CHAPTER 15

Energy Consumption, Conservation, and Fossil Fuels

IN THIS CHAPTER

Summary: This chapter will examine some of our historical and current fuel choices, while exploring in greater detail the impacts of consumption, conversion, and use.

KEY IDEA

Keywords

✪ Work, energy, calorie, power, joule, conversion, laws of thermodynamics, Hubbert's peak, oil shale, tar sands

Energy

All organisms need energy to function. More is needed for species-related or cultural activities (e.g., migration, hibernation, fight-or-flight response, finding food and shelter, or reproduction). Just as there are different energy uses, energy comes in different types. For example, people get energy from the compounds (e.g., proteins, carbohydrates, and fats) stored in food. A *calorie* is a unit of food energy.

KEY IDEA

> One *calorie* unit equals the amount of energy needed to heat 1 gram of water to 1 degree Celsius.

Energy provides the power to do work. *Work* is defined as force exerted over distance. *Power* is the rate of flow of energy or the rate at which work is accomplished. Another way to measure energy is to measure force and work. A *newton* describes the force needed to accelerate 1 kilogram by 1 meter per second. A *joule* is the amount of work accomplished when a force of 1 newton is performed over 1 meter or 1 ampere per second travels through 1 ohm (a unit of electricity). Several units of energy are listed on page 273.

Laws of Thermodynamics

STRATEGY

To understand energy, you also need to know the laws of thermodynamics. These affect all types of energy, their conversion, and storage. Here they are:

1. The *first law of thermodynamics* states energy can be neither created nor destroyed. It is simply transported or changed into another form. For example, deep ocean vents have communities of microorganisms that use sulfur compounds released from thermal vents for chemosynthesis in the same way plants use sunlight for photosynthesis.
2. The *second law of thermodynamics* describes how the universe tends toward *entropy* (chaos, disorder, or randomness). The original energy amount is no longer available in its original form but has changed to another form. For example, much energy produced by a power plant is lost through heat in turbines and when sent through electrical lines.

Conversions

TIP

One of the big energy concerns is the amount of energy needed during energy refining and production. In fact, processing accounts for nearly half of all energy lost during conversion to more usable forms, transportation, or use.

For example, when coal is used to produce electricity, nearly 65% of the original energy is lost during thermal conversion at the power plant. Another 10% is lost in electrical transmission and voltage changes for household use. Most losses are seen during fossil fuel refining. About 75% of oil's original energy is lost during distillation into gasoline and other fuels, transportation to market, storage, and engine combustion.

Natural gas has much less waste since it needs little refining. It is transported through underground pipelines and burned with 75 to 95% efficiency in regular and high-efficiency furnaces. It also contains more hydrogen-to-carbon atoms, and so produces much less carbon dioxide (about one-half less compared to oil or coal), reducing its impact on global warming.

Fossil Fuels

Fossils fuels are hydrocarbons formed into coal (solid), oil (fluid), and natural gas (mostly methane). These can be used as fuels by themselves or processed to produce purer products like propane and gasoline. Fossil fuels (oil and natural gas) are also used in the petrochemical industry to make chemicals, plastics, and fertilizers.

KEY IDEA

> *Fossil fuels* are solids, liquids, and gases created through the compression of ancient organic plant and animal material in the Earth's crust.

Fossil fuel burning is the biggest single source of human-created air pollution in the industrialized world. Reducing the amount of smoke, ash, and combustion products from fossil fuel burning is critical to the future of life on Earth.

Energy Production and Use

Fossil fuels produce around 85% of the energy used in the United States, with oil making up about 40% of that. North America also has coal resources that provide about the same amount of fuel as natural gas (e.g., 22%). Nuclear power only provides around 8% of U.S. energy, with all other alternative fuels providing about 7%.

Fossil fuels fuel vehicles, industrial manufacturing, and homes and businesses. Of U.S. energy consumption, over 40% is used in the mining, smelting, and forging of metals, as well as the manufacture of plastics, solvents, lubricants, fertilizers, and organic chemicals. Homes and businesses use about 35% in lighting, heating, air conditioning, cooking, and water heating. Transportation uses another 25%.

Hubbert's Peak

Fossil fuels have been exploited worldwide for decades following many technological advances. However, it wasn't until large cities became sooty, dirty places from fossil fuel burning that people began to think there might be a better way. Scientists debated whether it was easier to stick with fossil fuels and its problems or switch to a better energy source. In 1956, Shell Oil Company geophysicist M. King Hubbert calculated that the oil well extraction rate in the United States (lower 48 states) would peak around 1970 and begin dropping from then on. At the time, people didn't believe him. Hubbert was criticized by oil experts and economists, but it turned out he was right. Oil production peaked at around 9 billion barrels/day in 1970.

The *International Energy Outlook 2008 (IEO 2008)* published by the Department of Energy projects global energy consumption will increase by 50% from 2005 to 2030.

Since the industrialized world depends on fossil fuels, experts are trying to figure out how many years are left before all known fossil fuel (coal, oil, and natural gas) reserves are gone, based on world consumption rates. Currently, around 65% of electricity produced comes from fossil fuels worldwide, but that number is expected to shrink as supplies dwindle and alternatives expand.

Fossil Fuel Resources

Even if we use *all* available fossil fuels globally, there will always be some left in the earth. Liquid oil comes out readily, but oil trapped between rock layers or in honeycomb configurations is not easily extracted. In fact, a 30 to 40% yield from an oil formation is common. There are technological as well as cost limitations to oil drilling. Getting more oil from a drilled deposit using different methods is known as *secondary recovery.*

Currently, oil production in the United States from all sources is around 8 million barrels a day from over half a million wells. This can be compared to 10 million barrels per day in Saudi Arabia from only 750 wells. Nearly two-thirds of the world's *proven* oil reserves are located in the Persian Gulf countries of the Middle East.

Geologists, performing calculations with updated global oil data, found global oil production will peak by 2010. Of the approximately 2.5 trillion barrels of the Earth's total recoverable supply of oil (*United States Geological Survey* estimate), over 50% of it has already been used. Since fossil fuel consumption is still rising and proven reserves are less than 1 trillion barrels, worldwide supply is estimated to last between 30 to 40 years at current rates.

Surprisingly, Canada is the biggest supplier of oil to the United States, with Saudi Arabia a close second.

Fossil Fuel Disadvantages

It is estimated that around 270 billion cubic meters of *tar sands* in northern Alberta could also provide over 2 billion barrels of oil per day to the United States in the next 5 years.

This alternative oil resource could double the total North American oil reserves if it were possible to recover them without steep environmental impacts. However, unless better technology is found to reduce toxic sludge and water pollution caused during tar sand processing, public outcry will keep this resource from development. Similar concerns have been raised about U.S. *oil shale,* a sedimentary rock that contains solid organic matter called *kerogen.* When heated to 480°C (900°F), kerogen melts and can be drawn up out of the ground. Oil shale is located in Wyoming and Colorado as well as some eastern states. This makes the huge amounts of water needed for extraction a costly process, in addition to generating huge amounts of waste and pollution.

Another hotly debated area with large oil reserves is Alaska's Arctic National Wildlife Refuge (ANWR). This area, which contains millions of geese, swans, shorebirds, migratory birds, polar bears, arctic foxes, arctic wolves, and the largest herd of caribou in the world (130,000), is estimated to contain as much as 12 billion barrels of oil. Petroleum companies claim they can extract the oil with little environmental impact, but ecologists cite buried waste, heavy machinery impacts, and pipeline and drilling spills on the tundra as major negatives.

Native peoples are divided in their support of ANWR drilling. Those who work in the oil industry generally favor it, while others who support traditional ways and need caribou as a primary food source oppose it.

Conservationists agree with federal ANWR drilling advocates that we need to decrease U.S. dependence on foreign oil. However, they prefer vehicles with greater fuel efficiencies, and the use of alternative energy sources (e.g., wind and solar) to fill the gaps rather than the sacrifice of pristine environments.

TIP

The time for energy alternatives is now. Just like driving a car, you can't wait until you run out of gas to stop at a station and refuel. Fossil fuel depletion could be slowed if demand could be lowered by switching to new, more efficient energy resources.

Oil

Humans have used oil since the ancient Chinese and Egyptians burned oil for lighting. In 1839, Abraham Gesner, a governmental geologist in New Brunswick, Nova Scotia, discovered *albertite* (a solid coal-like material). After immigrating to the United States, Gesner developed and patented a process for manufacturing *kerosene.* He is often called the father of the petroleum industry.

Before the 1800s, however, light was produced from torches, tallow candles, and lamps burning animal fat. Because it burned cleaner than other fuels, whale oil was popular for lamp oils and candles. However, it was expensive. A gallon cost about $2.00, which today would be around $760 per liter ($200 per gallon). And we think our oil is expensive!

As whale oil became more and more expensive, people started looking for other fuel sources. In 1857, Michael Dietz invented a clean-burning kerosene lamp. Almost overnight, whale oil demand dropped. Most historians and ecologists believe that if kerosene had not come onto the market, many whale species would be extinct from overhunting.

Kerosene, known as "coal oil," was cheaper, smelled better than animal fat when burned, and it didn't spoil like whale oil. By 1860, around 30 U.S. kerosene plants were in production. Kerosene was used to light homes and businesses before the invention of the electric light bulb by Thomas Edison in 1879.

Oil Wells

Although the first oil well in North America was drilled in Oil Springs, Ontario, in 1855, U.S. oil discovery peaked in 1930 with the discovery of the Spindletop, East Texas, field, which produced 80,000 barrels of oil per day.

For decades, industrialized, developed countries with only 20% of the world's population used around 80% of all the commercial energy; the rest of the world's population used the remaining 20%. However, with progress in countries like China and India, energy use is increasing substantially. It is estimated that China will use approximately the same amount of energy as Europe and North America by the year 2025 due to their sharp yearly increases in the past 15 years.

Oil Demand

TIP

Worldwide consumption of liquid fossil fuels rose to nearly 84 million barrels of oil per day in 2005, is expected to reach nearly 96 million barrels of oil per day by 2015, and over 112 million barrels of oil per day in 2030.

Americans use nearly 20% more transportation oil than we did 40 years ago. Even though today's vehicles are more fuel efficient, there are 50% more vehicles on the road today than in the 1970s.

Coal

Like liquid and gaseous fossil fuels, coal is derived from decayed organic plant material formed and compacted by geological forces into a high-carbon-containing fuel. Coal is found in almost every region, and is thought to have started forming in the Carboniferous period (286 million to 360 million years ago) when the Earth's climate was hotter and wetter than it is now.

TIP

The reason so many people consider coal to be a great fuel source is because global coal deposits are about 10 times greater than conventional oil and gas resources added together. Coal seams in rock can be 100 feet thick (around 35 meters) and stretch thousands of square miles across huge areas that were originally tropical rain forests in prehistoric times.

KEY IDEA

Coal deposits that have been mapped, measured, and found to be economically recoverable are known as *proven reserves. Known reserves* are coal deposits that have been identified but not well mapped, while *ultimate reserves* include known and unknown coal deposits.

Coal Demand

In 2003, coal provided 24% of the energy used globally. The IEO 2008 estimates coal consumption will increase by 2% per year from 2009 to 2015, and will account for 29% of total world energy consumption in 2030.

Global coal reserves are estimated at 10 trillion metric tons. At current rates of use and population growth, this may last several thousand years. However, extractable proven reserves will only last another 200 years at current consumption levels.

About a quarter of known coal reserves are in the United States. Many electricity-generating plants burn coal, and many people consider coal the nation's backup energy source.

Unfortunately, coal burning creates a lot of atmospheric and particulate pollution. In fact, coal combustion accounts for nearly 25% of all atmospheric mercury pollution in the United States today. With current technology, coal energy appears to be a win-lose situation.

Extraction and Purification Disadvantages

TIP

The major drawback to coal is that its extraction from the earth is extremely dangerous. Thousands of miners are killed every year in mining cave-ins and other accidents. Coal dust, thick in the mining process, is also very toxic to the lungs, causing *black lung disease* and other debilitating respiratory diseases. Though lessened with advanced respirators, black lung is a major occupational hazard for coal workers.

Strip or surface coal mining has fewer direct hazards to workers, but a huge impact on the local environment. The removal and processing of rock makes the area unfit for any other use. Prior to mine reclamation laws, mine drainage and acidic runoff from coal tailings were toxic by-products of strip mining. Thousands of miles of streams and creeks were polluted from coal mining operations. An additional insult to the Appalachian environment comes from the dumping of excess strip mining soil and debris into valleys, rural streams, farms, and other sites.

Coal is often contaminated with sulfur, sometimes as much as 10% by weight. This must be removed by washing or flue-gas scrubbing, or it will be released during burning to form sulfur dioxide (SO_2) or sulfate (SO_4). Burning releases or reacts to form around 18 million metric tons of SO_2, 5 million metric tons of nitrogen oxides (NO_x), 4 million metric tons of airborne particulates, 600,000 metric tons of hydrocarbons and carbon monoxide (CO), and nearly a trillion metric tons of carbon dioxide (CO_2). These atmospheric releases account for nearly 75% of the SO_2, 50% of the industrial CO_2, and 30% of the NO_2 released yearly in the United States. These and other pollutants negatively impact the environment, human and animal health, plants, and buildings.

The good news is that sulfur can be removed before coal is burned and nitrous oxide reactions can be limited. However, government policy, as well as economic and technological incentives will have to be strengthened and supported to a much greater degree to motivate change.

❯ Review Questions

Multiple-Choice Questions

1. What percentage of United States energy comes from fossil fuels?

(A) 10%
(B) 18%
(C) 37%
(D) 62%
(E) 85%

2. Coal is often contaminated with what element?

(A) carbon
(B) silicon
(C) sulfur
(D) uranium
(E) sodium

3. The amount of energy needed to heat 1 gram of water to 1 degree Celsius is a

(A) gigabyte
(B) pound
(C) liter
(D) calorie
(E) nanosecond

4. Solids, liquids, and gases created through the compression of ancient organic plant and animal material in the Earth's crust are called

(A) biomass
(B) inorganics
(C) sustainable fuels
(D) nuclear fuels
(E) fossil fuels

5. About 75% of the original energy in oil is lost during distillation into

(A) kerosene
(B) gasoline
(C) jet fuel
(D) road tar
(E) ethanol

6. Coal deposits that have been mapped, measured, and economically recoverable are known as

(A) ultimate reserves
(B) sustainable reserves
(C) proven reserves
(D) clean reserves
(E) known reserves

7. The force needed to accelerate 1 kilogram by 1 meter per second is called a

(A) ton
(B) meter per second
(C) joule
(D) calorie
(E) newton

8. In the industrialized world, the burning of fossil fuels is probably the biggest single source of

(A) air pollution
(B) water pollution
(C) urban blight
(D) economic income of developed countries
(E) international tensions between nations

9. Twenty percent of the total U.S. energy demand is used for lighting, heating, air conditioning, water heating, and

(A) cooking
(B) plastics
(C) transportation
(D) international export
(E) construction

10. The first oil well in North America was drilled in Oil Springs, Ontario, in

(A) 1855
(B) 1875
(C) 1905
(D) 1935
(E) 1955

11. Natural gas has much less waste since it needs little refining, is transported through underground pipelines, and burns with

(A) boron as an additive
(B) 75 to 95% efficiency
(C) atmospheric particulates
(D) smaller smoke stacks
(E) the same efficiency as oil

12. Coal dust is very toxic to the lungs and causes

(A) arthritis
(B) cancer
(C) premature births
(D) black lung disease
(E) bad breath

13. Before fossil fuels became commonly used, what was popularly used for lamp oils and candles?

(A) Lye
(B) Bacon grease
(C) Whale oil
(D) Seal fat
(E) Natural gas

14. A sedimentary rock containing solid organic matter is called

(A) tephra
(B) kerogen
(C) granite
(D) igneous rock
(E) gneiss

15. Prior to mine reclamation laws, mine drainage and acidic runoff from coal tailings were toxic by-products of

(A) tillage
(B) urban development
(C) underground mining
(D) strip mining
(E) industrial processing

16. A hotly debated area with large oil reserves is

(A) NAWR
(B) USDA
(C) western Europe
(D) WARN
(E) ANWR

17. Coal contaminants must be removed by washing or flue-gas scrubbing or they will be released during burning to form sulfur dioxide (SO_2), sulfate (SO_4), CO_2, NO_x, and

(A) $C_8H_8O_3$
(B) particulates
(C) KCl
(D) CH_3NH_2
(E) Ga_2O_3

18. When coal is used to produce electricity, what fraction of the original energy is lost in thermal conversion at the plant?

(A) $\frac{1}{4}$
(B) $\frac{1}{3}$
(C) $\frac{1}{2}$
(D) $\frac{2}{3}$
(E) $\frac{3}{4}$

› Answers and Explanations

1. E

2. C—Sulfur is a big contaminant of coal when burned, and combines with oxygen into atmospheric pollutants.

3. D

4. E

5. B

6. C—Huge energy losses during conversion make fossil fuel a poor choice for global energy demands.

7. E—Energy reserves must be proven or they have little value in energy planning.

8. A—Fossil fuel burning releases many different chemicals into the atmosphere.

9. A—Transportation and other U.S. energy demands far exceed cooking needs.

10. A—The first North American oil well was drilled over 150 years ago.

11. B—Natural gas is a clean-burning, high-efficiency fuel.

12. D—Black lung disease is an occupational hazard of coal mining, which causes inflammation and scarring of the lungs due to the long-term breathing of coal dust.

13. C—Whale oil was plentiful during the early years of the whaling industry and was used for lighting.

14. B—Kerogen is a fine-grain sedimentary rock also called oil shale.

15. D—Strip mining shears away rock and soil to get to deeper resource-bearing layers leaving huge amounts of waste rock, polluted water, and openly erosive surfaces.

16. E—The Alaska Arctic National Wildlife Refuge (ANWR) is home to thousands of caribou as well as millions of other species that ecologists fear will lose critical habitat during energy exploration.

17. B—Chemical pollutants, soot and other particulates are released during coal burning.

18. D—When coal is burned, around 65% of its energy is lost at the plant during thermal conversion to electricity.

Free-Response Questions

1. The People's Republic of China leads the world in reliance on coal as a fuel source. Coal accounts for around 70% of China's energy production and has fueled the country's swift rise in the global market. China's ever-increasing industrialization continues to increase the county's dependency on coal as its main fuel source. Though demand is currently outpacing production, China has enough coal reserves to sustain its economic growth for another century.

(a) What are the benefits of using coal over other fossil fuels?
(b) What problems might China face in its reliance on coal as a fuel source?
(c) What steps can China take to minimize the social and environmental risks of coal use?

2. The second law of thermodynamics states that the universe tends toward entropy (e.g., randomness). In terms of energy use, this means a fraction of an original energy amount is always lost after changing to another form. For example, much energy is lost through heat from turbines in a hydroelectric power plant.

(a) Can lost electric energy be retained?
(b) What modern materials might make energy transmission more efficient?

Free-Response Answers and Explanations

1.

a. The main reason coal provides a much better fuel source than other fossil fuels like oil and gas is because there is so much more of it. Global coal deposits are about 10 times greater than conventional oil and gas resources added together. Further, because it has been mapped and found economically recoverable, it is a proven resource. Though also a limited resource, it is extremely abundant.

b. Coal production for electricity can be extremely harmful to both the environment and public health. The process, from mining to waste disposal, creates both public and environmental risks. Because of hazardous substances contained within it (like mercury, sulfur dioxide, nitrogen oxides, and particulates), when coal is burned, it contaminates the air, land, and water.

c. Clean coal technology exists to help stem the tide of problems associated with using coal to produce electricity. Gasification can be used to convert coal into carbon monoxide and hydrogen, which can then be used as a fuel called synthetic gas. Chemicals can be used to wash the minerals and impurities out of coal, and flue gases can be treated with steam to prevent sulfur dioxide from escaping into the environment. Beyond clean coal technology, China can use alternative fuel sources like solar and wind power to help offset the current socioeconomic and environmental costs of coal use.

2.

a. Energy can be retained by keeping the amount and number of losses to a minimum.

b. Engineers and scientists are excited about the capabilities of carbon nanotubes as electrical transmission conduits. Individual carbon nanotube fibers have an electrical conductivity better than copper at only one-sixth the weight and with negligible current loss. Several researchers have demonstrated that a single-walled carbon nanotube can carry currents up to 20 microamperes. With current technology, losses in power transmission lines are about 7%. Dropping these losses to 6% would reap a national annual energy savings of 4×10^{10} kilowatt-hours (i.e., equal to about 24 million barrels of oil).

› Rapid Review

- The first law of thermodynamics explains that energy can be neither created nor destroyed.
- The second law of thermodynamics describes how the universe tends toward entropy (chaos, disorder, or randomness).
- In 1956, Shell Oil geophysicist M. King Hubbert calculated that the oil well extraction rate in the United States (lower 48 states) would peak around 1970.
- Fossil fuels are solids, liquids, and gases created through the compression of ancient organic plant and animal material in the Earth's crust.
- Currently, oil production in the United States from all sources is around 8 million barrels a day from over a half million wells.
- Fossil fuels produce around 85% of U.S. energy, with oil making up about 40% of that.
- Fossil fuel burning is the biggest single source of human-created air pollution in the industrialized world.
- Getting additional oil from a drilled deposit is known as secondary recovery.
- Canada is the biggest supplier of oil to the United States.
- In 1839, Abraham Gesner, a governmental geologist in Nova Scotia discovered albertite, a coal-like material. Later he discovered a process to manufacture kerosene.
- Kerosene, or "coal oil," was cheap and smelled better than animal fat when burned.
- When coal is used to produce electricity, nearly 65% of the original energy is lost in thermal conversion at the plant.
- One calorie unit equals the amount of energy needed to heat 1 gram of water to 1 degree Celsius.
- The *International Energy Outlook 2008* projects that global energy consumption will increase by 50% from 2005 to 2030.
- Coal is often contaminated with sulfur, sometimes as much as 10% by weight.
- The *International Energy Outlook 2008* estimates that coal will account for 29% of total world energy consumption in 2030.
- Coal burning creates a lot of atmospheric pollution and particulates, and increasing its use will worsen the global greenhouse problem.