Chapter 15

FOSSIL FUELS AND THE ENVIRONMENT

> **Case Study: Oil Boom in North Dakota**
> Recent evaluations of the Bakken Play in North Dakota brings welcome news for developers and oil drillers as well as for those seeking jobs, but the growth of the area is playing havoc with both infrastructure and the environment. There may be more than 25x the amount of oil ~~is~~ available than previously suspected, which may reduce the appeal of alternative energy. Students may want to discuss what such a boom would mean to their local areas.

15.1 FOSSIL FUELS

Fossil fuels include petroleum (crude oil), natural gas, and coal. Petroleum is a complex mixture of organic molecules that are purified or refined into numerous products like gasoline, kerosene, heating oil, asphalt, synthetic fibers, plastics, and others. Natural gas is also a complex mixture that consists mostly of methane. Fossil fuels were formed millions of years ago from the debris of land and marine plants. The energy in fossil fuel originally came from the sun (recall the 1st law of thermodynamics), and is essentially stored sunlight. The major fossil fuels provide almost 90% of energy consumed in the world, mostly for transportation and industrial uses. Usage is increasing, mostly due to coal burning.

15.2 OIL

Fossil fuel is formed from organic matter made by plants that were trapped in the earth without a chance to decompose completely. The exact chemistry of the process is not fully understood. Most deposits are found at plate boundaries in depositional basins that were buried (source rock), although several important exceptions exist. Petroleum and natural gas formed during thousands of years of heat and pressure at least 500 feet deep. Petroleum and gas are light and will migrate to the surface (reservoir rock) and evaporate unless they are trapped by a confining layer of rock or a trap, known as a cap rock, that usually consists of shale (Figure 15.2). In other words, the geological requirements are exacting.

● Conventional and Continuous Oil and Gas Resources

Oil resources are deposits which are known to exist and are expected to be recoverable at some point in time. Conventional oil resources are those which are discrete and can be associated with a particular trap formation because the oil has migrated free from the source rock. In contrast, oil reserves are portions of a resource that can currently available to be extracted. This is confusing language since the word "reserves" is often associated with something that is put aside for later.

● Continuous Oil Resources
This term applies to areas with known resources but tend to be spread over a large area because the oil remains in the original source rock. These tend to have areas which have high extraction possibilities ("sweet spots") and those which are not so high. These areas require extensive fracturing in order to extract oil.

● Tar Sands and Shale Oil
These are currently being explored for future use but currently do not contribute much to overall energy production. Tar sands, also know as oil sands or bituminous sands, are sedimentary rocks or sands impregnated with oily residues of tar oil, asphalt, or bitumen. These can form when caps develop cracks, oil migrates near the surface, and lighter fractions evaporate. The oil in tar sand is recovered by mining the sand and extracting the oil with hot water. Some 75% of the world's known tar sand deposits are in the Athabasca Tar Sands near Alberta. Current production of the Athabasca Tar Sands is about 10% of North American oil production. The environmental cost of extraction can be enormous.

Shale oil is a sedimentary rock containing a type of organic matter called kerogen. When heated to 500°C the shale yields up to 60 liters of oil per ton of shale. This is one of the synfuels. There are large deposits of oil shale in Colorado, Utah and Wyoming. Oil shale is not yet economically viable, and the environmental costs of developing oil shale are huge.

Interesting point of discussion could be a quote from Edward Teller, who worked on the Manhattan Project, who once advocated using nuclear explosives to mine the oil shale. "What you can do here is to drill down under the shale, blow up a nuclear explosive, maybe 50 kt., maybe 100 kt. There would be an earthquake on the surface, so you better move the people out. But it is a desert area where for one shot you have to move out maybe 50 people. And the damage found afterwards in the few buildings is quite small. It's a moderate earthquake, not a very big one." (Dr. Edward Teller, in a presentation at Hillsdale College as part of the Center for Constructive Alternatives seminar titled "Energy or Exhaustion: The Planet as Provider.")

● Production of Oil
Production can be by primary or enhanced extraction methods. Primary production involves pumping the oil from wells, a method that can recover only about 25% of the oil in the field. Enhanced production methods, in which steam, water, or compressed gases are pumped into the field, can improve the efficiency up to 60%. Most proven reserves are located in only a few fields. One percent of all fields contains 65% of the oil, and the largest is located in the Middle East. Enormous trade imbalances have grown as world users purchase this oil.

15.3 NATURAL GAS

Natural gas is a complex mixture of organic gases that consists mostly of methane. World reserves of natural gas, about 155 trillion m^3, are estimated to be gone in ~~60-120~~ 100-120 years. Improvements in extraction of natural gas from known fields accounts for most growth of natural gas reserves is the U.S. Increased pressure to utilize natural gas for its clean burning and low pollution contribution may hasten the exhaustion. Perhaps your students could name other cases where addressing one environmental problem exacerbates another.

15.4 SHALE GAS

Shale is a sedimentary earth rock that forms from very fine particles of clay and silt. It may trap large amounts of natural gas in its pores, known as shale gas. There may be large supplies available in the US, but it can be difficult to extract.

● Methane

This gas is clean burning and produces lower amounts of carbon dioxide than other fossil fuels. There is a considerable amount of methane associated with coal beds that can be tapped by drilling as well as in continuous sources that require fracking (see A Closer Look 15.4). There are significant problems with the disposal of polluted water that is produced when the methane is recovered, along with foul smells and nuisance noise.

A Closer Look 15.1: Hydrologic Fracturing to Recover Oil And Gas

Hydrologic fracturing (fracking) is used to release natural gas from rock that has low permeability. The rock is simply broken by the pressure of water and other chemicals in order to allow the freed gas to flow into collection wells. There are many environmental concerns regarding this practice, such as seepage of methane that could cause fires, the large amounts of water used, and the nature of the chemicals used, which fracking companies have not always been willing to realize. Within hours of this writing, the California State Legislature passed a bill requiring drillers to disclose the chemicals they are using. A list of chemicals used in fracking appears in Table 15.1 and a more extensive list at http://fracfocus.org/chemical-use/what-chemicals-are-used.

● Tight Gas

Tight gases are in deposits of dense sandstone and limestone that have low permeability, so that the gas is held “tightly” and requires massive fracturing to be released. Sandstone and limestone are both sedimentary rocks, but sandstone forms from sand particles and limestone is generally deposited by chemical means. The US resource of tight gas is large and provides 25% of gas produced.

● Coal-bed Methane
Coal deposits produce and can hold natural gases. The US produces about 9% of its natural gas supply from coal-bed deposits. It can be drilled conventionally and is cheaper to get than gas deposits associated with oil, but the large amounts of water use and water pollution as well as the risks of migrating gas are serious environmental concerns. Social concerns over noise and mineral rights are also important.

● Methane Hydrates
Methane hydrates are found on the ocean floor in areas where deep, cold water under intense pressure has trapped methane within an ice lattice. This is a potentially large energy source, greater than all known oil, natural gas and coal reserves. However, these deposits occur at great depths (>1 km), and efficient technology does not currently exist for extracting methane hydrates.

15.5 ENVIRONMENTAL EFFECTS OF OIL AND NATURAL GAS
Environmental effects of burning oil and natural gas are extensive and well documented. These effects arise from processes associated with the extraction and refining stages, and the delivery and use stages.

● Recovery
In the recovery stage there is a land-use impact (road and pad building), pollution of surface water from leaks and accidents, release of hydrocarbons to the atmosphere, land subsidence (an issue in the Mississippi River delta), and damage to ecosystems. Other impacts specifically associated with marine recovery include seepage from operations, spills, drilling muds, and the aesthetics of drilling platforms.

● Refining
Refining oil and natural gas impacts include spills and leaks of products that damage water supplies and soil, and air pollution. Leaks of chemicals used in the refining processes are also of concern.

● Delivery and Use
Delivery and use impacts result from failure of pipelines and storage tanks as well as spills from ships and trucks.

A Closer Look 15.2: The Oil Spill in the Gulf of Mexico, 2010
Your students will likely remember the news coverage for the Deepwater Horizon oil spill disaster in the Macondo oil and gas prospect in the Mississippi Canyon of the Gulf of Mexico. Over the short term the spill was an environmental and economic calamity for those affected by it. The spill has cost BP a great deal of money (according to Forbes, $42.2 billion as of February 2013) and will likely cost more as additional lawsuits are filed.

15.6 COAL

Coal is the world’s largest conventional source of fossil fuel. There are may different types of coal that vary greatly in energy and sulfur content. Those most commonly used a fuel, in order of increasing energy per ton, are lignite, bituminous, and anthracite. The high sulfur content of some types of coal pollute the atmosphere. Sulfur can be removed from coal as it burns, but this produces toxic pollutants as well.

● Coal Mining and the Environment

The environmental impacts of coal use are severe. They range from acid mine drainage to outright elimination of whole landscapes. Land reclamation practices required by law vary by site, but so far only about half of all land disturbed by coal mining has been reclaimed. Open pit and strip mines are surface mining processes in which the overlying soil and rock is stripped off to reach the coal. This accounts for over ½ of the coal mining in the U.S.

● Mountaintop Removal

This special strip mining technique involves just what it sounds like. Any tree cover is removed, followed by the topsoil, and then the coal is excavated. Environmental consequences are particularly severe due to ecosystem destruction, runoff, and dust. Mountains are also particularly difficult to reclaim. An interesting class discussion can revolve around using a program such as Google Earth to find places where this type of mining, as well as strip mining, has taken place.

● Underground Mining

Underground coal mining accounts for 40% of coal production in the U.S. This method also produces subsidence as well as acid mine drainage from the mine tailings and sometimes coal fires that burn for decades. Underground coal mining is also associated with human disease and great danger from cave-ins, underground fires and floods (miners may inadvertently drill into old, abandoned mines filled with water), and other hazards.

● Transporting Coal

The transport of coal, usually by train, from the mines to electric power plants also has environmental costs and energy costs that reduce the efficiency. Alternative transport methods, including conversion of the coal to slurries, synthetic oil, or gas, often require large amounts of water.

● The Future of Coal

Coal accounts for about 40% of the electrical energy production in the U.S. Clean air legislation has forced utilities to seek cleaner types of coal and new technologies to remove pollutants before the coal is combusted and before the combustion products are released to the atmosphere. Coal is a lower quality of energy than the liquid and gaseous forms of fossil fuels, and it has a much greater environmental impact. As oil and natural gas supplies become limiting, the pressure to consume more coal may increase.

The US Environmental Protection Agency grants utility companies tradable allowances for polluting. This is a market approach to regulating pollution. For example, they are allowed to release a given amount of sulfur dioxide. If they release less than their allotment, they are allowed to sell the credits. This provides an incentive to use clean technology.