



# ESA21

Environmental Science Activities for the 21st Century

## Fossil Fuels: Oil

### Introduction

#### 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 actualized. 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.

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.<sup>1</sup>

#### 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 (Mbb/d), our demand for oil has increased such that we now supply less than half of all of the oil that we use. Figure 1 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 Mbb/d to about 17 Mbb/d) was due mostly to an American society that was

U.S. Oil Consumption and Production

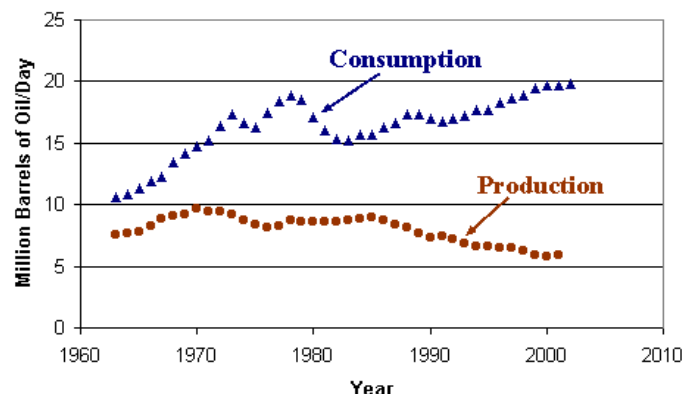


Figure 1: Historical U.S. Oil Data (Data: DOE)<sup>2</sup>

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 increased from about \$.25 per gallon to over a dollar per gallon. Since a low spot in the early 1980's, oil demand has 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, while the number of miles driven and the number of passenger cars increased. Currently, we use 19.6 Mbb/d in the U.S., which is 25% of the worldwide demand of 77 Mbb/d.

When we think of crude oil, gasoline naturally pops right into our heads. For most people, the two are inseparable. There is good reason for this connection in the U.S.: we use 45% of our crude oil to produce gasoline for use in our automobiles. This is necessary for the ever-burgeoning number of cars on the roads and miles that they drive. There were over 235 million registered vehicles in the U.S. in 2001, which were driven, on average, almost 12,000 miles each year.<sup>4</sup> Of this number, 137 million consisted of passenger vehicles that got an average of 22 miles per gallon. The most striking feature, though, was that this number includes 84 million light duty trucks (includes SUV's), which got an average of 17.6 miles per gallon. This represents a tremendous increase in fuel inefficient vehicles, as there were only 48 million light duty trucks on the road in 1990.

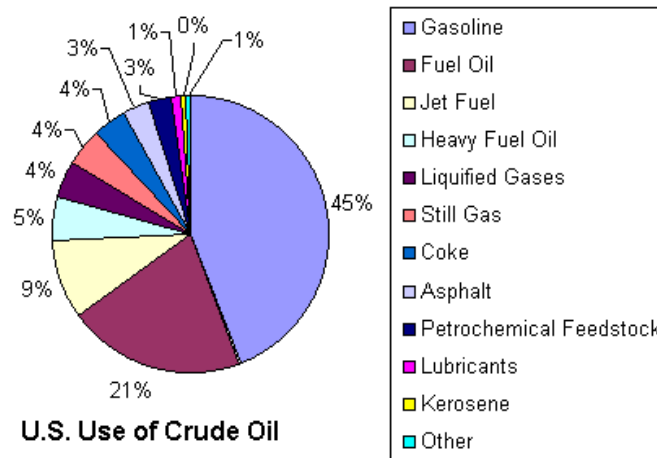


Figure 2: Breakdown of Oil Usage (Data: *petroleum.org*)<sup>3</sup>

Gasoline is not the only product that comes from crude oil, as Figure 2 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 over 5 billion miles in the U.S. each year, which accounts for almost 10% of the crude oil used. The remaining 25% 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 3% 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.

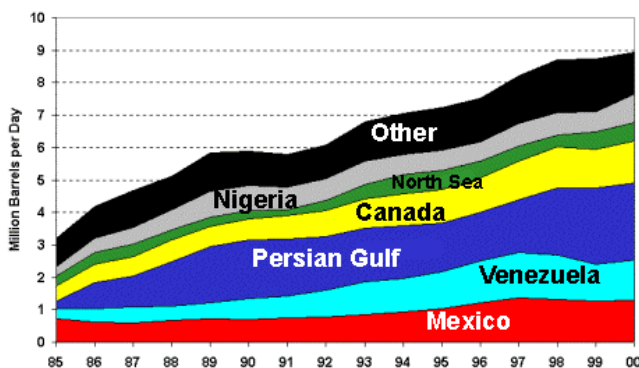


Figure 3: U.S. oil imports by source (DOE)

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 3 shows the breakdown of U.S. oil imports by country. OPEC currently contributes close to 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

Indonesia, Venezuela, and Nigeria are also member of OPEC, and they supply a large amount of our imported oil. The OPEC members from the Persian Gulf only supply about 28% (a little over 3 million

barrels of oil per day) of the total imports. Of this, a little over half, or about 1.8 million barrels per day, comes from Saudi Arabia. By comparison, both Mexico and Canada supply us with about 1.5 million barrels per day each. 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, although it is increasing) 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. The most likely scenario is that oil is the converted remains of countless numbers of microscopic phytoplankton and zooplankton. These plants and animals have thrived in the oceans for billions of years. When they die, their remains fall to the bottom of the ocean, where they 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. Eventually, the temperature and pressure become so great that the remains are slowly converted into kerogen and then 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 sediment 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.

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. Figure 4 shows several diagrams of potential traps. The easiest of these to understand is an anticlinal formation (A) in which the rock layer forms a hill-like structure that has a caprock of shale or siltstone (gray rock). Once the oil (blue) 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.

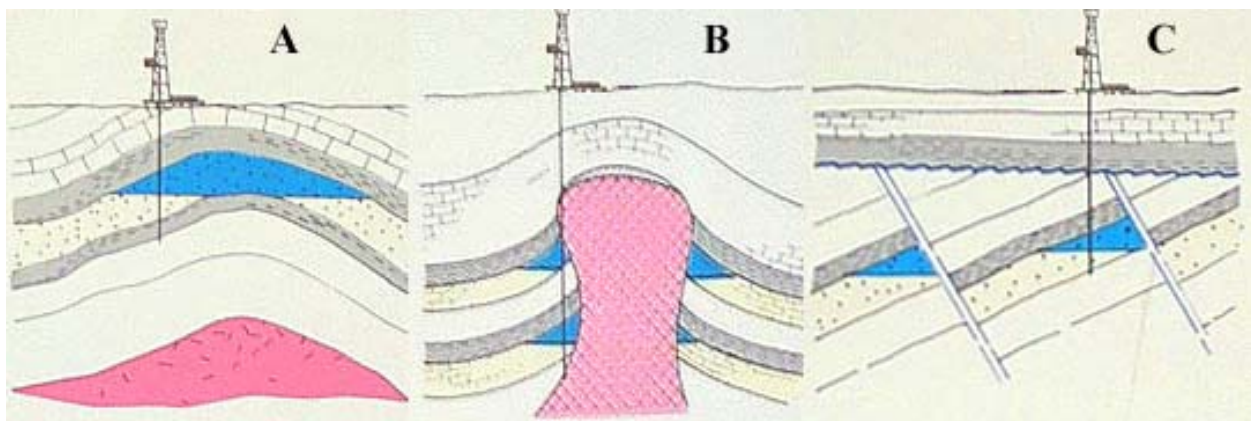


Figure 4: A) Anticlinal trap, B) salt dome trap, and C) tilted fault block trap (Pennwell Publishing)

## 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 the Earth to find both oil and rock features in which profitable supplies of it could be found.

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 some high tech equipment. 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.

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.

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 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 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 rock and still be picked up by the microphones, as the sound must go all the way down and then back up.

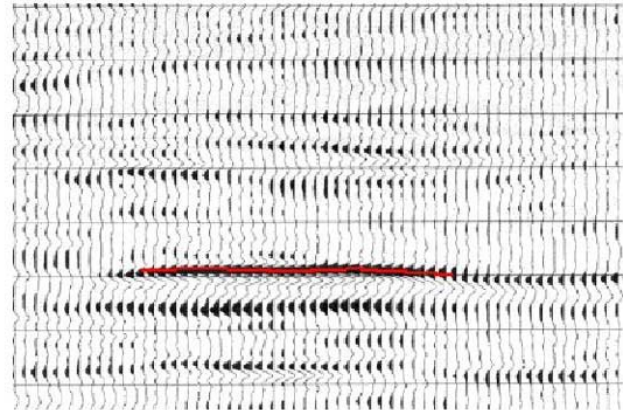


**Figure 5: High-pressure seismic air gun**

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.

After the data is collected, it must be interpreted. If the rock layers below the ground are not too complicated, the output from the computer will yield reflection data that can be used to map out the various rock layers. Figure 6 shows an example of this data from the deepwater area of the Gulf of Mexico. 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.



**Figure 6: Seismic section from Gulf of Mexico**

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 are the odds of hitting it. 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. While some of the techniques for doing this are fairly mature and well known, others are fairly new and are closely guarded secrets by individual companies. Whatever their techniques, at the end of all of the data analysis, all that a company will have are some probabilities based on past experience as to whether there is oil in a possible trap, and how much might be there.

### **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 to 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. If the federal government owns the mineral rights, then the oil company will have to take part in a lease sale held by the Department of Interior's Mineral 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 MMS. 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 2000, close to \$2 billion was received for oil leases and royalties alone, while natural gas brought in an additional \$3.2 billion<sup>5</sup>.

## **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 pipe is added onto the end. However, when a drill bit wears out, which is not uncommon, the entire length of pipe must be taken apart as the pipe is pulled up. The process of pulling the pipe back up to replace a drill bit can take up the better part of a day's work.

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 and permeable, 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 or 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 addition 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.

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 naphtha 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 done 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.

### **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.<sup>6</sup>


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 deepsea fishing is near oil rigs.

### Additional Reading

The following link provides an excellent primer on how the oil market functions, as well as some basics of oil exploration and production. The site is maintained by the Department of Energy and also contains a links to additional resources.

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| <br><a href="#">Department of Energy</a> | <b>Topic:</b> Oil Market Basics<br><b>Summary:</b> Contains information about how the oil market functions.<br><b>Link:</b> <a href="http://www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/oil_market_basics/default.html">http://www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/oil_market_basics/default.html</a> |
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The following link discusses the story of oil, from plankton in the sea to gasoline in your car. The site is maintained by Shell Oil.

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| <br><a href="#">Shell Oil</a> | <b>Topic:</b> The Story of Oil<br><b>Summary:</b> Contains information about oil exploration, production, refining, and usage<br><b>Link:</b> <a href="http://www.countonshell.com/welcome/history/oil_story.html">http://www.countonshell.com/welcome/history/oil_story.html</a> |
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### Activity

#### Exploration and Drilling Simulator

Finding and producing economical deposits of oil and gas is an extremely time-consuming and expensive venture. As discussed above, there are a lot of unknowns in the process that can change something that looks like a sure bet to a multimillion dollar hole in the ground. Yet, our modern way of life depends vitally on this process.

In this week's activity, we are going to get some practice in the world of exploration and production using a simulation game developed by the University of Texas. The premise behind the game is quite simple: you receive the mineral rights to an 8 mile by 8 mile plot of land in south Louisiana from your rich aunt. She also leaves you \$2,000,000 with which to search, drill, and produce oil and gas. The catch in the will is that you only receive the money if you actually find and produce the hydrocarbons. To help you in this venture, you can hire consultants for advice, but it comes at a price of \$10,000 a visit. You can also have seismic lines done over the plot at a cost of \$20,000 per seismic line.

The only way to win the game is to actually produce commercial quantities of oil or gas by drilling in the ground. This takes money, as well. Each 1,000 feet that you drill into the earth costs \$150,000. To complete the well and put in pumps costs \$400,000. To build pipelines and infrastructure takes an additional \$100,000. As you can see, that \$2,000,000 will go fast.

There are a few caveats to the game. The first of these is that you must hire an Environmental Consultant before you shoot any seismic lines. Furthermore, you must file an Environmental Impact Statement before you do any drilling. There are also a few quirks in the game. Each time you shoot seismic lines, you loose all of the information about previous seismic lines. This means that you should either print out the seismic lines as you shoot them, or you should shoot as many as you will need all at one time so that you do not have to go back to re-shoot them.

The activity sheet below should help you play the game. As you purchase services, please mark them down on the sheet. Try to find oil or gas within 4 attempts at the game. When you are finished, answer the questions on the sheet.

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| <a href="#">Virtual Oil</a> | <b>Topic:</b> Virtual Oil<br><b>Summary:</b> Contains game simulation of petroleum exploration and production<br><b>Link:</b> <a href="http://www.beg.utexas.edu/vow/index.html">http://www.beg.utexas.edu/vow/index.html</a> |
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