Energy: Global and Historical Background

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Abstract
The global and historical overview of energy use is presented with emphasis on energy diversity but also universality. Starting from ancient civilization a chronology of selected energy-related events is presented. It starts from the prehistoric age, when humans relied on their muscular power to survive; then they learned how to control and use fire, and to domesticate and use animal power, and slowly evolved from hunters and food-gatherers to developers of early agriculture. The use of water and wind power (waterwheels and windmills) expanded human activities and mobility. Further developments included smelting copper and iron ores; using charcoal; and developing different tools, gunpowder, and sailing ships. The use of coal in the mid-1700s and the development of steam engines set off fast growth of cities, population, and further inventions, including internal-combustion engines and the discovery and use of oil, natural gas, and electricity. This accelerated growth period, known as the Industrial Revolution, matured by the end of the 19th century with significant use of fossil fuels and further electrification, and resulted in almost-exponential growth of population and energy use. After the development of nuclear energy and the realization that the abundance of inexpensive fossil fuels will come to an end, along with concern about global environmental pollution, a modern era, with computerization and global Information Revolution, has been taking place. After all developments, life may be happier in the post-fossil fuel era, which represents only a bleep on the human-history radar screen.

INTRODUCTION AND GLOBAL OVERVIEW: ENERGY DIVERSITY AND UNIVERSALITY

The historical overview of energy intrinsically includes geological and societal (human) chronological developments. Energy is more than universal currency. The world view from inside to outside is possible, figuratively and literally, only through the energy prism. From shining stars to rotating planets; to global water, atmospheric, and life cycles; to the evolution, industrialization, and modernization of civilization, energy is the cause and measure of all that there has been, is, and will be.

Each and every material system in nature possesses energy. The structure of any matter and field is energetic, meaning active—i.e., photon waves are traveling in space; electrons are orbiting an atom nucleus or flowing through a conductor; and atoms and molecules are in constant interactions, vibrations, or random thermal motions. Energy is a fundamental property of material systems and refers to the system's potential to influence changes to another system by imparting work (forced directional displacement) or heat (forced chaotic displacement/motion of a system microstructure). Energy exists in many forms: electromagnetic, electrical, magnetic, nuclear, chemical, thermal, and mechanical. Electromechanical energy may be kinetic or potential, whereas thermal energy represents overall chaotic motion energy of molecules and related microstructures. Energy is the cause of all processes across all space and time scales, including global and historical changes. Actually, energy is "the building block" and fundamental property of matter and space; thus, it is a fundamental property of existence, as elaborated in the "Physics of Energy" article in this encyclopedia and elsewhere.[1,2] Energy is both the cause and the consequence of formation and transformation within the universe (everything we are capable of observing or comprehending) at the grand scale, down to the smallest subnanostructures within an atom nucleus and electromagnetic radiation.

Energy warms our planet Earth and keeps it alive. It moves cars and trains, and boats and planes. Energy bakes foods and keeps them frozen for storage. It lights our homes and plays our music. Energy makes our bodies grow and live and allows our minds to think. Through the centuries people have learned how to harvest and use energy in different forms to do work more easily and live more comfortably. No wonder that energy is often defined as ability to perform work—i.e., as a potential for energy transfer in a specific direction (displacement in force direction), thus achieving a purposeful process, as opposed to dissipative (less-purposeful) energy transfer in the form of heat.

Zooming in space and history from the formation of our planet Earth some 4.5 billion years ago, it is observed that our planet has been changing ever since due to energy

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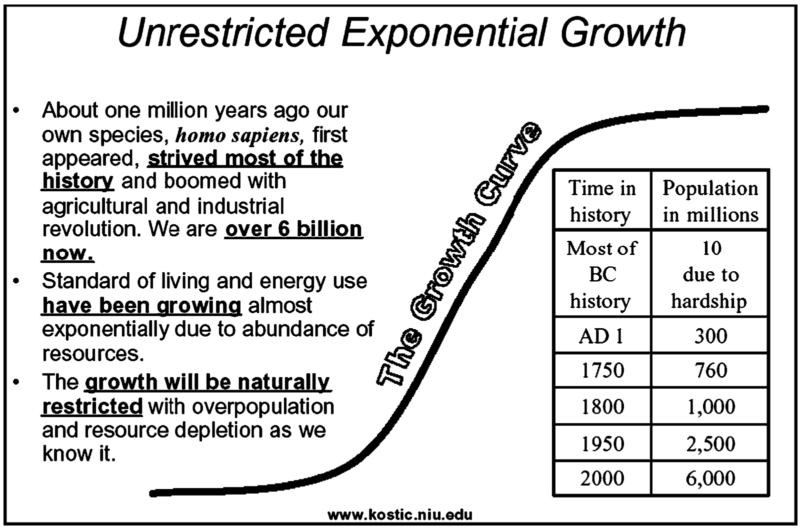


Fig. 1 Population historical growth caused by energy use.

exchanges or "energy flows" in different astrophysical, geological, chemical, biological, and intellectual processes. Hundreds of millions of years ago, life emerged from the oceans and transformed the landscape. Just a few million years ago, the first human species evolved and began its own process of interaction with its environment: the planet Earth. About 1 million years ago our own species, *Homo sapiens*, first appeared, then strived most of the history, and boomed with agricultural and the Industrial Revolution (see Fig. 1).

The current world population is about 6.3 billion. Standards of living and energy use have been growing almost exponentially due to an abundance of resources (see Fig. 2).[3] Today we humans have become sufficiently numerous and technologically active that we may be having a global impact on our planet Earth's environment.[4–6] Growth as we know it, however, will be naturally restricted by overpopulation and resource depletion (see Fig. 1). Two things are certain: in the not-too-distant future (1) the world population and its living-standard expectations will increase substantially, and (2) economical reserves of fossil fuels, particularly oil and natural gas, will decrease substantially. The difficulties that will face every nation and the world in meeting energy needs over the next several decades will be more challenging than what we anticipate now. The traditional solutions and approaches will not solve the global energy problem. New knowledge, new technology, and new living habits and expectations must be developed, both to address the quantity of energy needed to increase the standard of living worldwide and to preserve and enhance the quality of our environment.

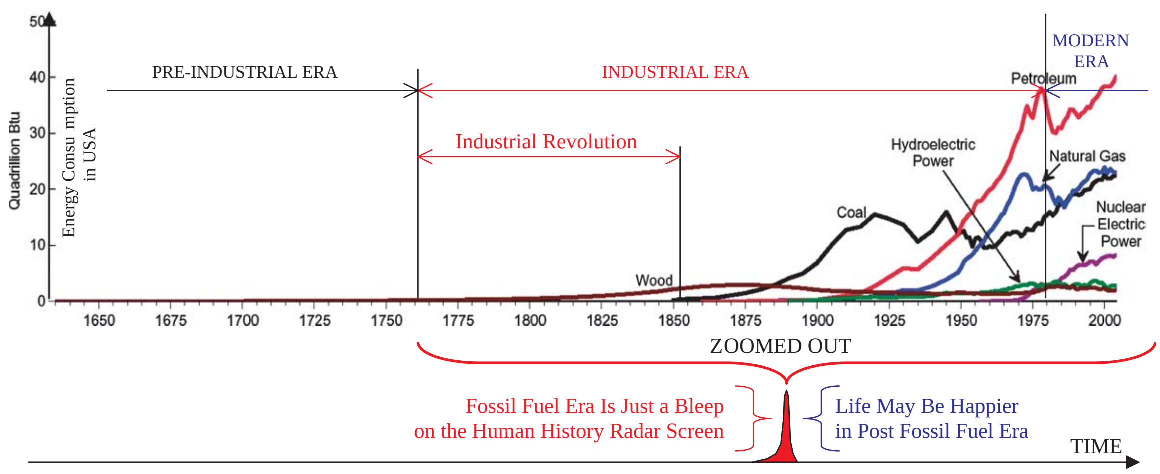


Fig. 2 Energy in history: PreIndustrial era encompasses human evolutionary survival and development of agriculture. Industrial era starts with Industrial Revolution and use of fossil fuels (just a bleep on the human history radar screen). Modern era start with human awareness of fossil fuel depletion and environmental pollution concerns.
Source: From U.S. Department of Energy (see Ref. 3).

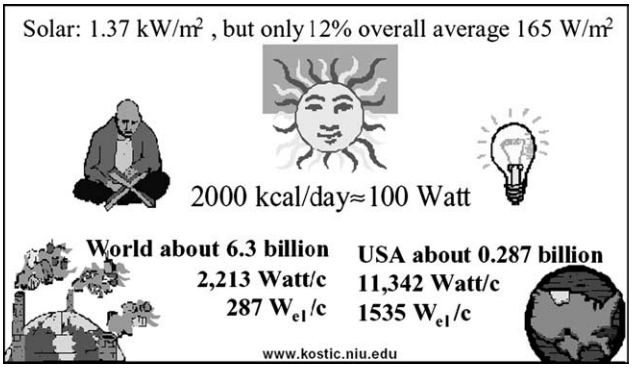


Fig. 3 Energy data: solar energy; dietary metabolic energy; and world and USA energy consumption per capita (per Person).

The human metabolism needed to maintain life is approximately equal to the dietary energy reference value of 2000 kcal/day, which is equivalent to 97 W or 331 Btu/h. Human sustained working power is about 75 W, or one-tenth of 1 hp. Human muscular power bursts may be a hundred times greater than basal metabolic or sustained power. By comparison, the world's population is about 6.3 billion, with total energy consumption about 7550 Btu/h or 2.21 kW per capita (or 11.34 kW per capita for a population of about 0.3 billion in the United States). The total energy rate in kW is often scaled by the typical 33% of thermal-to-electrical conversion efficiency to be compared qualitatively with the electrical energy rate in kW, and vice versa. The corresponding per-capita electricity consumption rate is 0.287 kW and 1.535 kW in the world and the United States, respectively (see Fig. 3).

The total energy coming to the Earth's surface is 99.98% solar, 0.02% geothermal, and 0.002% tidal/gravitational. Currently, about 14 TW (Terawatt, or 2.2 kW/capita [per person]) of the world's energy consumption rate represents only a tiny fraction—0.008%—of the solar energy striking Earth and is about six times smaller than global photosynthesis (all life). Global photosynthesis is only 0.05% of total solar energy, whereas global atmospheric water and wind are about 1% of solar energy. Note that the energy rate or power of $1\ TW = 10^{12}\ W = 29.9$ QBtu/year $= 5.89$ bbl/year (billion barrels of oil per year) and 1 Quad (QBtu) $= 10^{15}$ BTU $= 1.055 \times 10^{18}$ Joule $=$ 1.055 EJ (Exa-Joule). For energy-unit conversion and fuel, and other energy equivalents, see below and Table 1.

As an ultimate energy source for virtually all natural processes, the solar energy is available for direct "harvest" if needed and is absorbed by vegetation and water surfaces on Earth, thus being the driving force for natural photosynthesis and, in turn, for biosynthesis processes, as well as the natural water cycle and all atmospheric processes. (See the solar-related renewable energy sources in Table 2.) The solar-radiation power density incident to Earth's atmosphere, known as the Solar Constant, is 2 cal/min/cm^2 or about 1.4 kW/m^2—which, after taking into account average day/night time (50%), varying incident angle (50%), and atmospheric/cloud scatter and absorption (53%), reduces to only $0.5 \cdot 0.5 \cdot 0.47 = 11.7\%$ of the Solar Constant, or about 165 W/m^2 at the Earth's surface, as the all-time average (see Fig. 3).

Table 1 Energy units with conversion factors and energy equivalents

Energy units	J	KWh	Btu
1 Joule (J)	1	2.78×10^{-7}	9.49×10^{-4}
1 Kilowatt hour (kWh)	3.6×10^{6}	1	3.412×10^{3}
1 Kilocalorie (kcal = Cal = 1000 cal)	4187	1.19×10^{-3}	3.968
1 British thermal unit (Btu)	1055	2.93×10^{-4}	1
1 Pound-force foot (lb_f ft)	1.36	$3.78\ 10^{-7}$	1.29×10^{-3}
1 Electron volt (eV)	1.6×10^{-19}	4.45×10^{-26}	1.52×10^{-22}
1 Horsepower × second (hp s)	745.7	2.071×10^{-4}	0.707
Energy equivalents	**J**	**KWh**	**Btu**
1 Barrel (42 gal) of crude petroleum	6.12×10^{9}	1700	5.80×10^{6}
1 Ton (2000 lb) of bituminous coal	2.81×10^{10}	7800	2.66×10^{7}
1000 Cubic feet of natural gas	1.09×10^{9}	303	1.035×10^{6}
1 Gallon of gasoline	1.32×10^{8}	36.6	1.25×10^{5}
1 Gram of uranium 235	8.28×10^{10}	2.30×10^{4}	7.84×10^{7}
1 Gram of deuterium	2.38×10^{11}	6.60×10^{4}	2.25×10^{8}
2000 Dietary food calories (2000 kcal)	8.374×10^{6}	2.326	7.937×10^{3}
1 Solar constant × cm^2 × sec	8.374	2.326×10^{-6}	7.937×10^{-3}

Source: From Elsevier Inc. (see Ref. 1).

Table 2 Primary energy sources and conversion to work

Primary energy source	**Conversion**
	Non-renewable
Fossil fuels	
Coal	Combustion (heat and heat-engine H/HE/W[a])
Peat	
Oil/crude petroleum	
Natural gas	
Nuclear	
Uranium	Fission (H/HE/W)
Thorium	
Deuterium	Fusion[b] (H/HE/W)
	Renewable[c]
Geothermal[d]	
Hot steam/water	H/HE/W
Ground soil/rock heat	
Volcanic, etc.[b]	
Ocean-gravitational	
Tidal-ocean wave	Direct to work
Solar-related	
Ocean	
Ocean thermal	H/HE/W
Ocean currents	Direct to work
Ocean wave	
Biomass	
Wood	Combustion (H/HE/W)
Vegetation, etc.[e]	
Direct solar	
Solar-thermal	H/HE/W
Photoelectric	Direct to work
Photochemical	
Electrostatic	
Lightning, etc.[b]	
Wind	
Wind–air streams	
Hydro	
River/accumulation	
Muscular	
Human and animals	

Note: Secondary energy sources (electrical, synthetic fuels, hydrogen, etc.), with energy storage and distribution complete the energy supply domain, which with energy needs, consumption and efficiency complete the global energy realm.

Energy related processes: electromagnetic radiation; photosynthesis cycle in nature; biosyntheses cycle in nature; electrical processes: electro-dynamic, electro-magnetic, electro-chemical; nuclear reactions: fission, fusion, radioactive radiation; chemical reactions: combustion, oxidation, etc.; heat transfer and frictional dissipative processes; thermo-mechanical expansion and compression; natural air streams driven by solar dissipation and gravitational buoyancy (wind); natural water cycle driven by solar dissipation, gravitation and buoyancy (evaporation, precipitations, water streams); natural water streams (rivers and ocean streams); mechanical expansion and compression.

[a]H/HE/W, conversion to Heat and via Heat-Engine to Work.

[b]Not commercialized yet.

[c]All renewables, except tidal and geothermal, are due to solar radiation.

[d]Usually renewable, but may be non-renewable.

[e]Includes many types, as well as waste/garbage.

Source: From Elsevier Inc. (see Ref. 1).

Energy, Work and Heat Units, and Energy Equivalents

Energy is manifested via work and heat transfer, with a corresponding Force×Length dimension for work (N m, kg_f m, and lb_f ft, in SI, metric, and English system of units, respectively); and the caloric units, in kilocalorie (kcal) or British thermal unit (Btu), the last two defined as heat needed to increase a unit mass of water (at specified pressure and temperature) for 1 degree of temperature in their respective units. Therefore, the water-specific heat is 1 kcal/(kg ^{o}C) = 1 Btu/(lb ^{o}F) by definition, in metric and English system of units, respectively. It was demonstrated by Joule that 4187 N m of work, when dissipated in heat, is equivalent to 1 kcal. In his honor, 1 N m of work is named after him as 1 Joule, or 1 J, the SI energy unit, also equal to electrical work of 1 W s = 1 V A s. The SI unit for power, or work rate, is watt—i.e., 1 J/s = 1 W—and also corresponding units in other system of units, such as Btu/h. Horsepower is defined as 1 hp = 550 lb_f ft/s = 745.7 W. Other common units for energy, work and heat, and energy equivalents for typical fuels and processes are given in Table 1.

Energy is provided from different sources—i.e., those systems (substances or natural phenomena) that allow for abundant, convenient, efficient, and thus economical conversion of their energy into useful energy forms (for consumption needs). This form usually is thermal for heating, and mechanical and electrical for work, with the latter being also very convenient for transmission and very efficient for conversion into any other useful energy forms. Because energy consumption needs are time and location dependent, energy conversion rate, energy density (per unit mass, volume, area, etc.), transportation (transmission), and storage are important.

There are many sources of energy (see Table 2) that provide for the diverse needs of human activities and society in general. Energy consumption may be classified in four general sectors: (1) residential, for appliances and lighting, space heating, water heating, air-conditioning, etc.; (2) commercial, for lighting, space heating, office equipment, water heating, air-conditioning, ventilation, refrigeration, etc.; (3) industrial, for water and steam boilers, direct-process energy, machine drive, etc.; and (4) transportation, for personal automobiles, light and heavy trucks, air-, water-, pipe-, and rail-transport, etc., see Fig. 4.[7] In all four sectors, in addition to primary energy sources, electrical energy, as a secondary energy source produced from primary energy sources, is used extensively, as presented elsewhere. Conversion efficiencies from different energy sources to useful mechanical or electrical work are given in Table 3.

A chronology of selected energy-related events is presented in Table A1 in the appendix.[8–10] It starts from the prehistoric age, when humans relied on their muscular power to survive; then they learned how to control and use fire, and how to domesticate and use animal power, and slowly evolved from hunters and food gatherers to cultivators of crops and developers of early agriculture. The use of water and wind power (waterwheels and windmills) enabled humans to expand their activities and mobility. Further developments included smelting of copper and iron ores, using wood and charcoal, and developing different tools, gunpowder, and sailing ships. The use of coal in the mid-1700s and the development of steam engines set off fast growth of cities, population, and further inventions, including internal-combustion engines and the discovery and use of oil, natural gas, and electricity. This accelerated growth period, known as the Industrial Revolution, matured by the end of the 19th century with significant use of fossil fuels and further developments in electricity, resulting in almost-exponential growth of population and energy use. After the development of nuclear energy and realization that the abundance of inexpensive fossil fuels will come to an end, along with concerns for global pollutions, a modern era, with computerization and global Information Revolution, has been taking place.

Regardless of the depletion of fossil-fuel resources, however, the outlook for future energy needs is encouraging. There are many diverse and abundant energy sources with promising potential, so mankind should be able to enhance its activities, standard of living, and quality of life by diversifying energy sources and by improving energy conversion and utilization efficiencies while increasing safety and reducing environmental pollution.

PREINDUSTRIAL ERA: SURVIVAL AND AGRICULTURAL DEVELOPMENT

In contrast to today's mostly sedentary lifestyle, our ancestors spent most of their existence as hunters and food gatherers, with strong physical and mental challenges to succeed in survival. Those challenges and longtime adaptations ultimately evolved in the complexities of today's societies. It took about 1 million years for our own species, *Homo sapiens*, to survive, literally in hardship, and in most of BC history, the world population was below 10 million. Except for very few early communities living in "favorable" localities, most of our ancestors were surviving on grasslands and forests with population densities comparable to their roaming foragers. Development of traditional agriculture was followed by a rise in population; further cultivation of crops; and domestication of animals, including horses. Many cattle breeds provided draft and power, as well as milk. Virtually all fuel in preindustrial societies came from straw, wood, and charcoal. The latter was critical for smelting and processing, first metals (copper, iron, and steel) and then firing bricks. The power was provided by the muscular labor of people and animals. Even today, in undeveloped

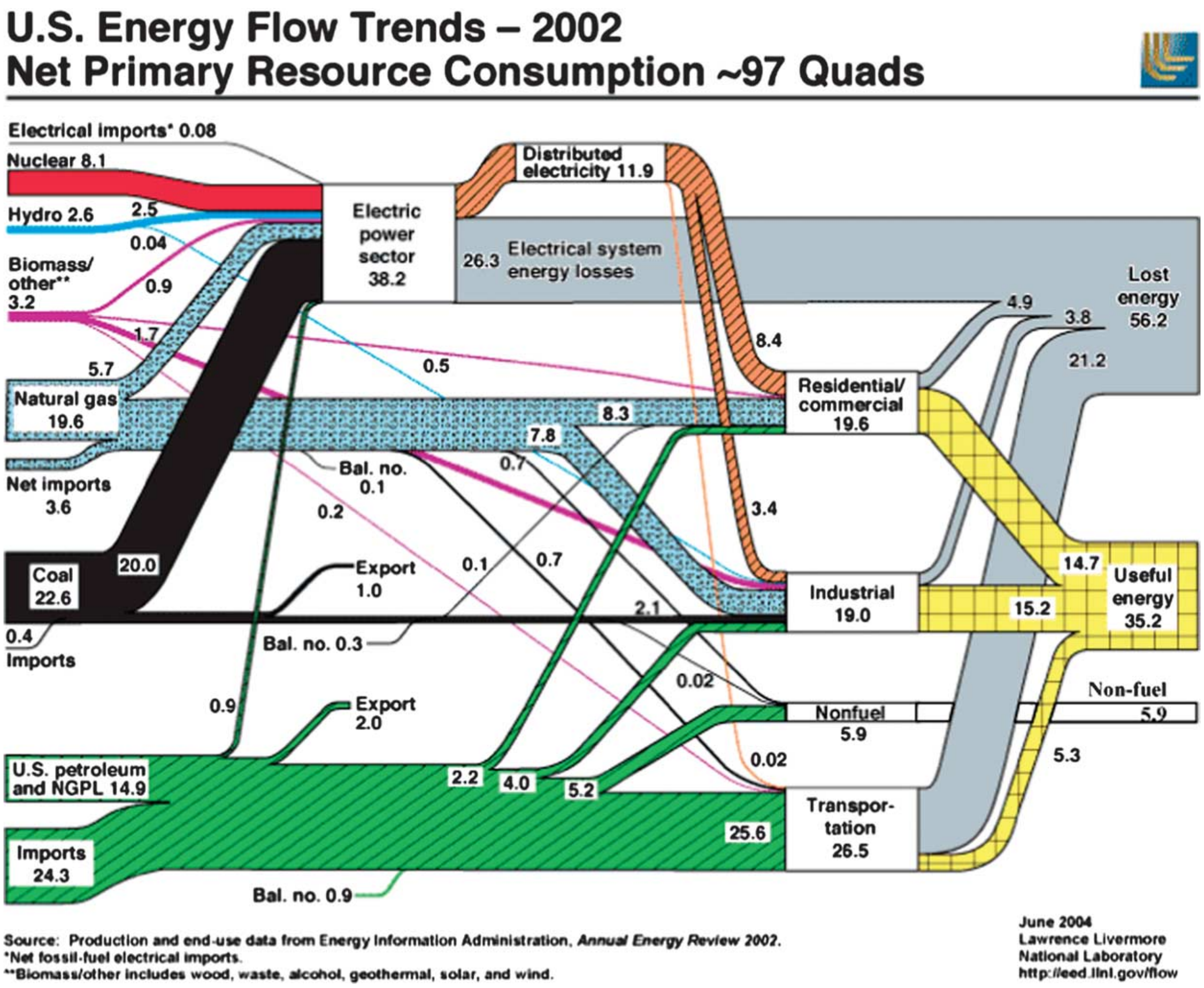


Fig. 4 Energy input–output cross-paths from primary sources to consumption sectors and energy losses. [Note that total energy is close to 100 QBtu, thus numbers are close to %].
Source: From Lawrence Livermore National Laboratory (see Ref. 7).

rural areas of Asia, Africa, and Latin America, most of the work is provided by human and animal labor.

Smelting metal ores required large quantities of wood and charcoal, as well as skills to sustain high temperatures in metallurgical pits and furnaces. In turn, improved tools and utilities were made of metals, leading to the development of waterwheels and windmills, as well as wheeled carts and sailing ships (see Table A1).[8,9] Increased mobility on land and sea helped in exchange of goods and skills from one area to another, which in turn helped the development of better goods, new materials and tools, and ultimately the rise of population.

INDUSTRIAL ERA: THE FOSSIL FUELS' BLEEP ON THE CIVILIZATION RADAR SCREEN

Development of prime movers using heat from fuels—the heat engines—was a critical historical event, because stored high-density energy in fuels like wood, and particularly coal and oil, could provide energy at any time and in any place. The abundance of fossil fuels (coal, oil, and natural gas) and energy independence from locality and seasonal natural phenomena, such as waterfalls and wind, opened many opportunities for unforeseen development. Invention of the first practical steam engine by Newcomen and Savery in 1712 and improvements by James Watt in 1765 started intensive development and utilization of fossil fuels—still the most dominant energy source, with an 85% share of the total energy use of modern society. The so-called Industrial Revolution was set in motion, with unprecedented developments, including internal-combustion engines; electrification and electrical motors; new devices, materials, and chemicals; and other inventions (see Table A1). The birth and intense development of the new energy science, thermodynamics, was taking place, along with the discovery of the fundamental laws of nature and many other discoveries in chemistry and physics. One invention was fueling another invention, and so on.

Table 3 Energy conversion efficiencies

Engine/process	Efficiency %
Otto (gasoline) engine	20–30
Diesel engine	30–40
Gas turbine	30–40
Steam turbine	35–45
Nuclear, steam turbine	30–40
Combined gas/steam turbines	40–60+
Fuel cell (hydrogen, etc.)	40–60+
Photovoltaic cell	10–25
Geothermal plant	5–15
Windmill	30–40 (59% limit)
Hydro turbine	80–85
Electro-mechanical motor/ generator	70–98

Note: Thermal-to-mechanical work conversion is limited by stochiometric combustion temperature and the Carnot cycle efficiency. Fuel cell efficiency is limited by Gibbs free energy values for process reactants and products, and may be close to 100%. Due to material property limitations and process irreversibilities (dissipation of energy), practical efficiencies are much lower and there is room for substantial improvements. For example, existing hybrid cars have 80% improved efficiency (and mileage) over the same classical cars, from 25 to 45%, by using electro/mechanical engines/storage hybrid systems.

The use of new heat engines and the need for more fuels were propelling discovery of many coal mine and oilfields. In return, available energy sources were enabling an intense rise in human activities, skills, and knowledge, as well as the growth of civilization, reaching 1 billion people by the end of the 18th century (see Fig. 1). The Industrial Revolution matured and continued with the Industrial Era and ultimately evolved into the modern era of societal development.

MODERN ERA: SOPHISTICATION, CONSERVATION, AND DIVERSIFICATION

The Modern Era in societal development represents a continuation of the Industrial Era, with development of new technologies (including nuclear energy, space exploration, computerization, and information technologies) as well as the realization that the abundance of inexpensive fossil fuels will come to an end, along with concern about global environmental pollution.

The primary energy sources for the world in 2003 and the United States in 2004 are presented in Table 4, and the primary sources for the production of electricity are presented in Table 5.[3,4] In addition, the U.S. energy supply by consumption sector, including electricity production, is given in Table 6. The world and U.S. populations, energy production, and consumption also are summarized in Table 4. Total energy production—including losses, import, and export—is available as energy supply for consumption and storage. Also, most of the world's electricity (about 65%, and about 71% in the United States) is produced from fossil fuels, with overall conversion efficiency of only about 33%. Conversion efficiency is similar in nuclear power plants, which contribute to about 16% of world and about 20% of U.S.

Table 4 World and U.S. total energy supply by source (in QBtu)

Source	World, 2003		U.S., 2004	
Coal	99.69	23.9%	22.528	22.6%
Petroleum	159.17	38.2%	40.130	40.2%
Natural gas	98.7	23.7%	22.991	23.1%
Fossil fuels	357.56	85.7%	85.649	85.9%
Nuclear electric	26.52	6.4%	8.232	8.3%
Hydro-electric	27.18	6.5%	2.725	2.7%
Renewables/others	5.87	1.4%	3.391	3.4%
Total	417.12	100.0%	99.740	100.0%

World and U.S. population and energy comparisons

Source	World, 2003		U.S., 2004	
Population	6,300	100%	294	4.7%
Energy production	417.12	100%	70.369	16.9%
Energy consumption	417.12	100%	99.740	23.9%

Note: Energy in Quadrillion Btu (1 QBtu = 10^{15} Btu) or %, population in Millions.
Source: From U.S. Department of Energy (see Refs. 3 and 4).

Table 5 World and U.S. electric energy supply by source (in Billion kWh)

Source	World, 2003		U.S., 2004	
Coal			1,976.3	50.0%
Petroleum			117.6	3.0%
Natural Gas			714.6	18.1%
Fossil Fuels	10,364.8	65.4%	2,808.5	71.0%
Nuclear Electric	2,523.1	15.9%	788.6	19.9%
Hydro-electric	2,645.8	16.7%	269.6	6.8%
Renewables/Others	241.9	1.5%	89.2	2.3%
Total	15,843.9	100%	3,955.9	100%

Note: Energy in Billion kWh or %; 1 kWh(electric) equivalent to 10580 Btu(thermal) at 33% efficiency, however 1 kWh = 3412 Btu (as unit conversion).
Source: From U.S. Department of Energy (see Refs. 3 and 4).

electricity production. When the global energy supply is given together with fossil fuels and expressed in British thermal units (Btu), all electrical energy (including hydro and wind) is given in equivalent Btu thermal units, accounting for the conversion efficiency (typically, 33%). When electrical energy is accounted separately, the actual electrical output is given in kilowatt hours (kWh), as shown in Table 5. Due to different forms and conversion efficiencies of primary energy sources, and due to the complexities of energy production and losses, transportation and storage, import, and export, it is virtually impossible to account correctly for all energy paths and forms in the same units; therefore, the total figures (and percentages) usually do not add up exactly (see Fig. 4 and Table 6 for examples).

Fossil fuels account for more than 85% of total world and U.S. energy consumption (see Table 4). Almost 40% of total world and U.S. primary energy is used for electricity production (see Tables 4–6), mainly in thermal and nuclear power plants (more than 80% in the world and more than 90% in the United States), using heat engines undergoing thermomechanical conversion processes with relatively low conversion efficiencies (see Table 3). The overall conversion efficiency from chemical or nuclear fuel energy to thermal energy of combustion gases or steam, to mechanical and electrical energy, is only about 30%–35%.

FUTURE ENERGY OUTLOOK: LIFE MAY BE HAPPIER AFTER FOSSIL FUELS

At present, most of the world's energy consumption is supplied by fossil fuels (about 85%). The proven fossil-fuel reserves are limited, however, and if they continue to be used at the present rates, it is estimated that coal (as used under current conditions) will be depleted in about 250 years; oil, in 60 years; and natural gas, in about 80 years. We have to keep in perspective that "proven reserves" refers to the customary and economical mining and utilization of fuels, but new reserves and more efficient technologies are being discovered, making new fuel reserves economical. At present, a substantial amount of the world's electricity is obtained from nuclear and hydro energy (about 16 and 17%, respectively), and the use of other renewable energy resources is increasing—namely, geothermal, wind, biomass, and solar. In addition, alternative synthetic fuels, including hydrogen, are being developed. It is worth noting that some countries (including Norway, Brazil, New Zealand, Austria, and Switzerland) produce almost all or most of their electricity from hydro energy, and France produces most of its electricity (more than 75%) from nuclear. Reserves of nuclear fuel are orders of magnitude higher than reserves of fossil fuels, and nuclear fuel does not contribute to CO_2 and greenhouse pollution.

Table 6 U.S. energy consumption by sector in 2004 (in QBtu)

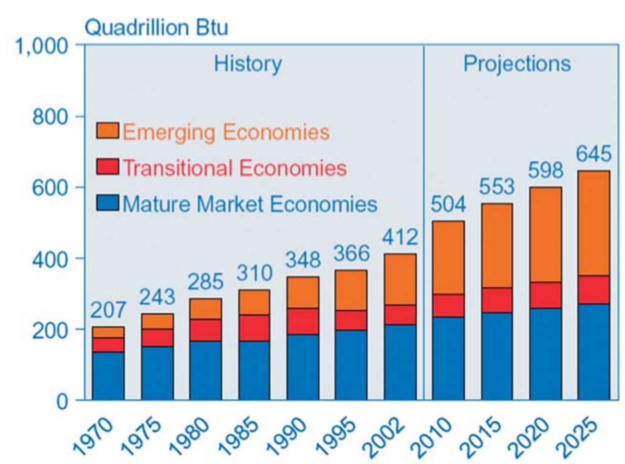
Sector	Primary		Electric		Total	
Residential	7,022	7.1%	14,154	36.43%	21,176	21.2%
Commercial	4,072	4.3%	13,443	34.60	17,515	17.6%
Industrial	22,076	22.3%	11,171	28.75%	33,247	33.3%
Transportation	27,709	27.6%	84	0.22%	27,793	27.9%
Electric	38,850	38.7%				
Total	99,729	100.0%	38,852	100%	99,740	100%

Source: From U.S. Department of Energy (see Ref. 3).

Furthermore, advances in energy conversion and utilization technologies, and increases in efficiency, including computerized control and management, contribute to energy conservation, an increase in safety, and a reduction of related environmental pollution. Actually, per-capita energy use in the United States and other developed countries has been reduced in recent years. The increase of the world's population, however, and the development of many underdeveloped and very populated countries (China, India and others) will influence continuous increase of the world's energy consumption.

Fig. 5 gives one of the most recent projections of the world's energy consumption, by region, until 2025.[5] The Mature Market Economies region (15% of the 2005 world population) represents North America, Western Europe, and Mature Market Asia (Japan, Australia, and New Zealand). The Transitional Economies region (6% of the 2005 world population) represents Eastern Europe (EE) and the former Soviet Union (FSU). The rest is the Emerging Economies region (78% of the 2005 world population), consisting of emerging Asia (53% of the 2005 world population), the Middle East (4% of the 2005 world population), Africa (14% of the 2005 world population), and Central and South America (7% of the 2005 world population).

World energy consumption is projected to increase by 57% from 2002 to 2025. Much of the growth in worldwide energy use is expected in the Emerging Economies countries. The increase is projected on average to be 2.0% per year over the 23-year forecast (from 2002 to 2025)—somewhat lower than the 2.2% average annual growth rate from 1970 to 2002. Worldwide, total energy use is projected to grow from 412 QBtu (quadrillion British thermal units) in 2002 to 553 QBtu in 2015 and 645 QBtu in 2025 (see Fig. 5).[5] Emerging Economies will account for much of the projected growth in energy consumption over the next two decades, with energy use in the group more than doubling by 2025 due to strong projected economic growth in the region. The world population is expected to grow on average by 1% per year (0.4, −0.2, and 1.2% in the Mature, Transitional, and Emerging regions, respectively) and to reach 7.85 billion by 2025. The gross domestic product (GDP) is expected to increase by 3.9% per year on average: 5.1% per year in the Emerging Economies countries, compared with 2.5% per year in the Mature Market Economies countries and 4.4% per year in the Transitional Economies countries of Eastern Europe and the former Soviet Union (EE/FSU). The long-term projections are more uncertain because future development may turn in many different, even unexpected, directions.



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219(2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

Fig. 5 World energy history and projection consumption by region.
Source: From U.S. Department of Energy (see Ref. 5).

As already stated, two things are certain: In the not-too-distant future (1) the world population and its living-standard expectations will increase substantially, and (2) economical reserves of fossil fuels, particularly oil and natural gas, will decrease substantially. The difficulties that will face every nation and the world in meeting energy needs over the next several decades will be more challenging than what we anticipate now. The traditional solutions and approaches will not solve the global energy problem. New knowledge, new technology, and new living habits and expectations must be developed, both to address the quantity of energy needed to increase the standard of living worldwide and to preserve and enhance the quality of our environment.

A probable scenario, in the wake of a short history of fossil fuels' abundance and use (a bleep on the human-history radar screen), the following energy future is anticipated:

1. Creative adaptation and innovations, with change of societal and human habits and expectations (life could be happier after the fossil-fuels era).
2. Intelligent, high-tech local and global energy management in a wide sense (to reduce waste, improve efficiency, and improve the quality of the environment and life).
3. Unforeseen large (higher order of magnitude) potential for energy conservation and regeneration in industry, transportation, and the commercial and residential sectors.
4. Nuclear energy and re-electrification for most stationary energy needs.
5. Cogeneration and integration of power generation and new industry on a global scale (to close the cycles at sources, thus protecting the environment and increasing efficiency).

6. Renewable biomass and synthetic hydrocarbons for fossil-fuel replacement (mobile energy, transportation, and chemicals).
7. Advanced energy storage (synthetic fuels, advanced batteries, hydrogen, etc.).
8. Redistributed solar-related and other renewable energies (to fill in the gap).

After all, life may be happier in the post-fossil fuel era, which represents only a bleep on the human-history radar screen. With increased population and technological developments, and sophistication in many areas of complex societies, there will be many unforeseen opportunities to enhance efficiencies of energy production and utilization. Therefore, the outlook for energy needs is encouraging. There are many diverse and abundant energy sources with promising potential, so the mankind should be able to enhance its activities, standard of living, and quality of life by diversifying energy sources and by improving energy conversion and utilization efficiencies, while at the same time increasing safety and reducing environmental pollution.

APPENDIX A

Table A.1 Chronology of selected energy-related events in history

Year	Event in energy history
500,000+ or BC	Middle Pleistocene humans control fire (burning wood). Direct evidence was found outside a cave at Chou k'ou-tien, China, where charcoal was found along with traces of a stone tool making-industry
10,000+	Paleo-Indians used hot springs in North American for cooking, and for refuge and respite
6,000+	The earliest known use of ships comes from Egyptian rock drawing dating from 6,000 BC
4,500+	Egyptians mine copper ores and smelt them
4,000+	Horses are ridden in what is now the Ukraine
3,500+	Wheeled vehicles are used in Mesopotamia as seen in a pictograph found in Uruk
1,000+	Coal from the Fu-shun mine in northeastern China may have been used to smelt copper
900+	The use of natural gas was mentioned in writings from China
480+	The Persians used incendiary arrows wrapped in oil-soaked fibers at the siege of Athens
400+	Greek philosopher Democritus theorized that matter consists of tiny, particles called atomos, that could not be divided
250+	Archimedes invents a number of items including the Archimedian screw—a helix-shaped screw in a tube for lifting water. He is also credited with having discovered the principles of the lever
211+	It was in China that the first known well was drilled for natural gas to reported depths of 150 m (500 ft)
100+ BC or +	In Illyria (ex-Yugoslavia and Albania), and probably in western Anatolia (Turkey), water-powered mills are used for grinding grain
100 AD	Hero of Alexandria invents the first steam engine called the aeolipile. It consisted of a spherical vessel fitted with two jets pointing in opposite directions. Hero also invented a wind device
300	Chinese learn to use coal instead of wood as fuel in making cast iron
300	Water mills appear in Roman Empire
300	First known references to a perpetual motion machine appears in a Sanskrit manuscript. It describes a wheel with sealed cavities in which mercury would flow in such a fashion that one half of the wheel would always be heavier, providing continuous spinning
600	The earliest known references to wind-driven grain mills, found in Arabic writings
1100	As a result of the Arab invasion of Spain, the industrial art of distillation of petroleum products into illuminants became available in western Europe by the 12th century
1200	The first documented proof that coal was mined in Europe, provided by the monk Reinier of Liège
1200	Alcohol is first distilled in Europe from grains
1221	Chinese use bombs and other uses of gunpowder, leading eventually to development of rockets
1500	Leonardo da Vinci invents many devices including a glider, parachute and a helicopter type of device
1570	William Gilbert studies magnetism and the corresponding attraction of rubbed amber and various rubbed jewels
1603	Hugh Platt discovers coke, a charcoal-like substance produced by heating coal
1609	The first attempt is made to harness ocean energy in the Bay of Fundy

(Continued)

Table A.1 (Continued)

1612	A primitive thermometer invented by Galileo
1650	Otto van Guericke develops a way to charge a ball of sulfur with static electricity. He is also observed light produced by electricity. The term electricity is coined to describe the force that is found when amber is rubbed with silk (static electricity)
1659	Natural gas is discovered in England; the first time in Europe
1660	Robert Boyle presented a law (Boyle's law), which states that pressure varies inversely with volume at constant temperature, paving the way for the ideal gas law
1670	Christian Huygens builds a motor driven by explosions of gunpowder
1680	Sir Isaac Newton proposes that a jet of steam could be used (like a rocket) to power a carriage, an idea now considered to be a precursor to development of the jet engine
1680	The match is first discovered by Robert Boyle who rubbed phosphorus and sulfur together
1687	In famous Principia, one of the most important and influential works on physics of all times, Isaac Newton presents the universal law of gravitation and the three fundamental laws of motion
1690	The recycled paper manufacturing process is introduced. The Rittenhouse Mill near Philadelphia made paper from fiber derived from recycled cotton and linen rags
1698	Dennis Papin describes an apparatus (called the Papin Cylinder in which the condensation of steam in a cylinder creates a vacuum. He later in 1698 develops the first piston that is moved by the pressure of steam rather than atmospheric pressure
1709	Sir Issac Newton builds an electric generator consisting of a rotating glass sphere
1712	Thomas Newcomen in collaboration with Thomas Savery build the first practical steam engine to use a piston and cylinder
1738	Daniel Bernoulli published the conservation of live forces in hydraulics (now known as Bernoulli equation) and the kinetic molecular theory of gasses
1747	Benjamin Franklin describes in a letter his discovery that a pointed conductor (Franklin's lightning rod) can draw electric charge from a charged body
1755	Leonhard Euler equations for the motion of inviscid incompressible fluid and contributions in mathematics, optics, mechanics, electricity, and magnetism
1765–1776	The steam engine is perfected by James Watt with condenser that is separated from the cylinder
1766	The element hydrogen (symbol is H) is discovered by Henry Cavendish (1731–1810) and English physicist and chemist
1774	Joseph Priestley and Karl Scheele independently discover the element oxygen (symbol is O)
1775	Allesandro Volta describes his electrofore perpetuo (electrophorus), a device for producing and storing a charge of static electricity, replacing the Leiden jar and eventually leads to modern condensers
1777	The first buildings in France since Roman times are heated by warm water central heating systems
1779	The first versions of the bicycle appear in Paris
1783	Montgolfier brothers of France create the first hot air balloons using flame fires that floated in the air
1787	First steamboat in America is demonstrated on the Delware River in Philadelphia, Pennsilvania
1789	The element Uranium (symbol is U) is discovered by Martin Klaproth, a German chemist
1789	Antoine Lavoisier presented a unified view of new theories of chemistry, contained a clear statement of the law of mass conservation, and denied the existence of phlogiston. He lists elements, or substances that could not be broken down further, which included oxygen, nitrogen, hydrogen, phosphorus, mercury, zinc, and sulfur. His list, also included light, and caloric (heat fluid), which he believed to be material substances. He underscored the observational basis as opposed to reasoning
1799	Alessandro Volta creates the first electric battery called the Voltaic pile
1804	Richard Trevithick develops a steam locomotive that runs on iron rails
1816	Robert Stirling invents a power cycle with heated air that operates without a high-pressure boiler
1821	Michael Faraday reports his discovery of electromagnetic rotation. He creates the first electrical "motors," although his rotating needle is not a real motor because it cannot power anything
1821	Johann Seebeck observes that two different metals joined at two different places kept at two different temperatures will produce an electric current. This is called thermoelectricity and the Seebeck effect will later be used in the development of the semiconductor

(Continued)

Table A.1 (Continued)

1823	Methyl alcohol was first discovered by condensing gases from burning wood into a liquid. It is used as a solvent and a chemical building block to make consumer products as plastics, plywood and paint
1824	In "On the motive power of fire," Sadi Carnot shows that work is done as heat passes from a high to a low temperature. He defines work and hints at the second law of thermodynamics
1827	George Ohm writes "The galvanic circuit investigated mathematically," which contains the first statement of the Ohm's law, that the electrical current is equal to the ratio of the voltage to the resistance
1830	The first locomotive in the U.S. to carry 26 passengers 13 miles over the tracks of the Baltimore and Ohio Railroad. George Stephenson's steam locomotive was chosen over three competitors to open the Liverpool to Manchester railway in England. This is considered the start of the railroad boom
1831	Michael Faraday independently discovers that electricity can be induced by changes in an electromagnetic field. Though Henry found it earlier, but didn't publish it, so Faraday is credited with the discovery
1832	Joseph Henry discovers self-induction, or inductance, the second current in a coil through which one current is passing that is induced by the first current
1838	The steamship Sirius is the first ship to cross the Atlantic on steam power alone, taking 18 days and very nearly running out of coal before reaching New York
1839	The first work done with photovoltaics was performed by Edmond Becquerel
1839	William Grove develops the first fuel cell, a device that produces electrical energy by combining hydrogen and oxygen
1841	Frederick de Moleyns obtains the first patent for an incandescent lamp, an evacuated glass containing powdered charcoal that bridges a gap between two platinum filaments
1842	Julius Robert Mayer is the first to state the law of conservation of energy (known as the first law of thermodynamics), noting that heat and mechanical energy are two aspects of the same thing
1943	Joule experimentally measure the "heat" equivalent of "work, also known as "mechanical equivalent of heat," thus discrediting the caloric theory
1948	William Thomson (i.e. Lord Kelvin) proposed an absolute scale of temperature. It was based on theory proposed by Sadi Carnot and later developed by Clapeyron
1850	Rudolf Clausius and later Rankine formulate the first law of energy conservation, which starts new science "Thermodynamics." The first statement of the second law of thermodynamics was enhanced by Clausius in 1865 as "entropy always increases in a closed system." In other words, other energies in a closed system will change toward heat and disorder
1851	William Thomson (i.e. Lord Kelvin) describes heat pump, a device where heat is absorbed by the expansion of a working gas and given off at a higher temperature in a condenser
1853	William Rankine, proposed a thermodynamic theory with Kelvin based on the primacy of the energy concept. He stated the Law of Conservation of Energy as "all different kinds of physical energy in the universe are mutually convertible." He also invented an absolute temperature based on the interval of one degree Fahrenheit termed the Rankine temperature scale
1853	Kerosene is extracted from petroleum for the first time
1855	Henry Bessemer introduces the Bessemer process for producing inexpensive steel in a blast furnace
1859	Gaston Plante in Paris invents the first lead-acid storage battery, which produces electricity from a chemical reaction and can be recharged again and again
1865	Natural gas first found near Stockton, California when workmen drilling for water found natural gas at 1,800 feet. It supplied gas for lighting the courthouse as well as warm water for nearby swimming baths
1867	Nicholaus Otto developed an internal combustion engine that is an improved version of Lenoir's engine
1870	Heinrich Hertz used Edmond Becquerel's discoveries that certain materials, such as selenium, produced small amounts of electric current when exposed to light. Not long after that, selenium photovoltaic cells were converting light to electricity at 1–2% efficiency
1875	Alfred Nobel accidentally discovered that nitroglycerine retain its explosive properties when absorbed by diatomaceous earth, calling it "dynamite." He left his estate to establish famous "Nobel Prizes."
1882	Joseph Fourier developed a mathematical theory of heat in terms of differential equations
1877	Nikolaus Otto develops the four-cycle internal combustion engine, similar to what we use today
1879	Thomas Alva Edison invented the first electric incandescent lamp of practical value

(Continued)

Table A.1 (Continued)

1880	Pierre Curie discovers the piezoelectric effect that certain substances produce electric current under pressure
1882	The first electric central station to supply light and power was the Edison Electric Illuminating Company of New York City. It had one generator which produced power for 800 electric light bulbs. Within 14 months, the service had 508 subscribers and 12,732 bulbs
1884	Nikola Tesla invents the electric alternator, an electric generator that produces alternative current
1885	James Prescott Joule builds an internal combustion engine that is the precursor to the diesel engine
1886	Henry Ford builds his first automobile in Michigan
1888	Heinrich Hertz detects and produces radio waves for the first time. Radio waves are called Hertzian waves until renamed by Guglielmo Marconi, who calls them radiotelegraphy waves
1890	Clement Ader's Eole is the first full-size aircraft to leave the ground under its own power, carrying its inventor as a pilot. The plane crashed on landing, so the invention was not credited to Ader
1891	Nikola Tesla invents the Tesla coil, which produces high voltage at high frequency
1893	Rudolf Diesel describes an internal combustion engines that will be named after him. The ignition of the gas mixture in the cylinder is obtained by heating during the compression cycle
1895	On the Willamette River at Oregon City, Oregon, the first dam is specifically built to drive a hydroelectric power plant
1897	Joseph Thomson discovers the electron, the particle that makes electric current and the first known particle that is smaller than an atom
1900	The first offshore oil wells are drilled
1901	Guglielmo Marconi transmits first long distance communication using electromagnetic or radio waves
1902	America's first moving-picture theater opens in Los Angeles, charging 10 cents for a one hour show
1902	Maie and Pierre Curie discover the atomic weight of radium
1902	Willis H. Carrier invents the first air conditioner, although his name is first used in 1906 to describe a different device
1905	Albert Einstein published his paper on the photoemissive photoelectric effect, along with a paper on his theory of relativity. The paper describes light for the first time as being both a wave and a particle. He later wins Nobel Prize in 1921
1908	Polish scientist Czochralski developed a way to grow single-crystal silicon, a necessary step for computer industry and solar cells
1919	British airship R-34 is the first airship to cross the Atlantic Ocean
1921	A German scientist, Friedrich Bergius succeeds in liquefying coal into oil in Stuttgart
1927	First successful long-distance television transmission was demonstrated, from President Hoover's office in Washington, DC, to the Bell Laboratories in New York
1929	The first "talking" movie filmed entirely in color was released
1929	Felix Wankel patents a rotary engine, but the engine is not practical until the 1950s
1929	Georges Claude develops the first electrical power plant to use the difference in temperature between the upper and lower layers of ocean
1937	Frank Whittle and A.A. Griffitsh build the first working jet engine in England. Independently in Germany, von Ohain and M. Muller develop a similar engine
1942	The first self-sustaining nuclear chain reaction was demonstrated by Enrico Fermi and his staff at the University of Chicago, making possible the development of the atomic bomb
1945	U.S. explodes the first nuclear weapon at Alamogordo, N.M, a different type of atomic bomb is dropped on the Japanese city of Hiroshima, followed by another nuclear bomb on Nagasaki on August 9, 1945
1946	The ENIAC computer is demonstrated to scientists and industrialists; even though it was used during W.W.II. It multiplies 360 ten-digit numbers and extracts a square root "in a single second."
1946	First Soviet nuclear reactor goes into operation
1947	The first peacetime nuclear reactor in the U.S. starts construction at Brookhaven, NY
1947	Andrei Sakharov and F.C. Frank propose the use of negative muons to produce fusion reactions in a mixture of deuterium and hydrogen. This possibility is rediscovered in 1957 by Luis Alvarez

(Continued)

Table A.1 (Continued)

1947	The first airplane to break the speed of sound, the Bell X-1, is flown by Chuck Yeager
1948	The first transistor, invented by Drs. John Bardeen and Walter Houser Brittain, was demonstrated. The essential element of the device was a tiny wafer of germanium, a semi-conductor
1948	Market acceptance of frozen orange concentrate leads to the expansion of the frozen foods industry, with associated increases in packaging
1951	An announcement was made of a battery that converts nuclear energy to electrical energy. Philip Edwin Ohmart of Cincinatti, Ohio, invented the radioactive cell
1952	Westinghouse Electric Corporation builds the first breeder reactor at the U.S. Atomic Energy Commission's laboratories in Arco, Idaho. It produces more plutonium than the uranium it burns, promising an era of cheap nuclear energy
1954	Bell Lab's Chapin, Fuller, Pearson, AT&T, patent "Solar Energy Converting Apparatus," submitted to U.S. patent office
1957	The Soviet Union launches the world's first artificial satellite, Sputnick 1. Another satelite Sputnick 2 carried a live dog Laika into space, but the dog did not return to earth
1958	Integrated circuits produced by Texas Instruments
1959	Francis Bacon builds a fuel cell in which hydrogen and oxygen react in a mixture of potassium hydroxide in water to produce electricity
1961	Yuri Gagarin becomes the first human in space making a single orbit of the planet in 1 h 48 min
1962	Telstar satellite launched; the first commercial telecommunications satellite; project of Bell Telephone Laboratories, proposed in 1955 by John R. Pierce
1969	Humans first steps on the Moon. Neil Armstrong and Michael Collins and Edwin Aldrin on the Apollo 11
1969	Geologists discover oil in Alaska's north slope
1971	Silicone chips are produced by Intel and Texas Instruments
1972	The first electric power using municipal refuse as a boiler fuel was generated by the Union Electric Company's Meramec Plant in St. Louis, Missouri
1973	The polyethylene terephthalate plastic bottle is patented by chemist Nathaniel Wyeth which soon began to replace glass bottles. The recycling of the plastic soon followed
1976	Unmanned US Voyager spacecraft lands on Mars
1977	Trans-Alaska oil pipeline opens
1980s	Personal computers take off
1982	CD players produced by Philips and Sony
1983	Specially built 1-kW, PV-powered car, the Solar Trek, drives across Australia, covering 4000 km in less than 20 days. The maximum speed was 72 kph, with an average speed for the trip of 24 kph
1984	A 20-MW geothermal plant opened at Utah's Roosevelt Hot Springs
1985	Martin Green team, University of New South Wales, Australia, breaks the 20-percent efficiency barrier for silicon solar cells under "1-sun" conditions
1986	Chernobyl nuclear reactor number 4 near Kiev in ex-Soviet Union explodes leading to a catastrophic release of radioactivity
1986	The world's largest 14,000 MW Itaipu Dam, along the border of Brazil and Paraguay, is opened
1986	NOVA, an experimental laser fusion device at the Lawrence Livermore National Laboratory create the first laser fusion reaction. Fusion, however, remains elusive through the end of the century
1989	Exxon Valdez, a 1,260,000 barrels-of-oil tanker strikes a reef in Alaska's Prince William Sound, spilling an estimated 240,000 barrels of crude
1992	The biggest array of 9600 thin film photovoltaic modules ever assembled starts operation in Davis, California, delivering up to 479 kW, enough for over 100 homes
2000s	Computerization with Internet information exchange, sophistication and globalization (see Energy Future Outlook section above)

Note: All early dates are approximate and other dates may differ due to reference to either conception, patenting, publication, or first application, in different sources[8–10] or elsewhere.

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Glossary

Energy: It is a fundamental property of a physical system and refers to its potential to maintain a system identity or structure and to influence changes with other systems (via forced–displacement interactions) by imparting work (forced directional displacement) or heat (forced chaotic displacement/motion of a system's molecular or related structures). Energy exists in many forms: electromagnetic (including light), electrical, magnetic, nuclear, chemical, thermal, and mechanical (including kinetic, elastic, gravitational, and sound).

Energy Conservation: It may refer to the fundamental law of nature that energy and mass are conserved—i.e., cannot be created or destroyed, but only transferred from one form or one system to another. Another meaning of energy conservation is improvement of efficiency of energy processes so that they could be accomplished with minimal use of energy sources and minimal impact on the environment.

Energy Conversion: A process of transformation of one form of energy to another, such as conversion of chemical to thermal energy during combustion of fuels, or thermal to mechanical energy using heat engines, etc.

Energy Efficiency: Ratio between useful (or minimally necessary) energy to complete a process and the actual energy used to accomplish that process. Efficiency may also be defined as the ratio between energy used in an ideal energy-consuming process vs energy used in the corresponding real process, or vice versa for an energy-producing process. Energy, as per the conservation law, cannot be lost (destroyed), but the part of energy input that is not converted into useful energy is customarily referred to as energy loss.

Industrial Revolution: Controversial term referring to the development of heat engines and use of fossil fuels, first in Britain and later in other countries, from 1760 to 1850.

Nonrenewable Energy Sources: The energy sources (such as fossil and nuclear fuels) created and accumulated over a very long period in the past, for which the creation rate is many orders of magnitude smaller than the consumption rate, so that they will be depleted in a finite time period at the current rate of consumption.

Renewable Energy Sources: The continuously or frequently available (renewed daily or at least annually) energy sources—solar energy, wind, water flows, ocean and tidal waves, biomass, and so on—that, for all practical purposes, are expected to be available forever.