

CHAPTER 1

A BRIEF HISTORY OF ENERGY CONSUMPTION

We all make decisions about energy. We decide how much electricity we will use to heat or cool our homes. We decide how far we will go every day and the mode of transportation we will use. Those of us in democracies choose leaders who create budgets that can support new energy initiatives or maintain a military capable of defending energy supply lines. Each of these decisions and many others impacts the global consumption of energy and the demand for available natural resources. The purpose of this book is to give you the information you need to help you make informed decisions.

The choices we make today will affect generations to come. What kind of future do we want to prepare for them? What kind of future is possible? We can make the best decisions by being aware of our options and the consequences of our choices. In this book, we consider the location, quantity and accessibility of energy sources. We discuss ways to distribute available energy, and examine how our choices will affect the economy, society, and the environment. Our understanding of each of these issues will help us on our journey to energy independence. We begin by defining energy and reviewing our history of energy consumption.

1.1 WHAT IS ENERGY?

Energy is the ability to do work. It can be classified as stored (potential) energy, and working (kinetic) energy. Potential energy is the ability to produce motion, and kinetic energy is the energy of motion. Forms of energy include energy of motion (kinetic energy), heat (thermal energy),

light (radiant energy), photosynthesis (biological energy), stored energy in a battery (chemical energy), stored energy in a capacitor (electrical energy), stored energy in a nucleus (nuclear energy), and stored energy in a gravitational field (gravitational energy).

Sources of energy with some common examples include biomass (firewood), fossil fuels (coal, oil, natural gas), flowing water (hydroelectric dams), nuclear materials (uranium), sunlight, and geothermal heat (geysers). Energy sources may be classified as renewable or non-renewable. Non-renewable energy is energy that is obtained from sources at a rate that exceeds the rate at which the sources are replenished. Examples of non-renewable energy sources include fossil fuels and nuclear fission material such as uranium. Renewable energy is energy that is obtained from sources at a rate that is less than or equal to the rate at which the sources are replenished. Examples of renewable energy include solar energy and wind energy.

Renewable and non-renewable energy sources are considered primary energy sources because they provide energy directly from raw fuels. A fuel is a material which contains one form of energy that can be transformed into another form of energy. Primary energy is energy that has not been obtained by anthropogenic conversion or transformation. The term “anthropogenic” refers to human activity or human influence. Primary energy is often converted to secondary energy for more convenient use in human systems. Hydrogen and electricity are considered secondary sources of energy, or “carriers” of energy. Secondary energy sources are produced from primary sources of energy. Secondary sources of energy can store and deliver energy in a useful form.

Modern civilization depends on the observation that energy can change from one form to another. If you hold this book motionless above a table and then release it, the book will fall onto the table. The book has potential energy when it is being held above the table. The potential energy is energy associated with the position of the book in a gravitational field. When you drop the book, the energy of position is transformed into energy of motion, or kinetic energy. When the book hits the table, some of

the kinetic energy is transformed into sound (sonic energy), and the rest of the kinetic energy is transformed into energy of position (potential energy) when the book rests on the table top.

Energy transformation is needed to produce commercial energy. As an illustration, suppose we consider a coal-fired power plant. Coal stores energy as chemical energy. Combustion, or burning the coal, transforms chemical energy into heat energy. In steam power plants, the heat energy changes water into steam and increases the energy of motion, or kinetic energy, of the steam. Flowing steam spins a turbine in a generator. The mechanical energy of the spinning turbine is converted to electrical energy in the generator. In a real system, energy is lost so that the efficiency of electrical energy generation from the combustion of coal is less than 100%. A measure of the energy that is available for doing useful work is called exergy.

Real power systems transform energy into useful work, but some of the energy is wasted. The energy efficiency of a system is the amount of energy needed by the system to perform a specific function divided by the amount of energy that is supplied to the system. Energy efficiency has a value between 0% and 100%. Some of the energy supplied to a real system is lost as non-useful energy so that the energy efficiency is less than 100%. For example, suppose we have two light bulbs A and B. Both light bulbs provide the same amount of light, but light bulb B uses less energy than light bulb A because light bulb B produces less heat than light bulb A. Light bulb B has a higher energy efficiency than light bulb A because light bulb B uses less energy to achieve its intended purpose, to provide light.

In the light bulb example, we can reduce energy use by adopting a more energy efficient technology. Another way to reduce energy use is to turn off the light when it is not needed. In this case, we are conserving energy by changing our behavior. Energy conservation is achieved by adopting a behavior that results in the use of less energy. An improvement in energy efficiency or conservation can be viewed as increasing

energy supply because improving energy efficiency or conservation lets us get more value from existing energy sources.

Point to Ponder: What does an energy unit mean to me?

To get an idea of the meaning of an energy unit such as kilocalorie or megajoule, it is helpful to compare the energy consumed by the operation of modern devices. For example, a 1200 Watt hair dryer uses approximately one megajoule of energy in 15 minutes. A megajoule is 1 million Joules, which can be written as 10^6 Joules or 10^6 J. A 100 Watt light bulb uses approximately one megajoule of energy in about three hours. [Fanchi, 2004, Exercise 1-3]

If we run the 1200 Watt hair dryer for one hour, we will use 1.2 kilowatt-hours of energy. We abbreviate 1.2 kilowatt-hours as 1.2 kWh. One kWh equals 1 kW times 1 hr, or about 3.6×10^6 J of energy. A typical American household will use between 20 and 50 kWh per day. Energy usage depends on many factors, such as use of appliances, heating or cooling, etc.

A typical power plant provides approximately 1000 megawatts of power, which is abbreviated as 1000 MW of power. The power plant can provide power to approximately 900,000 households that use 10,000 kWh per year for each household.

A unit of energy that is commonly used for discussing energy on a national scale is the quad. One quad equals one quadrillion British Thermal Units (BTU) or 10^{15} BTU. A BTU is approximately 1000 Joules, so one quad is approximately 10^{18} Joules. A quad is comparable in magnitude to global energy values. For example, in 2006 the United States consumed about 100 quads of energy and the world consumed about 472 quads of energy.

Units and scientific notation are reviewed in Appendix A.

1.2 HISTORICAL ENERGY CONSUMPTION

The history of energy consumption shows how important energy is to the quality of life for each of us. Societies have depended on different types

of energy in the past, and societies have been forced to change from one energy type to another. Global energy consumption can be put in perspective by considering the amount of energy consumed by individuals.

E. Cook [1971] provided estimates of daily human energy consumption at six different periods of societal development. The six periods from oldest to most recent are the Primitive Period, the Hunting Period, the Primitive Agricultural Period, the Advanced Agricultural Period, the Industrial Period, and the Technological Period. Cook's estimates are given in Table 1-1 for each period. The table shows that personal energy consumption was relatively constant until the Advanced Agricultural period when it increased substantially.

**Table 1-1
Historical Energy Consumption [Cook, 1971]**

Period	Era	Daily per capita Consumption (1000 kcal)				
		Food	H & C*	I & A**	Trans.***	Total
Primitive	1 million B.C.	2				2
Hunting	100,000 B.C.	3	2			5
Primitive Agricultural	5000 B.C.	4	4	4		12
Advanced Agricultural	1400	6	12	7	1	26
Industrial	1875	7	32	24	14	77
Technological	1970	10	66	91	63	230
* H & C = Home and Commerce ** I & A = Industry and Agriculture *** Trans. = Transportation						

Energy is essential for life, and food was the first source of energy. Cook assumed the only source of energy consumed by a person living

during the period labeled “Primitive” was food. Cook’s energy estimate was for an East African about one million years ago. Humans require approximately 2000 kilocalories (about eight megajoules) of food per day. One food Calorie is equal to one kilocalorie, or 1000 calories. One calorie is the amount of energy required to raise the temperature of one gram of water one degree Centigrade. A change in temperature of one degree Centigrade is equal to a change in temperature of 1.8 degrees Fahrenheit

The ability to control fire during the Hunting period let people use wood to heat and cook. Fire provided light at night and could illuminate caves. Firewood was the first source of energy for consumption in a residential setting. Cook’s estimate of the daily per capita energy consumption for Europeans about 100,000 years ago was 5,000 kilocalories (about 21 megajoules).

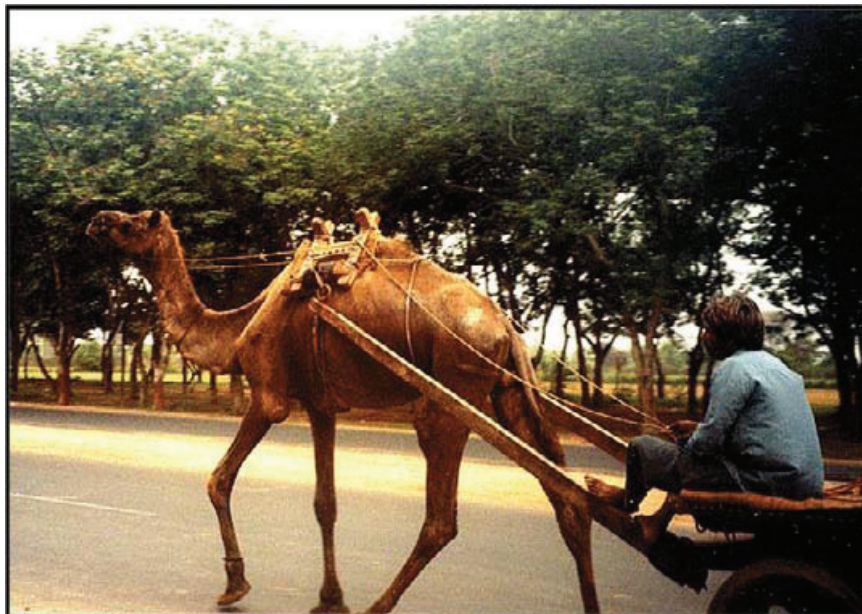


Figure 1-1. Animal Labor in Ahmedabad, India (Fanchi, 2000)

The Primitive Agricultural period was characterized by the domestication of animals. Humans were able to use animals to help them grow crops and cultivate their fields. The ability to grow more food than you needed became the impetus for creating an agricultural industry. Cook’s estimate of the daily per capita energy consumption for people in the

Fertile Crescent circa 5000 B.C. was 12,000 kilocalories (about 50 megajoules). Humans continue to use animals to perform work (Figure 1-1).

More energy was consumed during the Advanced Agricultural period when people learned to use coal, and built machines to harvest the wind and water. By the early Renaissance, people were using wind to push sailing ships, water to drive mills, and wood and coal for generating heat. Transportation became a significant component of energy consumption by humans. Cook's estimate of the daily per capita energy consumption for people in northwestern Europe circa 1400 was 26,000 kilocalories (about 109 megajoules).

The steam engine ushered in the Industrial period. It provided a means of transforming heat energy to mechanical energy. Wood was the first source of energy for generating steam in steam engines. Coal, a fossil fuel, eventually replaced wood and hay as the primary energy source in industrialized nations. Coal was easier to store and transport than wood and hay, which are bulky and awkward. Coal was useful as a fuel source for large vehicles, such as trains and ships, but of limited use for personal transportation. Oil, another fossil fuel, was a liquid and contained about the same amount of energy per unit mass as coal. Oil could flow through pipelines and tanks. People just needed a machine to convert the energy in oil to a more useful form. Cook's estimate of the daily per capita energy consumption for people in England circa 1875 was 77,000 kilocalories (about 322 megajoules).

The modern Technological period is associated with the development of internal combustion engines, and applications of electricity. Internal combustion engines can vary widely in size and use oil. The internal combustion engine could be scaled to fit on a wagon and create "horseless carriages." The transportation system in use today evolved as a result of the development of internal combustion engines. Electricity, by contrast, is generated from primary energy sources such as fossil fuels. Electricity generation and distribution systems made the widespread use of electric motors and electric lights possible. One advantage of electricity as an energy source is that it can be transported easily, but electricity is

difficult to store. Cook's estimate of the daily per capita energy consumption for people in the United States circa 1970 was 230,000 kilocalories (about 962 megajoules).

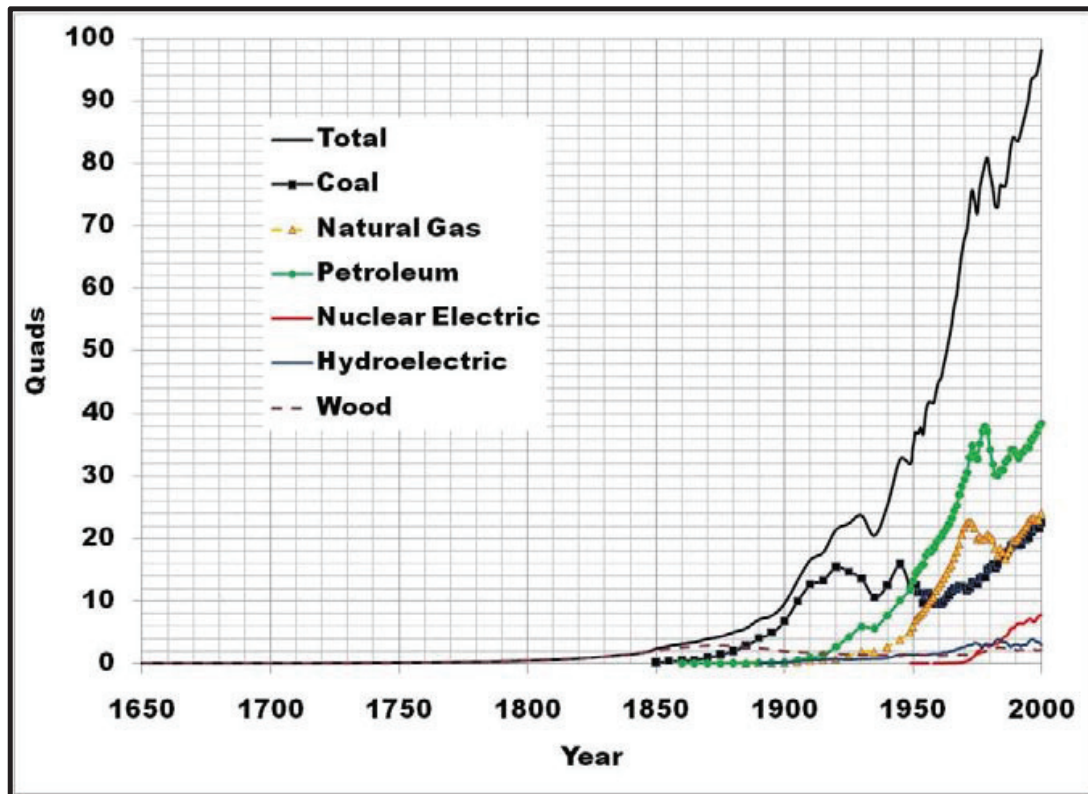


Figure 1-2. Historical Energy Consumption in the United States [US EIA website, 2001]

Figure 1-2 shows the consumption of energy in the United States from 1650 to 2000. The figure clearly shows that wood was the primary energy source for most of history. The transition from wood (a renewable energy source) to fossil fuels (a non-renewable energy source) began in the middle of the 19th century. Fossil fuels became the dominant energy source from the mid-19th century through the end of the 20th century. A similar scenario applies to other developed nations.

Table 1-2 shows that approximately 74 quads of energy were produced and 99 quads of energy were consumed by the United States in 2008. The energy that was not produced in the United States was imported.

Table 1-2
2008 United States Energy Production and Consumption
[US EIA website, 2008]

Energy Source	Production (quads)	Consumption (quads)
Total	73.71	99.30
Fossil Fuels	57.94	83.44
Electricity Net Imports		0.11
Nuclear Electric Power	8.46	8.46
Renewable Energy	7.32	7.30

The data in Table 1-2 is taken from data published by the Energy Information Administration (EIA) of the United States Department of Energy. Additional historical data for the United States from the EIA is presented in Appendix B, and analogous data for the world is presented in Appendix C. Energy data for the United States is used to illustrate energy production and consumption for an individual nation. All of the data reported in this book is subject to revision as data collection agencies acquire revisions and corrections of data from institutions to monitor and report energy consumption and production. Although the data is subject to revision, it is useful to view actual reported data so that we can get an idea of the magnitude of energy needed and the relative contributions of different energy sources to the energy mix.

Table 1-2 shows the production and consumption of energy in the United States. The unit of energy is the quad, or quadrillion BTU. Although four energy sources are identified, the three dominant energy sources are fossil fuels, nuclear electric power, and renewable energy.

Table 1-3 presents the relative contributions of different energy sources to 2008 United States energy production and consumption as percent of total values shown in Table 1-2. Fossil fuels were the dominant contributor to the United States energy mix in 2008. This provides a snapshot of the United States energy mix. The data in Appendix B shows that the relative contribution of energy sources to the United States ener-

gy mix is changing with the contribution of fossil fuels declining while the contribution of renewable energy sources is increasing. The increasing role of renewable energy sources is also occurring on a global scale, as discussed in Section 1-5.

Table 1-3
2008 United States Energy Production and
Consumption as % of Annual Amount
[US EIA website, 2008]

Energy Source	Production (%)	Consumption (%)
Total	100.0	100.0
Fossil Fuels	78.6	84.0
Electricity Net Imports		0.1
Nuclear Electric Power	11.5	8.5
Renewable Energy	9.9	7.4

Table 1-4 shows how the energy consumed in the United States in 2008 was distributed between energy sectors. Definitions of the composition of each energy sector are provided by the United States EIA. The transportation sector includes vehicles that transport people or goods.

Table 1-4
2008 United States Energy Consumption by Sector
[US EIA website, 2008]

Sector	Consumption (%)
Transportation	27.8
Industrial	20.6
Residential and Commercial	10.8
Electric power	40.1

1.3 ENERGY CONSUMPTION AND THE QUALITY OF LIFE

The existing per capita energy consumption discussed above gives us an idea of how much energy each of us uses today, but it does not tell us how much energy each of us should use. One way to estimate the amount of energy each person should use is to examine the relationship between energy consumption and quality of life.

Quality of life is a subjective concept that can be quantified in several ways. The United Nations calculates a quantity called the Human Development Index (HDI) to provide a quantitative measure of the quality of life. The HDI measures human development in a country using three basic factors: health, knowledge, and standard of living. Table 1-5 presents measures for each factor.

Gross Domestic Product (GDP) accounts for the total output of goods and services from a nation and is a measure of the economic growth of the nation. The HDI is a fraction that varies from zero to one. A value of HDI that approaches zero is considered a relatively low quality of life, while a value of HDI that approaches one is considered a high quality of life.

Table 1-5
Basic Factors of the United Nations Human Development Index

Factor	Measure
Health	Life expectancy at birth
Knowledge	Combination of adult literacy and school enrollment
Standard of Living	GDP per capita

A plot of HDI versus per capita electricity consumption for all nations with a population of at least one million people is shown in Figure 1-3. Per capita electricity consumption is the total amount of electricity consumed by the nation divided by the population of the nation. The amount of electricity is expressed in kilowatt-hours (kWh) in the figure. Per capita

electricity generation is an estimate of the average amount of electricity consumed by each individual in the nation. The calculation of per capita electricity consumption establishes a common basis for comparing the consumption of electricity between nations with large populations and nations with small populations. The HDI data are 2006 data from the United Nations Human Development Report [UN HDI, 2009], and annual per capita electricity consumption data are 2006 data reported by the Energy Information Administration of the United States Department of Energy [US EIA website, 2009].

Figure 1-3 shows that quality of life, as measured by HDI, increases as per capita electricity consumption increases. It also shows that the increase is not linear; the improvement in quality of life begins to level off when per capita electricity consumption rises to about 4000 kilowatt-hours. A similar plot can be prepared for per capita energy consumption and is shown in Figure 1-4.

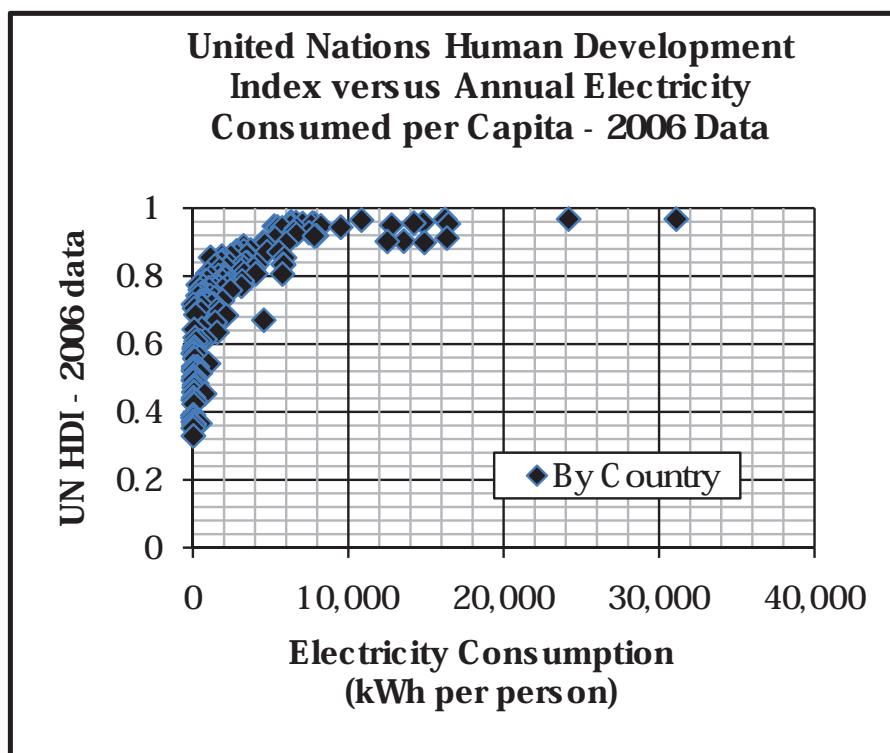


Figure 1-3. Human Development and Annual Electricity Consumption

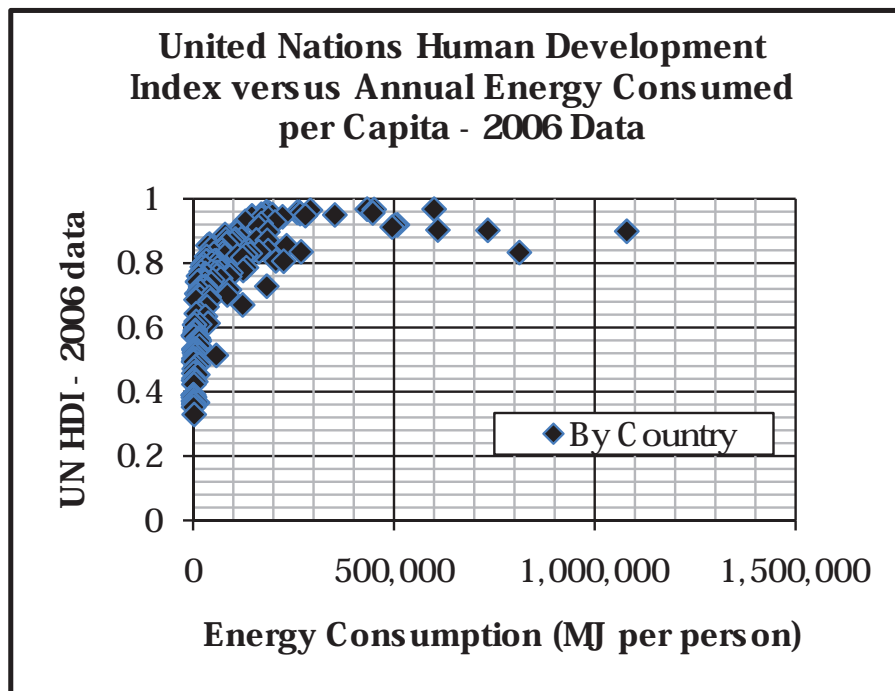


Figure 1-4. Human Development and Annual Energy Consumption

Figure 1-4 is a plot of HDI versus per capita energy consumption for nations with a population of at least one million people. The HDI data are 2006 data from the United Nations Human Development Report [UN HDI, 2009], and annual per capita energy consumption data are 2006 data reported by the Energy Information Administration of the United States Department of Energy [US EIA website, 2009]. The figure shows that quality of life increases as per capita energy consumption increases. As in Figure 1-3, the increase is not linear; the improvement in quality of life begins to level off when per capita energy consumption rises to about 200,000 megajoules per person.

The countries with the largest HDI values, in excess of 90%, are nations with relatively mature economies such as western European nations, Canada, Australia, the United Kingdom, Japan, and the United States. These countries tend to have relatively large middle classes. Table 1-6 lists per capita consumption for the 15 countries with the largest UN HDI. The numbers are subject to change when databases are updated or corrected, but the data in the table does illustrate the relative magnitude of per capita consumption for each country. Some people may

be surprised to see that the United States is not the largest consumer of energy or electricity on a per capita basis.

Table 1-6
Per Capita Consumption for Countries
with the Largest UN HDI (2006 Data)

Country	UN HDI	Per Capita Consumption	
		Electricity (kWh/person)	Energy (MJ/person)
Iceland	0.968	31103	599,905
Norway	0.968	24175	433,352
Canada	0.967	16228	450,670
Australia	0.965	10855	292,118
Ireland	0.960	6320	182,929
Netherlands	0.958	6643	264,681
Sweden	0.958	14812	259,274
Japan	0.956	7705	188,519
Luxembourg	0.956	14224	447,457
France	0.955	7063	190,669
Switzerland	0.955	7811	180,055
Finland	0.954	16446	266,622
Denmark	0.952	6362	170,199
Austria	0.951	7610	197,501
United States	0.950	12789	352,990

Point to Ponder: How can we use quality of life to forecast energy consumption?

The data used to prepare Figures 1-2 and 1-3 can also be used to make a quick forecast of energy demand. Suppose we assume that the world population will stabilize at approximately 8 billion people in the 21st century and that all people will want the quality of life represented by an HDI value of 0.9 (which is

approximately the HDI value achieved by Portugal, Qatar, and the Czech Republic). In this scenario, the annual per capita energy demand from Figure 1-4 is approximately 200,000 megajoules per person, or 1.6×10^{15} MJ \approx 1500 quads. The world population of approximately 6.4 billion people consumed approximately 472 quads of energy in 2006. According to this scenario, worldwide energy demand will need to triple by the end of the 21st century when compared to worldwide energy consumption in 2006. Annual per capita energy consumption will have to increase from an average of 76,000 megajoules per person in 2006 to the desired value of 200,000 megajoules per person in 2100. This calculation illustrates the types of assumptions that must be made to prepare forecasts of energy demand. At the very least, a forecast of demand for energy at the end of the 21st century needs to provide an estimate of the size of the population and the per capita demand for energy at that time. [Fanchi, 2004, Chapter 1]

1.4 ENERGY IN TRANSITION

Coal was the first fossil fuel to be used on a large scale. J.U. Nef [1977] described 16th century Britain as the first major economy in the world that relied on coal. Britain was dependent on wood before it switched to coal. The transition from wood to coal during the period from about 1550 A.D. to 1700 A.D. was made necessary by the excessive consumption of wood that was leading to the deforestation of Britain. Coal was a combustible fuel that could be used as an alternative to wood.

Coal was the fuel of choice during the Industrial Revolution. It was used to boil steam for steam turbines and steam engines. Coal was used in transportation to provide a combustible fuel for steam engines on trains and ships. The introduction of the internal combustion engine made it possible for oil to replace coal as a fuel for transportation. Coal is used today to provide fuel for many coal-fired power plants.

People have used oil for thousands of years [Yergin, 1992, Chapter 1]. Civilizations in the Middle East, such as Egypt and Mesopotamia, collected oil in small amounts from surface seepages as early as 3000-2000 B.C. During that period, oil was used in building construction, waterproofing boats and other structures, setting jewels, and mummification. Arabs began using oil to create incendiary weapons as early as 600 A.D. By the 1700's, small volumes of oil from sources such as surface seepages and mine shafts were being used in Europe for medicinal purposes and in kerosene lamps. Larger volumes of oil could have been used, but Europe lacked adequate drilling technology.

Pulitzer Prize winner Daniel Yergin [1992, page 20] chose George Bissell of the United States as the person most responsible for creating the modern oil industry. Bissell realized in 1854 that rock oil - as oil was called in the 19th century to differentiate it from vegetable oil and animal fat - could be used as an illuminant in lamps. He gathered a group of investors together in the mid-1850's. The group formed the Pennsylvania Rock Oil Company of Connecticut and selected James M. Townsend to be its president.

Bissell and Townsend knew that oil was sometimes produced along with water from water wells. They believed that rock oil could be found below the surface of the earth by drilling for oil in the same way that water wells were drilled. Townsend commissioned Edwin L. Drake to drill a well in Oil Creek, near Titusville, PA. The location had many oil seepages. The project began in 1857 and encountered many problems. By the time Drake struck oil on Aug. 27, 1859, a letter from Townsend was en route to Drake to inform him that funds were to be cut off [van Dyke, 1997].

Drake's well caused the value of oil to increase dramatically. Oil could be refined for use in lighting and for cooking. The substitution of rock oil for whale oil, which was growing scarce and expensive, reduced the need to hunt whales for fuel to burn in lamps. Within fifteen months of Drake's strike, Pennsylvania was producing 450,000 barrels of oil a year from seventy-five wells. By 1862, three million barrels of oil were being produced

and the price of oil dropped to ten cents a barrel [Kraushaar and Ristinen, 1993].

The Pennsylvania oil fields provided a relatively small amount of oil to meet demand. In 1882, the invention of the electric light bulb caused a drop in the demand for kerosene. The drop in demand for rock oil was short lived, however. The quickly expanding automobile industry needed oil for fuel and lubrication. New sources of oil were discovered in the early 20th century. Oil was found in Ohio and Indiana, and later in the San Fernando Valley in California and near Beaumont, Texas.



Figure 1-5. Spindletop, Gladys City Boomtown Museum, Beaumont, Texas (Fanchi, 2003)

The world's first gusher, a well that produced as much as 75,000 barrels of oil per day, was drilled at Spindletop Hill near Beaumont (Figure 1-5). The well was named Lucas-1 after Anthony F. Lucas, its driller and an immigrant from the Dalmatian coast (now Croatia). The well was notable because it was drilled using rotary drilling, a modern drilling technique discussed in more detail later, and it produced so much oil at such a high rate that it demonstrated oil could be used as an energy source on a global scale.

Industrialist John D. Rockefeller began Standard Oil in 1870 and by 1879 the company held a virtual monopoly over oil refining and transportation in the United States. Rockefeller's control of the oil business made him rich and famous. The Sherman Antitrust Act of 1890 was used by the United States government to break Rockefeller's grip on the oil industry. Standard Oil was found guilty of restraining trade and a Federal court ordered the dissolution of Standard Oil in 1909. The ruling was upheld by the United States Supreme Court in 1911 [Yergin, 1992, Ch. 5].

By 1909, the United States produced more oil than all other countries combined, producing half a million barrels per day. Up until 1950, the United States produced more than half of the world's oil supply. Discoveries of large oil deposits in Central and South America and the Middle East led to decreased United States production. Production in the United States peaked in 1970 and has since been declining. However, oil demand in the United States and elsewhere in the world has continued to grow. Since 1948, the United States has imported more oil than it exports. Today, the United States imports about half of its oil needs.

Until 1973, oil prices were influenced by market demand and the supply of oil that was provided in large part by a group of oil companies called the "Seven Sisters." This group included Exxon, Royal Dutch/Shell, British Petroleum (BP), Texaco, Mobil, Standard Oil of California (which became Chevron), and Gulf Oil. In 1960, Saudi Arabia led the formation of the Organization of Petroleum Exporting Countries, commonly known as OPEC. It was in 1973 that OPEC became a major player in the oil business by raising prices on oil exported by its members. This rise in price contributed to the "first oil crisis" as prices for consumers in many countries jumped. OPEC members in 2008 are Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela [US EIA website, 2009, OPEC Revenues Factsheet].

Today, fossil fuels are still the primary fuels for generating electrical power, but society is becoming increasingly concerned about the global dependence on finite resources and the environmental impact of fossil

fuel combustion. As a result, society is in the process of changing the global energy mix from an energy portfolio that is heavily dependent on fossil fuels to an energy portfolio that depends on several energy sources. The transition process began in the latter half of the 20th century and is illustrated in Figure 1-6.

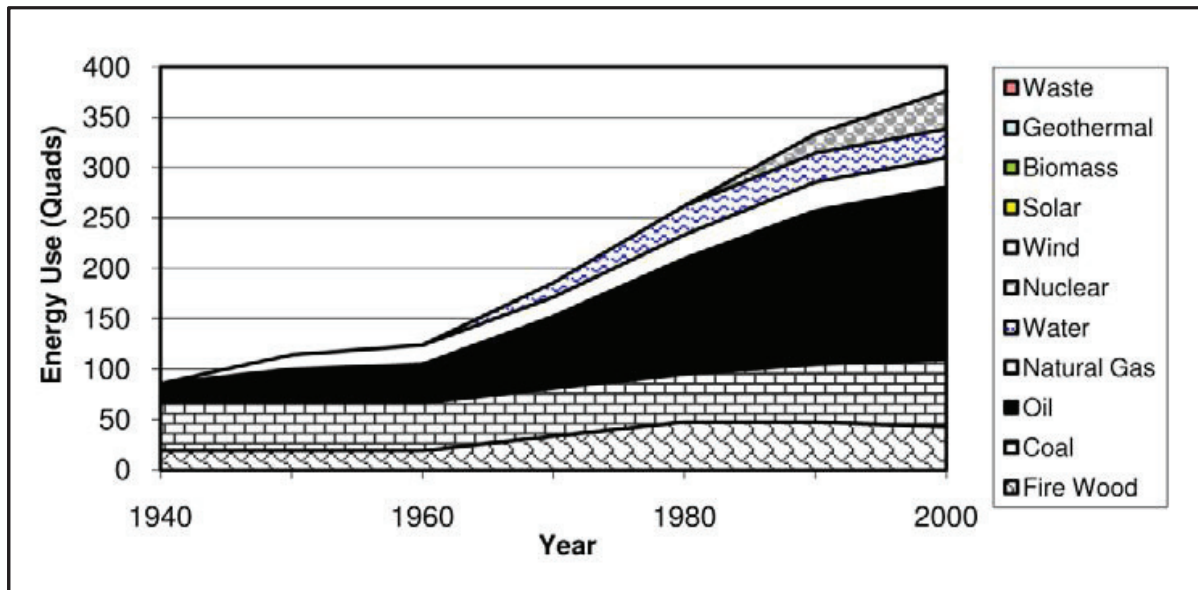


Figure 1-6. World Historical Energy Consumption

Figure 1-6 shows total energy consumption in quads from 1940 to 2000. In 1940, the world relied on firewood, coal and oil. Natural gas, energy from water, especially hydropower from dams, and nuclear energy joined firewood, coal and oil as important contributors to the energy mix by the end of the 20th century. Other energy sources - identified as wind, solar, biomass, geothermal and waste in Figure 1-6 - were beginning to make an appearance in the global energy mix at the beginning of the 21st century. They do not appear in the figure because their impact was negligible in the last half of the 20th century. One of the factors that supported the selection of fossil fuels and nuclear energy as fuels of choice is energy density.

Energy density is energy contained per unit volume of material. Fossil fuels have relatively large energy densities and have been preferentially chosen as the raw fuel for power plants. Raw fuels such as oil, coal, natu-

ral gas, and uranium are present in nature and can be used to provide primary energy.

The dominance of fossil fuels in the energy mix at the end of the 20th century is being replaced by a move toward sustainable energy. Sustainable energy is the mix of energy sources that will allow society to meet its present energy needs while preserving the ability of future generations to meet their needs. This definition is a variation of the concept of sustainable development introduced in 1987 in a report prepared by the United Nations' World Commission on Environment and Development. The Commission, known as the Brundtland Commission after chairwoman Gro Harlem Brundtland of Norway, said that society should adopt a policy of sustainable development that allows society to meet its present needs while preserving the ability of future generations to meet their own needs [WCED, 1987].

Point to Ponder: Why should I care about the global distribution of energy?

Suppose a country with a population of 20 million people wants to provide enough energy to sustain a quality of life corresponding to a United Nations HDI of 0.9. The country will require 200,000 megajoules per person of energy each year. This corresponds to approximately 127 power plants with 1000 megawatts capacity each. [Fanchi, 2004, Exercise 1-10] Where will this energy come from?

Today, energy on a national scale comes primarily from fossil fuels such as oil, gas and coal. In a few countries such as France, it is provided by nuclear fission. If the country does not have significant reserves of fossil fuels or uranium - a material needed for most nuclear fission reactors - it will have to import the materials it needs. In this case the country is a "have not" country that is dependent on countries that have the resources and technology it needs. This creates an opportunity for "have" countries to manipulate "have not" countries. On the other hand, it creates an incentive for "have not" countries to use its human

resources to take what is needed. For example, the “have not” country could maintain a large standing army or sponsor acts of violence to influence “have” countries. The global distribution of energy influences relationships between nations and can affect geopolitical stability.

1.5 "DECARBONIZATION"

Energy forecasts rely on projections of historical trends. Table 1-7 presents historical data for global energy production reported by the United States Energy Information Administration for the last four decades of the 20th century.

Table 1-7
World Primary Energy Production by Source, 1970 - 2006
 [US EIA website, 2009]

Primary Energy	Primary Energy Production (as % of total)				
	1970	1980	1990	2000	2006
Total	100.0	100.0	100.0	100.0	100.0
Fossil Fuels	93.2	90.1	86.7	85.4	86.2
Nuclear Electric Power	0.4	2.6	5.8	6.5	5.9
Renewable Energy	6.4	7.2	7.5	8.1	7.9
Total (quads)	215.4	287.6	349.9	395.7	469.4

The table shows historical energy production as a percent contribution to the total energy mix. The row of data labeled “Fossil Fuels” includes coal, petroleum and natural gas. Petroleum refers to hydrocarbon liquids such as crude oil and natural gas plant liquids. The row of data labeled “Renewable Energy” includes hydroelectric energy, geothermal energy, wind energy, solar energy, and bioenergy. The line of data labeled “Total (quads)” shows the total energy in quads produced for the specified year.

Published statistical data are subject to revision, even if the data are historical data that have been published by a credible source. Data revisions may change specific numbers as new information is received and used to update the database, but it is reasonable to expect the data presented in Table 1-7 to show qualitatively correct trends.

The data in Table 1-7 are graphically displayed in Figure 1-7. The data show the dominance of fossil fuels in the energy mix at the end of the 20th century. The current contribution from fossil fuels is approximately 86%.

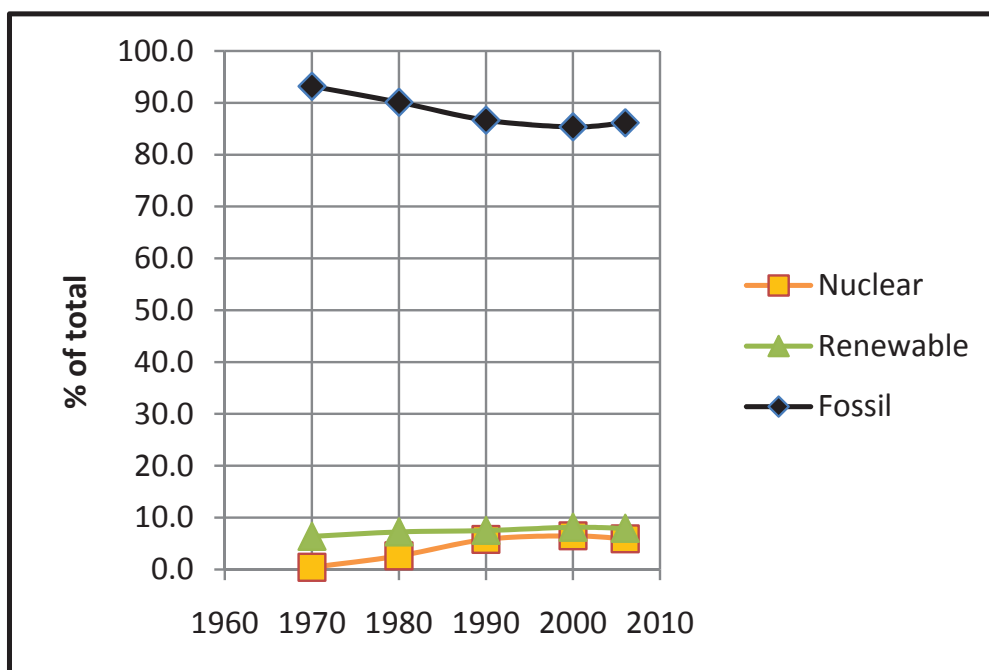


Figure 1-7. Percent Contribution of Different Energy Types to Historical Energy Production for the World from 1970 to 2006

The trend in the 20th century has been a “decarbonization” process, that is, a move away from fuels with many carbon atoms to fuels with few or no carbon atoms. H.J. Ausubel [2000, page 18] defined decarbonization as “the progressive reduction in the amount of carbon used to produce a given amount of energy.” Figure 1-8 illustrates how the carbon to hydrogen ratio (C:H) declines as the fuel changes from carbon-rich coal to carbon-free hydrogen. The result of decarbonization will be a low carbon economy, or a low fossil fuel economy, but not necessarily a hy-

drogen economy. The use of hydrogen as a fuel in a hydrogen economy and other possible scenarios are discussed in more detail later.

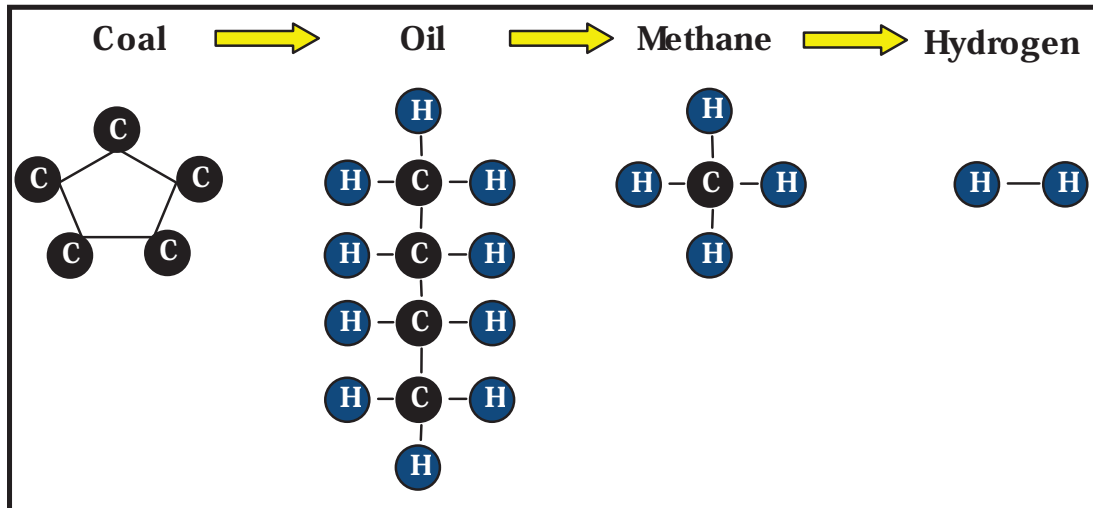


Figure 1-8. Decarbonization Among Fuels

Point to Ponder: Why would an oil rich country worry about alternative energy?

The trend toward decarbonization can help explain why a country, like Iran, that is rich in fossil fuels would seek to develop nuclear energy and alternative energy sources. Even if the country is able to export fossil fuels such as oil and gas for centuries to come at its current rate of export, the country can look at forecasts of energy consumption and see that the market is changing. They can use revenue from the sale of fossil fuels to help them transition to new energy sources. The remaining fossil fuels, especially oil, can be used for other applications besides fuel. For example, oil is used in the manufacture of plastics and other refined products such as lubricants.

1.6 ACTIVITIES

True-False

Specify if each of the following statements is True (T) or False (F).

1. The steam engine transformed heat energy to mechanical energy.
2. Decarbonization is the progressive increase in the amount of carbon used to produce a given amount of energy.
3. Per capita energy consumption is the amount of energy consumed per person.
4. The Sherman Antitrust Act of 1890 was used to break up Standard Oil in 1909.
5. The use of rock oil reduced the need to hunt whales for fuel.
6. A quad is a unit of energy and refers to a quadrillion BTU.
7. Per capita energy consumption is the amount of energy consumed per day.
8. Energy efficiency has a value between 0% and 100%.
9. Fossil fuels are preferred as raw energy sources because of their small energy densities.
10. "Sustainable Development" seeks to reach a balance between meeting current needs and preserving the ability of future generations to meet their needs.

Questions

1. What is the maximum value of the Human Development Index that a country can reach (the highest possible number)?
2. Which of the following companies was *not* one of the "Seven Sisters": Exxon, Royal Dutch/Shell, British Petroleum, Marathon, Texaco, Mobil, or Gulf Oil?
3. Name three non-fossil energy sources included in the global energy mix.
4. What are the three components of the United Nations Human Development Index?
5. Why did Britain switch to coal from wood as its primary energy source in the 16th century?

6. Use the following table to estimate the percent of world energy consumption that was due to fossil fuels in 2002.

Primary Energy Type	Total World Energy Consumption [Source: US EIA website, 2002]
Oil	39.9 %
Natural Gas	22.8 %
Coal	22.2 %
Hydroelectric	7.2 %
Nuclear	6.6 %
Geothermal, Solar, Wind & Wood	0.7 %

7. A measure of the energy that is available for doing useful work is called _____.
8. Which measure of energy is larger: one BTU or one megajoule?
9. What is Gross Domestic Product?
10. Why might a “have not” country with a large standing army be dangerous?