Part Four
Energy and Fossil Fuels

Issue 7

OIL AND NATURAL GAS

Key Questions

- What are proven reserves of oil and gas?
- How fast are we consuming oil and gas?
- Where are global reserves of oil and gas?
- What is hydrofracturing, and why is it controversial?
- What are the environmental effects of oil and gas use?
- What are the issues surrounding drilling for oil in the ANWR?
- What is *peak oil,* and has it been reached yet?
- How is oil and gas use related to sustainability?

Background

Oil is the energy basis of modern industrial society. For over fifty years after the first successful well was drilled in the mid-nineteenth century, oil use was insignificant. Although he thought his vehicles would be powered by peanut oil, Henry Ford changed all that with his mass-produced automobiles. World War I generated immense demand for gasoline-powered vehicles. During the period 1919 to 1949, oil gradually overtook coal as the most important fuel source in the United States. Today, oil provides 40% and natural gas provides more than 23% of U.S. energy. Oil provides virtually all of our transportation fuel.

By 2012, global oil demand was around 88 million barrels (1 barrel = 42 U.S. gal) per day, with the United States responsible for more than 18 million barrels per day.[1]

Question 7-1: What percent of global oil demand is accounted for by the United States?

Question 7-2: What percent of the world's 7.05 billion population is represented by the 310 million of the U.S.?

[1] U.S. Energy Information Administration, www.eia.gov.

Because of growing demand for oil from Asian economies, especially India and China, as well of political turmoil in oil producing countries, mainly the Middle East, oil prices have risen sharply. Chinese demand alone accounted for 9.4 million barrels a day (mb/d), more than half that of the U.S. As recently as 1994, Chinese demand was only around 3 mb/d. Indeed, since 2008, demand in Brazil, Russia, China, and India has increased by 3.7 mb/d, while demand in the U.S. and Eurozone countries has fallen by only 1.5 mb/d.[2]

ORIGIN, DISTRIBUTION, AND EXTRACTION OF OIL

Oil is not a renewable resource. The oil fields of today originated tens of millions of years ago when organic remains were buried within sediments in the absence of oxygen. The organic matter was subjected to a critical combination of pressure (caused by deep burial) and increased temperatures. Over millions of years, the organic matter reorganized into more volatile organic molecules that we call *crude oil* or *petroleum,* usually accompanied by *natural gas.* To be extracted and used, petroleum must migrate upward, out of its deeply buried *source bed,* and into rock strata or a favorable geological structure that will trap the oil and prevent its escape (Figure 7-1).

Sometimes, pressure forces the oil all the way to the surface, where it forms *seeps,* which were known to Native Americans. The nineteenth century's oil discoveries came when "wildcatters" (oilmen who drilled speculative wells) simply drilled holes into the rocks underlying oil seeps.

Once extracted from underground reservoirs, oil is processed to remove other fluids, such as water, hydrogen sulfide, and natural gas, and then it is sent to refineries. There the oil is heated in the absence of oxygen to break or "crack" the molecules into lighter forms, which emerge as products such as gasoline, diesel fuel, or asphalt. Much, but not all, associated sulfur is usually removed at refineries as well. The sulfur that is left in motor fuels when burned forms oxides of sulfur (SOx), a toxic air contaminant, which cannot be removed by the present generation of catalytic converters. The oil may then be shipped by pipeline or oil tanker to destinations around the world.

HOW MUCH OIL IS LEFT?

Calculating the amount of oil present in all known world oil fields that can be extracted at a profit using present technology yields a value called *proven oil reserves* (Table 7-1).

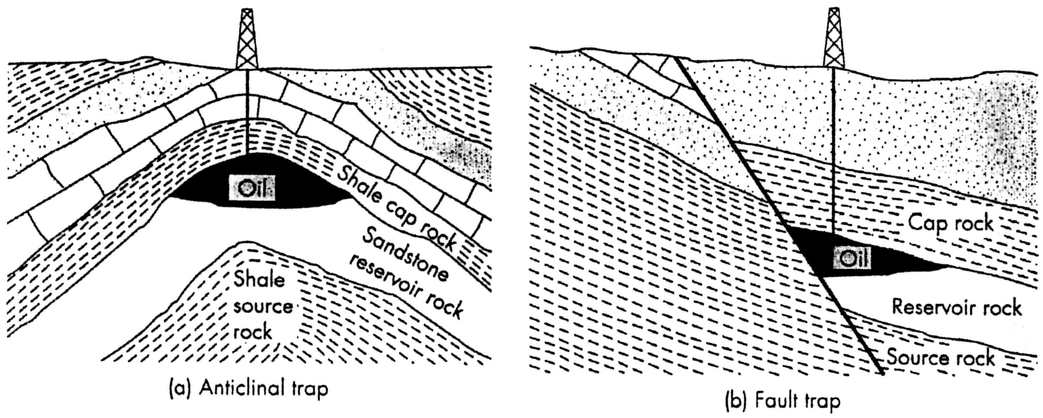

FIGURE 7-1 Typical oil and gas "traps." Oil, being lighter than water, floats to the top of the reservoirs. The oil is usually associated with natural gas as well. (Keller, E.A. 2000. *Environmental Geology* 8th ed., Fig. 15.10, page 411. Prentice Hall, Upper Saddle River, NJ. Courtesy of E. A. Keller/Pearson Education.)

[2] *The Economist,* 6/23/12 p. 73.

TABLE 7-1 ■ Proven Oil Reserves (billion barrels) by Country, 2011[1]

1. Saudi Arabia	262
2. Venezuela	211
3. Canada*	175
4. Iran	137
5. Iraq	115
6. Kuwait	104
7. U.A.E.	98
8. Russia	60
9. Libya	46
10. Nigeria	37
11. Kazakhstan	30
12. Qatar	25
13. U.S.A.	20

*Canada has over 130 billion barrels of waxy petroleum solids in sedimentary deposits called "tar sands." Although they could be, and are, extensively mined, they are not conventional deposits.

[1]Source: US CIA.

Organizations such as the U.S. Department of Energy and the International Energy Agency collect and publish such information. World proven oil reserves are less than the actual oil in place. Variable amounts of oil in underground reservoirs always remain in the rock. However, new technology may increase oil recovery, or the price may go up making it economic to spend more money to get more oil out. Moreover, companies frequently underestimate the amount of oil in a field or may not publicize the actual amount for competitive reasons. For example, in 1970 BP estimated its Forties North Sea oil field contained 1.8 billion barrels of proven reserves. However, by 2012, BP, and new owner Apache, had produced 4.0 billion barrels from the field!

If oil price rises, marginal fields—those not economic to develop at current prices—may become profitable and may be added to reserves. Chevron Oil Corporation estimated in 1991 that 6,700 billion barrels of oil could be ultimately recovered, assuming *a price of $60 per barrel in 1990 dollars.*[3]

Question 7-1: According to the Department of Labor, the consumer price index (CPI) is a measure of the representative cost of a "basket" of goods and services. It stood at 127.4 in 1990, and had reached 230 by mid-2012.[4] Therefore, by what percent had the CPI increased between 1990 and 2012?

[3] Holyoak, A.R. Written communication.

[4] U.S. Department of Labor Bureau of Labor Statistics (http://www.bls.gov/bls/.

Question 7-2: To determine the 2012 price that would be equivalent to a 1990 price of $60 per barrel, first multiply the 1990 minimum price by the percentage you just calculated. What would be the 2012 price needed to "guarantee" 6,700 million barrels of ultimately recoverable oil?

Question 7-3: For a world price of $100+ per barrel to stimulate increased oil production, the price would have to be maintained long enough for companies to be able to make investment decisions on it, since producing oil from a new discovery can take ten years. What do you think would happen to oil exploration and ultimately production if the world price were to fall precipitously?

TECHNOLOGY ENHANCES OIL DISCOVERIES AND PRODUCTION

Over the past several decades, technology has helped discover new oil and gas fields. It has also increased ultimate recovery of the oil and gas in place, both in known fields and new discoveries. Companies use seismic data and powerful computers to create 3-D images of deeply buried geologic structures more than 5 kilometers below the surface. And recent advances in drilling techniques have lowered production costs and increased oil and gas yields from known fields. Using new techniques, companies have increased the ratio of discoveries to "dry holes." Dry holes are exploratory wells that didn't hit oil and can cost up to $15 million each!

For the past twenty-five years, with only two exceptions, estimates of ultimately recoverable oil have ranged from around 1,800 billion barrels to around 2,400 billion barrels. We will discuss a new method of natural gas exploration and production, hydrofracturing, below.

Where Is the World's Oil?

As you can see from Table 7-1, the Persian Gulf region contains more than half of the world's proven oil reserves. It similarly produces half the world's oil. The Gulf region is such an extraordinary source of oil because it has huge oil *fields* and extremely low costs of exploration and production. For example, it can cost as little as a few dollars per 42-gallon barrel in the Persian Gulf to produce oil. In new oil fields of North America and the North Sea of Europe, costs can range from $20 to $60 a barrel.

Question 7-4: What is today's world price for oil? Check the web, a daily newspaper, or a business network.

We can determine how long world proven reserves (1,300 billion barrels at the end of 2011) will last by simply dividing the total oil by the annual production—approximately 32 billion barrels per year.[5] Note that when we do this, the resultant number is years since "barrels" cancel out.

[5] U.S. Central Intelligence Agency (CIA), www.cia.gov.

This number represents the total number of years from 2011 that oil could be produced at current rates before it is all gone, *assuming* constant production *and* demand. In reality, the depletion of a resource like oil does not follow such a simple pattern. Rather, oil production will gradually decline over a long period of time.

Question 7-5: Assuming no new discoveries, in what year, starting from 2011, would the world run out of oil?

However, the rate of consumption is increasing each year, and new discoveries are being made (Table 7-2).

Consult Table 7-2. Describe the change in global demand from 1986 to 2012.

TABLE 7-2 ■ World Oil Demand[2]

Year	Consumption (million barrels per day)
1986	61.8
1987	63
1988	64.8
1989	65.9
1990	66
1991	66.6
1992	66.7
1993	67
1994	68
1995	70
1996	71.7
1997	73.7
1998	73.6
1999	74.7
2000	75.8
2001	76.4
2002	77.8
2003	79.3
2004	82.6
2005	83.7
2006	85.1
2007	85.8
2008	85.4
2009	85.6
2010	87.0
2011	88.0
2012 (est)	88.7

[2] U.S. Energy Information Administration. International oil data for crude oil production, available at http://www.eia.doe.gov.

Question 7-6: What was the average annual growth rate in oil consumption from 1986 to 2012? (The most accurate way to calculate the average rate of increase is to use the formula $r = (1/t)\ln(N/N_0)$; see "Using Math in Environmental Issues," pages 6–8).

It is important to note how a tiny rate of increase can lead to such a change in oil consumption over a long period of time. The concept of doubling time, $t = 70/r$ introduced earlier, can be applied to illustrate growth of consumption.

Question 7-7: What is the doubling time for the average increase in demand you just calculated?

Question 7-8: To estimate the total amount of oil that was consumed over a given period, first convert the beginning and ending rates of consumption (say, 80 million barrels a day) to barrels per year. Then add the beginning and ending consumption rates together and divide by 2. Finally, multiply this number by the number of years. How much oil was consumed between 1986 and 2011?

Question 7-9: EPA reports that 0.43 tonnes of CO_2 is emitted per barrel of oil burned. How much CO_2 was emitted by burning this much oil between 1986 and 2011?

Author and environmental provocateur Garrett Hardin, in addressing the issue of energy supply, said, "Whenever it is thought to be impossible to limit the growth of either population or desire, *it is impossible to solve a shortage by increasing the supply*" [emphasis his].[6]

Question 7-10: Explain why you agree or disagree with this statement. Can we ever accommodate the world's increasing demand for oil? (If you have some background in economics, cite reasons why an economist might disagree with Hardin's quotation).

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[6] Hardin, G. November/December 1996. Letter to Editor. *Worldwatch Magazine,*

ANWR's Oil Reserves

The American Petroleum Institute, among others, would like to open the Arctic National Wildlife Refuge (ANWR) on Alaska's North Slope to oil exploration.[7] The U.S. Geological Survey (USGS) estimates between 5.7 and 16 billion barrels ultimately might be produced over several decades.[8] Environmental scientists are concerned about (1) the impact of oil exploration on the tundra environment and (2) the impact of oil exploration and production on caribou and other migrating animals.

Question 7-11: The mean estimate by the USGS of recoverable oil in ANWR is about 10.3 billion barrels without regard to price. Based on the mid-2012 U.S. annual consumption rate of about 7 billion barrels of oil per year, how many months would these new fields last?

Question 7-12: Did we phrase Question 7-12 fairly and accurately? Why or why not? Cite evidence for your position.

Impacts of Oil Refining

Oil refineries are one of the top sources of industrial air pollution in the United States, and a dangerous place to work. For example, in 2010 four workers were killed and three severely injured in an explosion at a refinery in Washington State. And in 2005 a fire and explosion at a Texas refinery killed 15 workers and injured more than 170. Moreover, refineries are one of the largest stationary sources of volatile organic compounds, the primary component of urban smog. They are the fourth largest industrial source of toxic emissions and the single largest source of benzene emissions, which are carcinogenic.

Question 7-13: Research this issue and explain why oil refineries are so dangerous.

[7] American Petroleum Institute (www.api.org).

[8] U.S. Geological Survey, www.usgs.gov.

Question 7-14: Most politicians express horror at the prospect of higher oil prices. Identify advantages and disadvantages of higher prices for oil and refined products like gasoline and diesel fuel.

China became a net oil importer in 1995, and the Chinese demand for petroleum has increased significantly since 2001. Chinese oil demand was 9 million barrels a day in 2010 and was forecast by U.S. EIA to increase to 19 million barrels a day by 2020.

Question 7-15: What are the implications for the world oil price if Chinese demand sharply increases?

NATURAL GAS

Methane, CH_4, is the main constituent—about 75 percent—of natural gas, but natural gas usually also contains ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}). It is one of the planet's most important commodities. It presently meets more than 20 percent of world energy needs, and nearly a quarter of the energy needs of the United States. Since burning gas produces no SOx pollution, no ash or toxic emissions like heavy metals, and half the CO_2 of coal, natural gas is poised to be the fastest-growing fossil fuel source in the twenty-first century.

Natural gas can be produced in any geologic environment in which organic matter is decomposed by microorganisms in the absence of oxygen, with or without heat and pressure.

Deposits of Natural Gas

Natural gas deposits fall into four categories:

1. Natural gas is usually found with petroleum in reservoir rocks.
2. Important reserves of gas are also found in rocks with little or no oil, most recently in black shales.
3. Natural gas originates with coal and is typically found with coal deposits.
4. Methane can be formed by the action of certain bacteria in oxygen-free environments, such as waterlogged soils in permafrost regions and in deep marine sediment.

Methane deposits in deep marine sediments are called *methane hydrates*. Recent research on methane hydrates in the world's oceans point to hydrates as a potential new category of natural gas resources, though none is produced at present.

Transporting Natural Gas

Natural gas may be transported in two ways: in pipelines (the Chinese built the first ones of bamboo in the sixth century BCE) as a pressurized gas, or as a super-cooled liquid (LNG, liquified natural gas) using specially constructed tankers.

Global Gas Reserves

The U.S. EIA estimated global proven reserves of natural gas at 6,500 trillion cubic feet (TCF) in 2012. In 2011, the world used more than 113 TCF of gas, and this quantity was projected to increase at 1.6% per year through 2035. In the United States, natural gas consumption averaged around 22 TCF during 2005–2011. Reserves of natural gas are shown in Table 7-3. This does not include coalbed methane. The volume of gas in coal seams is more uncertain. What is certain is that methane seeping from coal mines is a major greenhouse gas, as well as a valuable potential resource. The presence of natural gas along with coal poses the biggest hazard to miners working underground, since it is under pressure, is odorless and colorless, and easily ignited. The Chinese government acknowledges that several thousand coal miners die yearly, and labor activists argue the figure is much higher. Most of these deaths were caused by methane explosions.

Even though burning methane produces CO_2, the primary greenhouse gas, methane is a far more powerful greenhouse gas than CO_2. Extraction of methane in deep marine sediments is not presently economically viable, although the amount of methane in such deposits is enormous.

TABLE 7-3 ■ World Natural Gas Reserves by Country 2005 and 2011 (trillion cubic feet)

Country	Reserves, 2005	Reserves, 2011
World	6,040	6,500
Russia	1,680	1,680
Iran	940	1,050
Qatar	910	900
Saudi Arabia	235	280
United States	189	277
Turkmenistan	74	270
United Arab Emirates	212	230
Nigeria	176	190
Venezuela	151	180
Algeria	161	160
Iraq	110	115
Australia	—	110
Indonesia	90	105
Kazakhstan	66	85
Malaysia	29	85
Egypt	57	75
Norway	75	72
Uzbekistan	71	65
Netherlands	65	—
Canada	62	60
Ukraine	40	40

Source: CIA World Factbook (https://www.cia.gov/library/publications/the-world-factbook/rankorder/2179rank.html)

Hydraulic Fracturing

Hydraulic fracturing ("fracking") permits gas production from rocks containing gas but with very low permeabilities, such that the gas cannot be extracted using conventional methods. Fracking injects large volumes of fluids and "proppants"(small particles of solids) at high pressure, fracturing the rock, which allows gas to escape. The fluids inject the proppants into the fractures to keep them from sealing shut when production begins. The fracking fluid is typically water-based and contains such chemicals as bactericides, buffers, fluid-loss additives, and surfactants (essentially, detergents), to make the fracturing efficient and prevent damage to the formation.

There are two problems with fracking: first, companies usually, for proprietary reasons, are reluctant to disclose the precise content of the fracking fluid, and second, large amounts of water are used, whose content is modified by mixing with water from deeply buried rocks, as well as the fracking fluid itself. Potential environmental impacts include contaminated wells, and local water supplies may be threatened. One of the nation's greatest reservoirs of "tight" shale gas, the Marcellus Shale, underlies much of the eastern United States, but production from the formation may be severely restricted if means to prevent water contamination are not perfected.[9] Indeed, half the new natural gas wells in the U.S. involve fracking. Globally, EIA estimates shale ("tight") gas reserves to exceed 60 trillion cubic feet.

Question 7-16: Global gas consumption is projected by the U.S. Energy Information Administration to grow at 1.6% percent per year. Use the doubling time formula to project how long at this rate it will take for consumption of natural gas to double from 2011's 113 TCF per year.

Question 7-17: From the perspective of global sustainability, what role should natural gas play in the world's energy future? Why?

Question 7-18: Summarize the important points of this Issue.

FOR FURTHER THOUGHT

Natural Gas from Prudhoe Bay

The Prudhoe Bay oil field in Alaska's North Slope has large reserves of natural gas, estimated by field operator BP at 35 TCF, but no way to get the gas to market. Gas cannot be transported using the existing oil pipeline, which cost over $7 billion to build in the 1970s.

[9] West Virginia Rivers Coalition www.wvrivers.org/articles/Marcellus%20Report%202010.pdf.