractionating column. Oil is heated in the bottom of the column, which causes the different components such as methane, octane, and naptha to boil away. As one moves up the column, there are horizontal trays that are kept at a temperature slightly below that at which some components condenses. The highest temperature tray is at the bottom of the column, while the lowest is at the top. When that component vapor comes in contact with the tray that is set for it, it condenses and is drawn out of the column. Hot oil is fed continuously into the bottom of the column to insure a ready supply of vapor and keep the refinery operating constantly.

This process of distillation can only provide components of oil in the ratios that they are found in the crude oil. These ratios might not be what the market demands, though. During most of the year, the highest demand is for the lighter fractions that comprise gasoline, LPG, and natural gas. Yet, a third to a half of some crude oils are comprised of the heavier fractions such as fuel oil. To change the ratio of components, some refineries rely on “crackers” that break the heavier components down into lighter ones. This can be down with heat, as in a viscracker, or with the introduction of catalyzing agents, such as in a catcracker.

The products that are produced by a refinery are many and varied. They all have different markets, and different methods for getting to market. Some are shipped from the refinery in barrels, while others are pipelined directly to market.

Oil Shale

There are two other forms of petroleum available that either cannot be extracted by the methods above or that require some modification of them. The first of these is called oil shale, which, as the name implies, is a form of kerogen that is found in shale deposits. As you might remember from the chapter on rocks, shale is a sedimentary rock formed from thin, flat clay grains. This rock has some porosity (open space that can be filled with fluids), but almost no permeability (connected pore space that allows fluids to flow through), much like clay layers. Because of this, any hydrocarbon fluid in the pores of shale cannot flow out of the rock very well, if at all.

The hydrocarbon in oil shale is a form of kerogen that is similar to that found in source rock. A major difference is that the kerogen in oil shale is at a higher concentration (between 4% and 40%) than that of the source rock (about 1%). Because the oil shale was never exposed to the high temperatures and pressures that the source rock was, this kerogen was never converted into oil. However, because of the concentration of the kerogen in this rock, it is still valuable, as we can supply the heat necessary in a refinery to finish the processing to oil. When heated to the necessary temperatures (above 350 ^{o}C), oil shale will produce anywhere from 6-50 gallons of oil per ton of processed rock.

The biggest reserves of oil shale exist in the deposits in the Western U.S. In particular, the Green River shale deposits in Wyoming, Colorado, and Utah are estimated to hold about 130 billion barrels of oil. This is several times larger than the proven reserves of the U.S. However, the economic feasibility of producing these reserves depends greatly on the price of oil remaining above $100 per barrel.

Fig. 14: Green River in Wyoming

The biggest impediment to producing oil shale is that this kerogen will not flow out of the rock due to its lack of permeability. This means either that the shale must be mined, brought to the surface, and crushed into very small sediments or that it must be fractured in place to allow for the kerogen to flow. The first of these is expensive and incredibly damaging to the environment, as it leaves giant slag heaps of crushed rock. The latter was not possible until recently because vertical drill pipes could only fracture small zones around the pipe where it pierced the shale layer. However, with the development of horizontal drilling techniques, the area over which the shale can be fractured in situ has been greatly increased.

This fracturing is achieved by the introduction of high-pressure fluids that consist of water with proprietary additives that enhance the fracturing process. As we will discuss in the chapter on natural gas, this process has been almost exclusively been used for gas shale, which is easier to recover, as natural gas is able to flow through tiny fractures that kerogen liquid cannot; however, it is currently under development. The current estimates for recoverable oil in just the four largest fields in the U.S. are 24 billion barrels of oil.

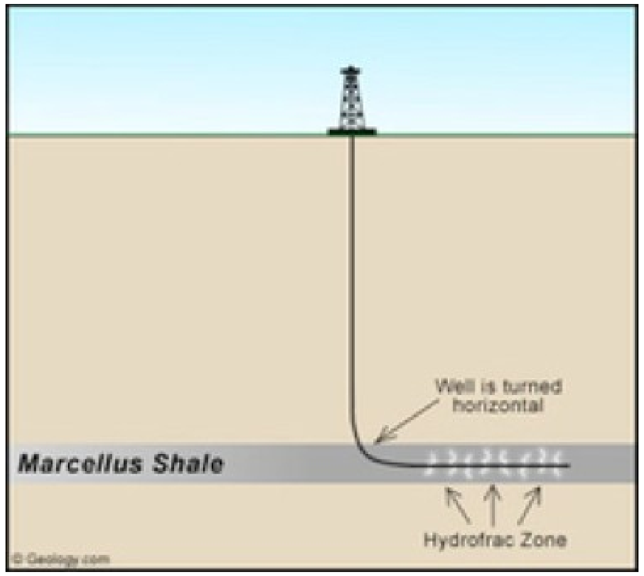

Fig. 15: diagram of horizontal drilling

Tar Sand

The other source of petroleum that is difficult to recover is tar sand. As the name implies, these are reservoirs of a very thick, tarry petroleum product called bitumen that is imbedded in a sand or rock with large porosity and permeability. The viscous nature of the bitumen does not permit the petroleum to flow from the reservoir, even though the sand or rock might have excellent permeability. This means that the material will have to be mined, crushed into sediment, and then scrubbed with steam unless some method can be created to economically heat the oil in situ to reduce its viscosity. However, once it has been extracted from the sediment, it does not need to be converted into oil. Instead, it can be processed similar to heavy crude oils. About 70% of the bitumen can be refined into heavier petroleum products through simple distillation. The remainder of the bitumen can either be burned as a heat source for other processes or it can be cracked into lighter grade oil products.

Fig. 16: the Athabasca River

Canada has very large deposits of tar sand that are located very near the surface. In the Athabasca River region of Alberta, the tar sand actually intersects the surface. Over one million barrels of oil per day come from that region into the U.S. and Western Canada, and plans are for expansion of these fields to increase production. It is estimated that there are over 100 billion barrels of tar sand in that region. However, the toll on the environment can be enormous, as the land is strip-mined and petroleum products are released into the local water system.

Environmental Impact

The environmental damage from oil ranges from the sublime to harsh. Most people are already aware of the harsh types of damage done by oil. The burning of oil products in our cars produce greenhouse gases and pollutants such as ground-level ozone and particulate matter. Gases are released from refineries that have been linked to cancer and other ailments. Large oil spills from tankers have devastated wildlife in some regions and left lingering effects that still harm wildlife years later. All of these effects have been documented numerous times by the popular media.

There are other effects of the oil business that are not as well documented or well known. Oil spills during the transport of oil account for an estimated 44 million gallons being dumped into the world’s water systems, with 29 million gallons of this coming in the form of oil tanker spills. This is the type of oil pollution that gets most of the press. What gets less press is that oil spilled during the process of producing the oil from wells adds an additional 11 million gallons to the total. Most of this pollution is in the form of produced water (water pulled up in the well) from offshore rigs that gets dumped directly into the ocean. This form of pollution is preventable, but it would add costs to the price of oil. However, all of this oil pollution is dwarfed by the estimated 140 million gallons that enter the environment through such consumer usage problems as oil leaking from cars and boats and runoff from paved roads, which rarely, if ever, gets any press.6

The environmental damage during the exploration process also does not get much press. As we have already stated, the exploration process can have a considerable environmental footprint. The loud, low frequency output of seismic guns can injure marine mammals, even when an effort is made to screen the area for their presence. Onshore exploration often requires that paths be bulldozed through the vegetation to allow for easy access. Segmenting of ecosystems in such a manner has been shown to be very disruptive many forms of wildlife

Oil companies are quick to point out that they take every measure possible to limit their impact on the environment. They have improved considerably from their operations in the past, and no longer do things such as pouring out produced water on the ground. They will also point out that some aspects of their business actually help the environment. For instance, oil rigs provide a stable base near the oceans surface for coral and other creatures. This creates a community for other forms of wildlife such as game fish. As some fishermen will tell you, one of the best places for deep-sea fishing is near oil rigs.

How Much Longer

In the late 1950's, a geophysicist for Shell Oil named M. King Hubbert predicted that the production of oil in the U.S. would peak in 1970. At the time, this was an amazing prediction to make, as there was no evidence that a peak was anywhere in sight. During World War II and the decade that followed it, the production of oil in the U.S. had increased at a steady rate, as the need to fuel vehicles for military purposes gave way to a larger need to fuel more cars for commuters from suburban enclaves. Production was just slightly about 7 million barrels per day when Hubbert made his prediction, and within 10 years, it would climb to almost 10 million barrels per day.

This ability to accurately predict energy in the future is important to our future way of life, as decisions about how we will grow crops, get to work, produce goods, etc. in ten years depend greatly upon actions that we take today. If we know or suspect that oil is not going to be plentiful and cheap in a decade, then we need to begin taking action today to develop new sources of energy and the infrastructure to use them now.

The first thing to do when trying to make this prediction is to see where we are by developing a McKelvy diagram. This is a plot of known sources of a particular energy resource on a scale of uncertainty about the source versus the cost of producing the source (Figure 17). If a particular rock layer is known with a high level of assurance that it contains hydrocarbons, then it will plot near the Y-axis on the diagram. If it can be produced very cheaply, then it will plot near the X-axis. If a rock layer is either very uncertain to contain hydrocarbons or will be very expensive to produce, then it will plot far out along the axis.

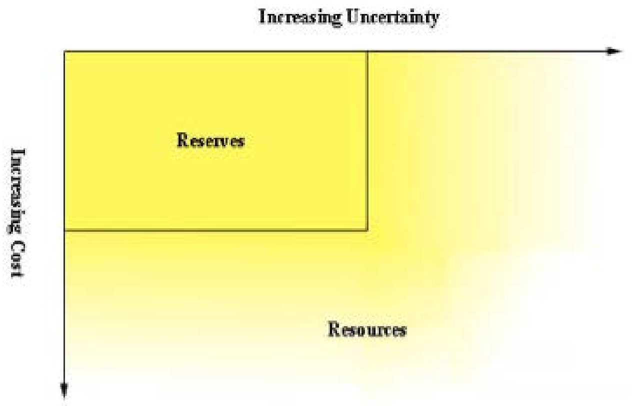

Fig. 17: McKelvy diagram

Creating a McKelvy diagram allows you to visualize what you will include and will exclude from the known reserves of energy for your model. Of course, this diagram is not static, as new inventions might make a rock layer cheaper to produce or might give you greater certainty about whether it contains hydrocarbons. Thus, there is a fluid nature to this diagram. However, it is a starting point to any model that will be constructed. You add to this information about market projections for energy demand, the rate of innovation in the field, and/or a host of other factors that you feel are important to deciding the fate of energy use.

What did Hubbert use to make his prediction? He had developed a behavioristic model of resources that differed greatly from the technological models of the time. Technological models are based solely on what has happened in the past, the technology used to extract the resources, and the possible changes in technology that will occur in the future to allow you to continue to produce this resource. These models recognize that oil is getting harder to find in easy-to-access reservoirs, but they assume that we will become inventive enough to develop new ways to extract the oil at a reasonable price.

Hubbert’s model differed from this by looking at how society responds to price changes in an energy resource as it matures over time. When a new energy resource is discovered that gets some use, the easiest to access and cheapest sectors of the resource are the first to be exploited. As an example, we started this chapter by pointing out that the first oil well was less than a hundred feet deep when it struck oil. This took no extra technology than what was available at that time. Even if oil was known to be found several miles deep in the ground, nobody would have drilled for it, as the price would have made it much too prohibitive to even consider. These cheap, easily exploitable sources of the resource are needed to make it popular, as it is competing with other sources of energy (at the time, whale oil was used for many purposes) for the market. While the earliest sources are cheap, lack of an infrastructure to deliver this resource to market and the lack of available uses for it might keep the resource from being heavily exploited.

If the resource is cheap enough, the infrastructure needed to exploit it will be built. As this opens up the market, the extraction of the resource will increase dramatically. This will require that sources that were not initially cheap will need to be exploited, which will require new and better ways of extracting this resource. At some point, all of the really cheap sources of this resource will be depleted, and the industry will move to more expensive sources. The higher prices for the resource will be accepted by the public (grudgingly), as the infrastructure for this resource will be fully mature and our way of life would require significant change to move away from it. Further extraction will lead to even moderately cheap sources being depleted.

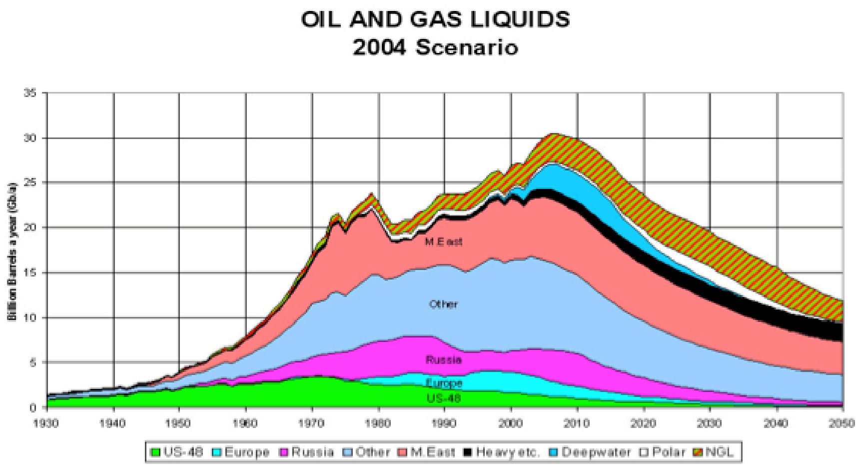

Figure 18: Application of Hubbert's model (Hubbert Peak)

The technological model would look similar to Hubbert's model up to this point. However, the technological model would say that this situation of high energy prices would spur further innovation that allows seemingly more expensive sources to be extracted at a reasonable price. Hubbert's model posits that a tipping point will occur at which the price of extraction becomes too much for the market to bear, and new sources of energy will be exploited. Once this tipping point is reached, production will begin to decrease as other energy resources are exploited. As the infrastructure for them increases, and the price of oil extraction increases, you will see a plummet in the production of the initial energy resource. Eventually, it will stop being used as an energy source and be supplanted by the second one.

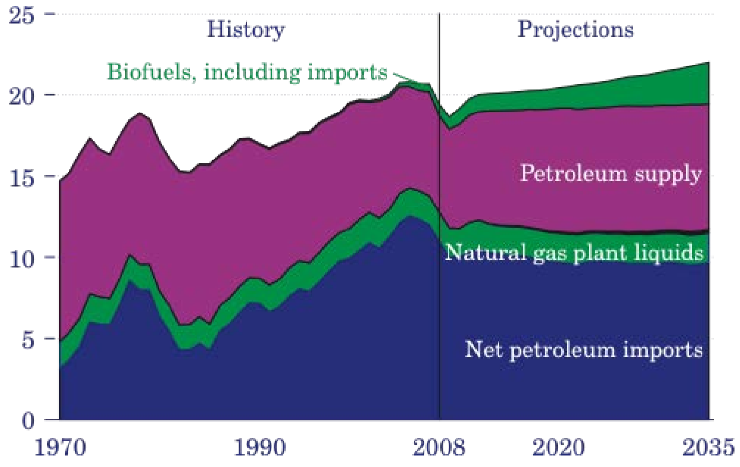

Figure 19: NEMS predictions for oil (DOE)

Are there other models that might be more correct? The U.S. Department of Energy uses a complicated model known as the National Energy Modeling System[7] to predict what will happen in the future. This computer model takes into account data from the different energy sectors, the demand for energy from sectors such as industry and households, and the forecast for the state of the economy, and predicts energy production over the next 20 years. It has many more inputs than Hubbert's model and does not really weigh the evidence of history on how energy sources mature and develop. Figure 19 shows the 2013 prediction from the NEMS model as to the use of petroleum over the next 25 years. It is interesting to note that even though it shows a downturn in usage over the next several years, it still predicts that this will turn around and head back up after that time. This is exactly the same prediction that it had several years ago before oil usage started to shrink in the U.S.

Which of these models is the most correct? That is hard to know until we move into the future and see how things play out. Hubbert's model did predict the peak in U.S. production fairly accurately, but that was at a time when innovation was not as fast as it is progressing today. A good example of this is seen in Figure 18. Applying Hubbert's model in 2004 shows that we should be seeing a global leveling in production by 2014. This has not happened for several reasons, chief amongst them being the changing political situation worldwide and the adoption of new hydrofracturing technologies that have opened up oil and gas shale deposits in the Western U.S. and other locations to exploitation.

This is not to say that this model is bad and should be ignored. Applying this model to hydroelectric generation in the U.S. gives a good example of where it does work and what factors might be necessary for it to be more accurate. In the early days of electricity production (1910's-1930's), this field expanded rapidly, as rivers that were easily dammed and could produce electricity cheaply were put into production. By the late 1950's, all of the cheap and easy locations on rivers had been put into production, and it became harder and more expensive to build new ones. At this point, other sources of electrical energy (nuclear power and coal) became cheaper and more widespread, causing production of new dams to tail off considerably over the subsequent decades Since the 1980's, the production of hydroelectricity in the U.S. has actually peaked and begun to drop, as some older dams are breached to restore the river habitat. If one plots new production over time, it perfectly fits a Hubbert curve.

What has not happened to oil production is the rise of an alternative source that is so much cheaper that we leave oil. Hydrofracturing has caused oil prices to drop as domestic production has increased. However, there is a growing concern that this process is causing a huge amount of environmental damage (toxic chemicals showing up in well water), which could cause the price to shoot up if we have to change how this process is done. Or, we could see innovation in other forms of energy that cause less environmental damage to drive down their prices and make them more attractive. As we look at other sources of energy over the next several chapters, we need to keep this in mind.

Discussion Questions

1. What is the primary method of oil exploration? How does it work?

2. If we were to go to all electric cars tomorrow, what impact would it have on oil production?

3. What role has oil played in wars around the world?

4. If Jed Clampett had actually seen oil bubbling up from the ground on his farm, would he be right in selling it? What about if he was hunting in a national forest?

5. How do we know that oil companies are not lying about how much oil there is in the U.S.? In the world?

6. Could we develop an environmentally friendly method for finding and extracting oil?

7. What impact will worldwide demand have on the Athabasca River region of Canada?

8. Which model of future oil prediction do you think is most accurate? Why?

9. Does the environmental damage done by oil outweigh the benefits of it?

10. If oil were gone tomorrow, what would you need to do to maintain your lifestyle?

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