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THE ENVIRONMENT AND WORLD HISTORY

Edited by

Edmund Burke III
and Kenneth Pomeranz

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CONTENTS

PART ONE OVERVIEW

PART TWO RIVERS, REGIONS, AND DEVELOPMENTALISM

World History: Rethinking 'the Rise of the West' and the Industrial Revolution," *Journal of World History* 13, no. 2 (2002): 323–89.

34. In fact, Robert Ayres and Benjamin Warr argue that increases in "useful work"—energy consumed times the efficiency of the converters—account for almost all of the productivity increases in the U.S. economy in the twentieth century. See Ayres and Warr, "Accounting for Growth: the Role of Physical Work," homepage of the International Energy Agency (Fontainebleau: Center for the Management of Environmental Resources; www.iea.org/dbtw-wpd/Textbase/work/2004/eewp/Ayres-paper1.pdf, accessed August 2, 2005). There are, however, methodological problems in their analysis: the effective energy use series and the GDP series do have a strong correlation, but so might various other series that tended to increase steadily over the century.

35. In the Netherlands, for instance, per capita energy use in 1650 was between double and triple the figure for 1560, but then fell by 15–20 percent by 1750. This would make the overall increase probably about 100 percent over two hundred years (Jan de Vries and Ad van der Woude, *The First Modern Economy: Success, Failure, and Perseverance of the Dutch Economy, 1500–1815* [Cambridge: Cambridge University Press, 1997], 709–10). By contrast, global per capita energy use rose more than tenfold between the late nineteenth century and the end of the twentieth: see Vaclav Smil, *Energy in World History* (Boulder, CO: Westview Press, 1994), 187.

36. Fernand Braudel, *The Structures of Everyday Life* (New York: Harper and Row, 1981), 196–97.

37. For humans and animals, see McNeill, *Something New under the Sun,* 10–11. These figures naturally vary with circumstances. For modern electrical plants, see Smil, *Energy in World History,* 174. One irony here is that the machines that used essentially free energy—wind and running water—improved their technical efficiency first.

38. Smil, *Energy in World History,* 161, 164. Twentieth-century steam engines were typically between 10 percent and 20 percent efficient.

39. Charles Tilly, *Coercion, Capital, and European States,* 1.

40. For U.S. examples, see Karl Jacoby, *Crimes against Nature: Squatters, Poachers, Thieves, and the Hidden History of American Conservation* (Berkeley: University of California Press, 2001); for southern African ones, see William Beinart, "Introduction: The Politics of Colonial Conservation," *Journal of Southern African Studies* 15, no. 2 (January 1989): 149–51, 156–57.

41. See "Rice Yields Plunging Due to Balmy Nights," *New Scientist* 10, no. 23, www.newscientist.com/article/dn6082.html, accessed June 29, 2004.

TWO ·

The Big Story

Human History, Energy Regimes, and the Environment

EDMUND BURKE III

Most histories depict the present as the endpoint of an ascending trajectory that links the agricultural revolution, classical Greece, the Renaissance, the Industrial Revolution, and modern times. This may make for good teleology, but is such a graph plausible? There are several reasons to think not. First, we have no evidence that modernity is a permanent stage in human history, particularly when we consider the human impact on the biosphere—deforestation, species extinctions, and other forms of environmental damage. It is unlikely that modern levels of consumption can be generalized for all humans or last indefinitely into the future. Indeed, humanity's talent for fouling its own nest is not uniquely modern, and the world economy and the state are the product of millennia of experimentation and interaction.

In this chapter I examine the environmental consequences of human development over the very long term as a way of providing a different perspective on the environmental quandary we currently face. The other essays in this book address the environmental legacies of world civilizations and regions over the more recent past or survey different regions' environmental histories. Here I examine the deep history of humanity, energy regimes, and the environment. My purpose is threefold. First, by placing modernity in the larger context of the flow, conversion, and storage of planetary bioenergy, I want to call into question the conventional historical narrative, which views the Industrial Revolution as a natural outcome of human development, and instead insist on the ways in which it constituted an unprecedented break in human relations with nature and the environment. Second, by focusing on the history of energy regimes, I want to disaggregate the Industrial Revolution into analytically distinct processes in order to argue for the decisive importance of the fossil-fuel revolution. Third, by studying energy regimes throughout world history, I seek to contextualize current concerns. At a time of renewed anxiety about the end of oil, the current moment seems an especially appropriate one in which to conduct such an exercise.

The close connection between humans and the environment was mediated first and foremost by fire. The Big Bang of course provides the ultimate fire story: its concentrated energy is still expanding. At the moment of the Big Bang, 13.7 billion years ago, incomprehensibly enormous amounts of energy were released, illuminating billions of stars and setting all in motion, including the history of Earth and of our species. The second law of thermodynamics tells us that, infinitely gradually and imperceptibly, this energy is being exhausted. Once created, the stars provided stable, long-lived stores of free energy. Energy is thus central to the universe.

But what is energy? Authorities have no single, specific answer to this question. Richard Feynman, for one, famously cautioned that "we have no knowledge of what energy *is*. We do not have a picture that energy comes in little blobs of a definite amount."[1] Conventionally, energy is defined as the capacity to do work. In our solar system, the temperature differential between our sun and the Earth provides the free energy necessary to create most forms of complexity. (Free energy is energy available to do work.) Complex entities, such as the life forms on Earth, absorb huge flows of energy and dissipate large amounts of free energy. Complex structures thus constantly increase disequilibrium and entropy in the universe.[2]

The mastery of fire provides a way of framing the relations of humans and the biosphere. Stephen J. Pyne has powerfully argued that at some early point in the history of the species, this mastery distinguished humans from other mammals.[3] The ability to manipulate fire allowed early humans to tap the solar energy stored in wood (biomass) and to transform the natural environment; it thus gave humans a crucial advantage over other megafauna. The systematic use of fire by humans to open clearings in the forest propitious to human settlement is one of the earliest signs of the emergence of *Homo sapiens*, apparently predating even the development of language. It may also have marked the origins of agriculture. For this reason, Johan Goudsblom has seen in fire the source of civilization.[4]

Vaclav Smil's *General Energetics* provides an integrated approach to forms of energy flow, storage, and conversion that links the geosphere, the biosphere, and human society.[5] The primary source of all forms of energy on this planet is the sun. (The molten core of the earth—itself stemming from the origins of the solar system—is a secondary source.) Energy conversions at all levels are driven by solar energy. Scientists recognize four forms of energy in the universe: nuclear, chemical, thermal, and mechanical (kinetic). The last three especially have, in different combinations, been important in the emergence of life on earth.

Central to life on earth is photosynthesis, the process by which solar energy is captured and stored by plants. All complex life forms have devised methods of accessing the solar energy stored in plants. Human metabolism allows us to unlock this store of energy either directly, by consuming plants, or indirectly, by consuming animals. Alone among other complex life forms on earth, humans have been able to devise means of storing and using solar energy. Seen in the light of energy conversions, human history assumes a rather different, indeed remarkable shape.

In the context of the deep history of humans and the flows of energy on this planet, some historians see the Industrial Revolution as a breakthrough that allowed first Western Europeans and then others to transcend the previously existing material limits on growth. For them, the Industrial Revolution is only the most recent phase in the development of our species. These historians emphasize its scientific and technological dimensions and neglect its energetic aspects. But if we rethink modernity in terms of its bioenergetics, we see that there have been only two major energy regimes in human history: the age of solar energy (a renewable resource) from 10,000 B.C.E. to 1800 C.E., and the age of fossil fuels (a nonrenewable resource) from 1800 C.E. to the present. This latter category includes coal, petroleum, and natural gas. Nuclear power constitutes an additional, if problematic, source of energy.[6] This unprecedented transformation lies at the heart of any history of humans and their relationship to the environment.

For one thing, this view suggests a rather different chronology of human history from the one we are used to. Organizing this alternative history in tabular form yields something like table 2.1. Both the age of solar energy and the age of fossil fuels can be further subdivided. Our story begins in the Paleolithic era (250,000–100,000 B.C.E. to 10,000 B.C.E.) when early human hunter-gatherers first incorporated the use of fire into processing a diet of wild grains, fruits, nuts, and plants and hunting. By roughly 20,000 B.C.E., their enormous success had resulted in the distribution of hunter-gatherers all around the world (dates on the peopling of the Americas lag but have been consistently revised backward).[7] Over the ensuing thousands of years, humans, plants, and animals underwent imperceptible but cumulatively important genetic changes in interaction with one another. The culmination of this process of coevolution was the Neolithic revolution (ca. 5000 B.C.E.), when, as a result of ever-increasing human populations, hunter-gatherers

TABLE 2.1 Human Energy Regimes through History

The Age of Solar Energy (origins to c. 1800 C.E.)	
Hunter-gatherers; mastery of fire	2.5 million B.C.E.–10,000 B.C.E.[1]
Early farming	10,000 B.C.E.
Early agrarian age under regional empires	5000 B.C.E.–1400 C.E.
Late agrarian age under conditions of globality	1400 C.E.–1800 C.E.
The Age of Fossil Fuels (c. 1800 C.E.–present)	
Early fossil-fuel era; coal and steam	1800 C.E.–present[2]
Late fossil-fuel era; petroleum, natural gas, and atomic power	1800 C.E.–present

[1] Hunter-gatherer lifestyles have continued in isolated locales to the present.
[2] Coal continues to be a major source of energy.

discovered a means of obtaining a reliable food supply: farming. Although Neolithic peoples adopted farming with reluctance, once they had done so there was no going back. Farming transformed the relationship of humans to the bioenergetic system of the planet by allowing them to extract much greater energy yields from animal husbandry and agriculture. Farming had one huge advantage: it supported more people in a given area and thus encouraged the development of more densely packed settlements with an increased capacity for cooperation and mutual learning (as well as conflict). Over the next several millennia, agriculture emerged in various locations around the world, including Egypt, Mesopotamia, the Ethiopian highlands, West Africa, the valley of the Yellow River, the Indus valley, and—somewhat later—the highlands of Mesoamerica and the Andes.[8] Thus began the agrarian age, which lasted from around 5000 B.C.E. until 1800 C.E. (The agrarian age can in turn be divided into two unequal periods: the classic agrarian age, 5000 B.C.E. to 1400 C.E., and the late agrarian age, 1400 C.E. to 1800 C.E.)

This agricultural revolution transformed the relations between humans and the environment. Agriculture can be viewed as a solar-energy system controlled by humans, in which the energy output of selected plants is monopolized for human purposes. Humans can be regarded by states as ambulatory solar-energy storage systems, and cities containing many humans can be seen as complex energy machines. Over the next several millennia, a species-level step up the energy-conversion staircase occurred as complex societies and cities emerged across Eurasia. Humans developed additional methods of energy conversion as well as a greater need for stored energy.[9] Agriculture encouraged the clearing of land for farming. Civilizations emerged, and with them trade, warfare, and religion. These developments established the basic rules of the energy conversion game that shaped the relations of humans to the environment until the dawn of the Age of Fossil Fuels around 1800 C.E. The ability of societies to mobilize large numbers of people to perform specific tasks greatly multiplied the ability of humans to access the solar energy embedded in crops (as well as to construct walls, pyramids, canals, and cities). Cities organized and transformed the energy of urban artisans, merchants, religious specialists, bureaucrats, military personnel, and other specialists. We can thus think of cities as complex energy machines.

Control over people was therefore a central feature of the energy strategy of most states and societies in the age of solar energy. Those able to organize large numbers of humans gained a major energy premium. To execute an important project, much human labor would have been required, as humans are quite inefficient machines.[10]

A second type of energy leveraging that occurred more or less simultaneously with the rise of agriculture was the domestication of horses and other traction animals (another type of ambulatory solar-energy storage system). Animal power was especially important for basic agricultural tasks such as plowing and harvesting, as a horse generates roughly six times the power of a man and has much greater endurance. Because horses could only do certain types of work, however, a mix of human and animal power was needed for most purposes. The use of animal power became widespread across much of Afroeurasia (but not the Americas).

Finally, technological invention enabled humans to leverage additional energy. Simple technologies (such as water-lifting devices, pulleys, and levers) developed early in the agrarian age multiplied the energy available from human power. Further technical innovations over the centuries provided solutions to a host of energy bottlenecks. By the early agricultural era, the use of fire had progressed beyond cooking food and providing warmth to propel advances in metallurgy for making tools and weapons, firing ceramics, brewing, and dyeing textiles. However, these technologies were prone to environmental "overshoot" because of large-scale deforestation.[11] Succeeding millennia saw the development of technologies for water management, mining, writing systems, maritime communications, textiles, mathematics, and astronomy. Important as these inventions were in enabling humans to maximize their use of the solar energy, their overall contribution was relatively modest, given their relatively low efficiency. New inventions and the modification of old ones, along with their gradual diffusion, continued to provide incremental advantages.

Although agrarian-age societies might under favorable conditions press against their ecological limits through the complex linking of demographic increase, technological change, the expansion of the economy, and the reach of the state, they were inherently unstable and prone to sudden collapse from famine, disease, and warfare.[12] In the ensuing centuries, control over people (and animals), as well as control over croplands, defined the bioenergetic limits of human development. The size of ancient empires therefore provides a crude measure of their energy capabilities.[13] Anthropogenic damage to the environment (deforestation, for example) was sometimes extensive, but agrarian-age systems were essentially self-correcting and self-limiting, as the consequences of environmental overshoot were readily apparent within a generation or two. The transition to agriculture thus provides a powerful way of visualizing the environmental feedback loops that occurred with the onset of modernity.[14] The rules of the energy game of the agrarian age remained in effect during the six and a half millennia of the classic agrarian age (5000 B.C.E. to 1400 C.E.).

The remarkable stability of human population levels in this period provides a powerful demonstration of this point. Empires rose and fell, to be sure. But the energy calculations remained much the same. The only way populations could increase significantly was through improved technology and agricultural cropping practices. Around 100 C.E. the world population peaked at about 250 million (see figure 2.1). Between ca. 300 C.E. and 650 C.E. there was a hemispheric-wide dip, before human populations began once again to increase across Afroeurasia. Not until ca. 1000 C.E. did they again reach 250 million.[15]

Agrarian societies always had a tendency to push their ecological limits. Peasant families tended to maximize births as a survival strategy. States and entrepreneurs tended to seek a technological edge over local competitors by modifying existing technologies. Mining, in particular, tended to stimulate technological innovations, as its high energy demands continually provoked crises and bottlenecks requiring solutions. Trade and migration provided access to goods, ideas, and people not locally available, but introducing these could have unforeseen destabilizing consequences.

Improvements in existing technologies and the diffusion of new technologies stimulated population growth as well. For example, according to Andrew Watson, with the spread of Islam, a "medieval Islamic green revolution" occurred, spurred by the diffusion of new crops, irrigation systems, and agricultural technologies, which led to the rebuilding of old cities (and the construction of new ones) both in the old Middle Eastern core areas and in Central and South Asia, North Africa, and Spain.[16] A similar burgeoning of populations occurred in China under the Song dynasty (960–1279). There, as a result of internal colonization and the construction of the Grand Canal, the center of gravity of the Chinese empire gradually shifted from the northern China plain, where dry farming had dominated, to the southern Chinese rice-growing areas (see Kenneth Pomeranz's essay on China in this volume).[17] In roughly the same period, new technologies such as the moldboard plow and the horse collar enabled European peasants to farm the heavy soils of Eastern Europe and led to significant population increases there. In South Asia, the big push started somewhat earlier. The opening of the vast delta of the Ganges valley to rice cultivation decisively shifted the focus of Indian civilization to Bengal (see the essay by Mahesh Rangarajan in this volume).[18] By the tenth century the regional empires of Africa, Europe, and Asia had become more densely networked, and commercial exchanges were becoming more important.

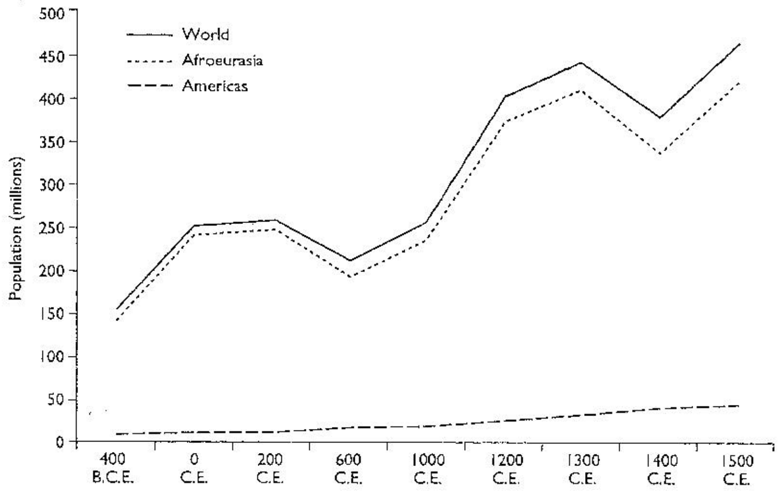

FIGURE 2.1.
World population, 400 B.C.E.–1500 C.E. *Source:* Adapted from Massimo Livi-Bacci, *A Concise History of World Population* (Cambridge, MA: Blackwell, 1992), 31.

From about 1000 C.E. onward, an unprecedented population increase defied the old limits on growth and pushed the global population to around 350 million by 1400 C.E. This period can be seen as a culmination of the potentialities of the old-style agrarian empires, even though its advances were in some ways obscured by the Mongol conquests of the thirteenth century and the Black Death of the 1340s.

TABLE 2.2 Estimated World Regional Populations

(*millions*)

	1400 C.E.	1500 C.E.	1600 C.E.	1700 C.E.	1800 C.E.
China	70	84	110	150	330
India	74	95	145	175	180
Europe	52	67	89	95	146
Sub-Saharan Africa	60	78	104	97	92
Latin America	36	39	10	10	19
World totals	375	476	578	680	954

SOURCE: J.R. Biraben, "Essai sur l'évolution du nombre des hommes," *Population* 34 (1979): 16.

Three developments in this period enabled humans to improve on the energy calculus of the age of solar energy: the diffusion and perfection of basic technologies and concepts that enhanced the efficiency and productivity of Eurasian societies; the growing efficiency and wider application of wind energy (which enabled ocean navigation); and the development and adoption of more powerful and reliable gunpowder weapons. By 1400, it was clear that the terms of the energy equation were shifting throughout the hemisphere, provoking wars of conquest, more efficient exploitation of old territories, and the encouragement of trade. Nonetheless, the underlying energy equation of the age of solar energy remained in place.

One sign that humanity was entering a new energy context was the expansion of world population from 375 million to 954 million between 1400 and 1800 (table 2.2).[19] These changes especially affected the interlinked societies of North Africa, Europe, and Asia (where the vast majority of humans lived). Between 1400 and 1800 the Chinese population increased from 70 million to 330 million; India's population grew from 74 million to 180 million; and Western Europe saw growth from 52 million to 146 million. Only the Americas, which suffered an unparalleled demographic catastrophe following the arrival of Europeans, constitute an exception to this pattern. The Great Dying was the most devastating epidemiological event known in world history.[20]

In response to the new conditions of incipient globality, new agrarian empires emerged across Eurasia, reflecting their greater efficiency in mobilizing people and energy resources. States and empires such as Spain, France, the Hapsburg Empire, imperial Russia, the Ottoman Empire, the Safavid Empire, the Mughal Empire, Ming and Qing China, and Tokugawa Japan attained unprecedented power.

Although statistical measures are lacking, it seems evident that early modern empires wielded significantly greater power than their predecessors because of their mastery of new military and mining technologies, and techniques of shipbuilding and navigation. Early modern societies also showed an increased capacity for social organization and political management. Long-distance trade and oceanic fishing brought protein (herring and cod), basic food grains (rice, maize, and manioc), precious metals, stimulants (spices, sugar, coffee, tea, and cacao), and textile fibers (silk and cotton) across oceans. The diffusion of new agricultural technologies, know-how, and crops brought vastly increased production and profits for some, and also made it possible to feed unprecedented numbers of people worldwide. As John F. Richards argues in the next chapter, the land-use policies put into place between 1400 and 1800 encouraged the establishment of state-enforced property rights in land, as well as more specialized and more capitalist uses of land. As a result, the local property regimes of indigenous peoples, and the community property rights of peasant communities, came under increasing challenge.

By 1800 complex social organizations, including larger and more elaborate bureaucratic state structures and systems of economic exchange, technology, and communication had emerged all around Eurasia as well as in parts of Africa. As centralizing states sought to maximize the productivity of their lands, they also tried to devise policies that would channel the energies of local agrarian elites and entrepreneurs. Between 1400 and 1800, agriculture in early modern Europe became increasingly delocalized as agricultural products became commodified.[21] Many states deployed increasingly well-tuned systems of exploitation and more effective technologies that strengthened their power in agrarian core areas and along internal frontiers. More particularly, Western European states were able to exploit their external frontier regions (the Americas, Africa, and the Indian Ocean zone), notably for silver, spices, sugar, silk, and cotton. One consequence, as Richards has argued, was a sharp increase in environmental degradation of all kinds.[22]

Indeed, the increased environmental degradation of this period can be seen as a sign that the energy dynamics of the late agrarian age had shifted into a new phase. The huge increase in global population between 1400 and 1800 sent the price of fuel and wood soaring, and global energy demands began to push against the existing local and regional ecological limits. The consumption of wood for mining, shipbuilding, industrial uses, and domestic heating reached unprecedented levels, especially in Europe, the Mediterranean, and Japan. By around 1800 (earlier in Britain), Western Europe, Japan, much of China, and parts of the Americas found themselves in an energy crisis. As world population increased, the clearance of forest land for agricultural purposes accelerated. Simultaneously, the principal industrial fuels (wood and charcoal) fell into increasingly short supply. In addition, the expansion of mining and metallurgy led to the deforestation of entire regions around the major mining sites. Silver and mercury mining in Japan and Latin America (and in Potosí and Huancavelica in the Peruvian Andes, and Zacatecas in central Mexico) were especially destructive. Mining also significantly decreased forest cover in England, northern France, and central Europe. The wood crisis was further exacerbated by the boom in naval construction. The demands for ship's timbers, masts, and spars strained the forests of the Baltic and New England, as well as the Indian Ocean rim, where vessels for the Asian trade were constructed. Finally, in Brazil and the Caribbean, the sugar industry, which consumed vast quantities of wood and charcoal to fire sugar boilers, was another cause of local deforestation.[23]

At this point, something unprecedented occurred: the transition from biomass (wood and charcoal) to fossil fuels (initially coal, later petroleum and natural gas) as the principal source of heat energy. Thus began the age of fossil fuels. Thus far there have been two major phases: the age of coal (1800–1914) and the age of petroleum and natural gas (1880–present). Although coal had been known for centuries, it was little used as a fuel. Burning coal produced a nasty smell, gave off clouds of inky smoke, and had evident health consequences. As a result, there was enormous resistance to employing it. The shift began first in Britain, whose economy was the most severely affected by the wood shortage. By a lucky circumstance, moreover, Britain was well endowed with coal, and the coalfields were conveniently located near rivers (thus making coal easier to transport).[24] The transition from wood and charcoal to fossil fuels marks a fundamental shift in human and planetary history. Like the transition from the hunter-gatherer lifestyle to farming, it was neither desired nor sought after. With the availability of vast quantities of coal, the amount of heat energy accessible to humans became virtually limitless (although, as coal deposits are not universally distributed around the world, some societies inevitably profited more than others).

The advent of the age of fossil fuels released humans from their dependence on organic materials and from the trade-offs between heat, food, and raw materials. Previously, wood had been the main building material worldwide, and brick making had been very expensive because of the prodigious quantities of wood it required. With coal, it became possible to produce bricks cheaply and in quantity. This development lessened the demands on local wood resources both as fuel and as building material. Finally, the shift to coal lessened the dependency of its users on human and animal labor. As increasingly efficient technologies were developed, previously labor-intensive sectors such as agriculture and transport began to shed labor, freeing up workers for other purposes.

The effect of the coal revolution was multiplied exponentially by the development of the steam engine. Steam engines made it possible to capture the heat energy from burning coal, to concentrate it, and to use it to power machinery. The development of steam engines thus deserves to be considered analytically as separable from and as significant as the transition to coal itself.

Mechanization and steam engines transformed British (and subsequently European, U.S., and Japanese) industrial production in the nineteenth century in three important ways. One was the revolution in transport brought about by railroads and steamships. Steam power enormously increased the ability of humans to transport bulky, heavy goods like coal and iron over long distances. Previously, mining operations had tended almost literally to burn out once they had exhausted the fuel potential of nearby forests. With steam engines and railroads, coal could be moved long distances for pennies a ton, stimulating industries far from the mineshaft. Beginning in the early nineteenth century, railroads soon linked local communities to distant cities and countries, with accelerating economic and social consequences.[25] Steamships fueled by coal sounded the death knell for sailing ships following their introduction in the 1840s. Cheaper, more reliable, and faster than sail, steamships stimulated an unprecedented increase in trade and human migration.[26] In sum, steam power made possible a revolution in global communication, shrinking the globe and facilitating both European imperialism and nationalism.

At first, steam engines were restricted to powering the pumps that removed water from the mines. (The original Newcomen engine was bulky and immovable, consumed coal at prodigious rates, and was only 0.7 percent efficient.) But as efficiency increased, coal came to power the steam locomotives that moved the coal and iron ore to the foundries and factories of Europe. Soon coal and steam power were being used to power the Industrial Revolution. Steam engines and machines of all kinds gave humans an ability to produce far greater quantities of goods of all kinds than ever before, decisively altering the balance between man and nature. Coal (and its more energy-intensive derivative, coke) made it possible to produce vastly greater quantities of iron and steel while sparing the forests. It also allowed blast furnaces to reach much higher temperatures and to produce steel of much higher quality. (The fact that coal was a nonrenewable energy source was not yet widely recognized.) By 1812 coal gas was being used to light public streets, factories, and homes in London, and by midcentury it was widely used in Europe and America.[27]

From an environmental perspective, the availability of fossil fuels dramatically transformed the energy equation for societies all over the world. In the nineteenth century, energy consumption per capita rose rapidly in Europe, and later in other parts of the colonial developing world. Today, a nation's energy consumption correlates closely with its position in the world economy.

Although there is no denying that the Industrial Revolution was a remarkable event, the way we tell its history has tended to skip over the centrality of the energy transformation. We trace its origins instead to ineluctable processes of economic change fortuitously hard-wired into the DNA of "the West" (all those amazing technical inventions and that capitalist entrepreneurial zeal).[28] However, this perspective misconstrues a central element of the transition. The epochal move from solar-fueled to fossil-fueled economies depended crucially on the presence of coal in apparently unlimited quantities and readily exploitable forms. From an energy perspective, we might say that without fossil fuels, there would have been no Industrial Revolution, or at most a much-reduced and self-limiting one.

But if there had been no coal, then, too, Europe would look more like sub-Saharan Africa, much of the Mediterranean world prior to the twentieth century, or Latin America. These regions have little or no coal and depend heavily on external energy sources. If European coal were not conveniently located near water, then Europe would have had a history like China or South Asia (which have lots of coal, most of it difficult to access). The geography of the distribution of coal seems to map the developed world. Another way of thinking about this is to say that Britain's coal consumption in 1800 made available an additional 15 million acres to agricultural purposes that had previously been dedicated to producing wood for fuel.[29] If British factories had been dependent on wood (or more likely, charcoal) for fuel, there would not have been enough wood in all of Britain to fuel the boilers of the "dark Satanic Mills." The consequences of what Vaclav Smil calls the "Great Transition" from wood to coal was therefore momentous.[30]

This transition involved many trade-offs. Although it spared the forests, it caused terrible air pollution. Carbon dioxide emissions increased greatly, as did pollution of rivers and streams, and acid rain. By the nineteenth century, the killer fogs that bedeviled Charles Dickens's London had their counterparts everywhere in the industrial world. Inky black clouds enveloped cities and their hinterlands for weeks at a time, causing epidemics of respiratory diseases, shortening lives, and poisoning the atmosphere. The transition to fossil fuels shattered all previous human expectations of how much was too much. Previously, the overuse of resources was readily apparent: now resources could be consumed without regard for the environmental consequences.

Another major step up the energy-consumption ladder occurred with the invention of electric power. The principles behind electricity had been known since the end of the eighteenth century, and several important discoveries in the nineteenth century (notably by Michael Faraday) showed that electricity could be produced from mechanical energy. The first electrical generating plants (developed by Thomas A. Edison) came on line in 1882 and were at first used to generate electric lighting. But Edison was wedded to direct current, which was more costly to produce and of limited applicability. Nicola Tesla's 1887 discovery of alternating current (which, unlike direct current, could be transmitted over long distances at high voltages) and its successful commercial production by Westinghouse in 1893 (using hydropower generated by Niagara Falls) set the stage for the electrification of the United States. By 1900 dynamos and steam turbines were being used to generate electricity for use in factories and households and to power railroad locomotives. Coal-fired steam generators were for a long time the standard for most electrical utilities providers. With the coming of electricity, world human energy consumption soared to record levels. As the applications of electricity mushroomed in the twentieth century, its use spread around the globe. Engines of all types became ubiquitous. Our modern world is unimaginable without electricity.

By 1900, the consumption of fossil fuels began to shift from coal to oil. Oil was first exploited commercially in Pennsylvania in 1859 and was primarily used for lighting and heating, in the form of kerosene. The technical challenges of transporting and refining oil were eventually solved, as pipelines and oil tankers were developed. With the development of the internal combustion engine, the place of petroleum as a source of energy was assured. The transport sector remained the primary consumer of oil until after World War II.

Since the early nineteenth century, there has been a thousandfold increase in the consumption of fossil fuels. Figure 2.2 provides figures for a sample of world societies in different periods. Global per capita energy consumption was about 5 billion joules per year in the Neolithic period (ca. 10,000 B.C.E.). With the coming of the agrarian-age empires, per capita energy use increased notably. For example, the Han Chinese empire (206 B.C.E.–20 C.E.) consumed around 20 billion joules per year, about half of it being used for food-production and household needs. By 1300 C.E. European societies had doubled their energy consumption in all categories.

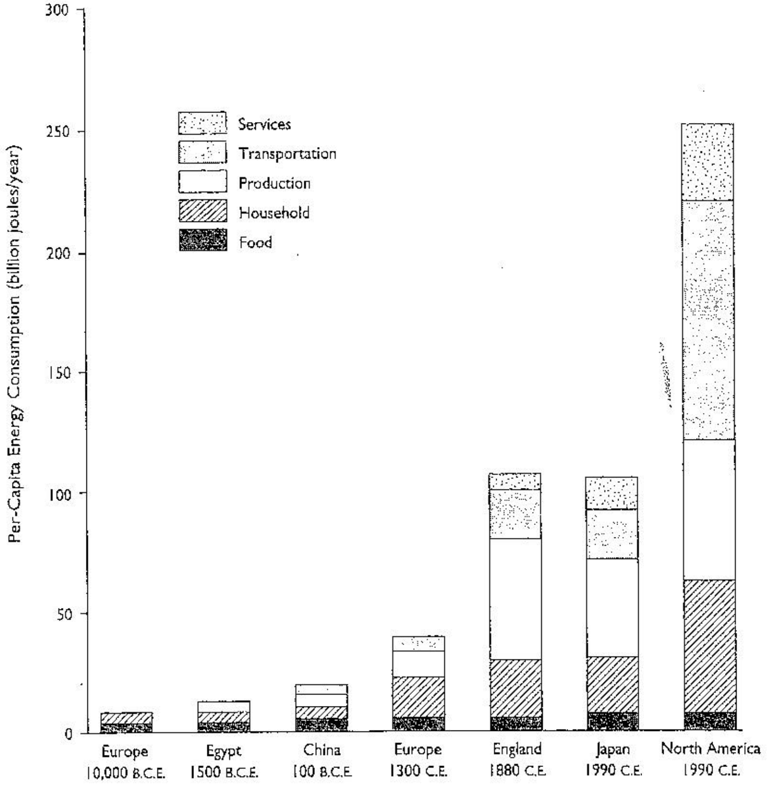

FIGURE 2.2.
Per-capita energy consumption in world history, selected societies. *Source:* Vaclav Smil, *Energy in World History* (Boulder, CO: Westview Press, 1994), 236.

Unfortunately, this figure does not include data on the late agrarian age, when we know that both energy consumption and energy efficiency increased significantly. As a result, it exaggerates the rapidity of the transition to fossil fuels. Between 1330 and 1880, British per capita energy consumption more than doubled. The portion of energy consumption devoted to production and transportation increased dramatically, both in absolute terms and per capita. This marks the apex of the coal phase of the age of fossil fuels. Indeed, in 1990 Japanese per capita energy consumption had still not reached the levels enjoyed by Britain in 1880. By this time, however, North American per capita energy consumption was more than double that of Britain in 1880. In the United States, an unprecedented proportion of this total was devoted to transportation and services. Overall, per capita energy consumption increased more than twenty-five-fold between the Neolithic period and the present.

Table 2.3 offers an even more stunning demonstration of increases in energy use, showing average energy consumption in different historical eras. For most of human history, from the Paleolithic period to the advent of industrial society, human energy consumption was barely adequate to fulfill basic metabolic needs. There was a slight increase in energy use with the coming of advanced agrarian societies. Then, about a century ago, global energy use suddenly shot up to around 123.2 billion calories per day. This reflects the larger food and domestic usage figures seen in figure 2.2. But the greatest expansion of energy use occurred in the most recent period, which I. G. Simmons calls advanced technological society, where it rose to a truly extraordinary 1,380 billion calories per day.[31] Since the early nineteenth century, there has been a thousandfold increase in the consumption of fossil fuels worldwide.[32]

The importance of oil and natural gas to human energy consumption has increased remarkably. Figures compiled by the Worldwatch Institute for the second half of the twentieth century show that total world fossil-fuel consumption has increased from less than 2 billion tons in 1950 to 8 billion tons in 2000 (figure 2.3). These are extraordinary figures: both the 1950 total by itself, and the 2000 figure, which reflects a fourfold increase in energy consumption worldwide in fifty years.

These figures may conceal a somewhat paradoxical trend: a rise in the consumption of coal. In 2005, those best placed to know suggested that global coal resources should last for 250 years, at current levels of consumption. (Because coal consumption has been rising, this assumption may need to be reexamined.)[33] Geologists estimate petroleum and natural gas reserves at 5 percent of coal reserves. With world oil consumption currently rising, coal may become far more important in the future. China and India, the two most populous countries in the world, each with populations exceeding one billion, are petroleum-poor and coal-rich and have rapidly increasing energy requirements. Coal production has been increasing in recent decades, even in North America and Europe.

The age of fossil fuels has also seen the rise of an entirely different source of energy: nuclear power. The use of nuclear energy now seems likely to increase as well, even though there has been no solution to the key bottleneck, the disposal of highly toxic nuclear wastes. European states such as Britain and France have recently begun planning the next generation of reactors to replace the aging reactors

TABLE 2.3 Average Daily Per-Capita Energy Consumption in Different Historical Eras

	Food (including animal feed)	Home and Commerce	Industry and Agriculture	Transportation	Total per Capita	World Population (millions)	Total
Protohumans	2*				2		
Hunters' society (12,000 B.C.E.)	3	2			5	6	30
Early agricultural society (3000 B.C.E.)	4	4	4		12	50	600
Advanced agricultural society (1000 C.E.)	6	12	7	1	26	250	6,500
Industrial society (1900 C.E.)	7	32	24	14	77	1,600	123,000
Present era	10	66	91	63	230	6,000	1,380,000

SOURCE: Adapted from David Christian, *Maps of Time: An Introduction to Big History* (Berkeley: University of California Press, 2004), 141.

*Units of energy = 1,000 calories/day.

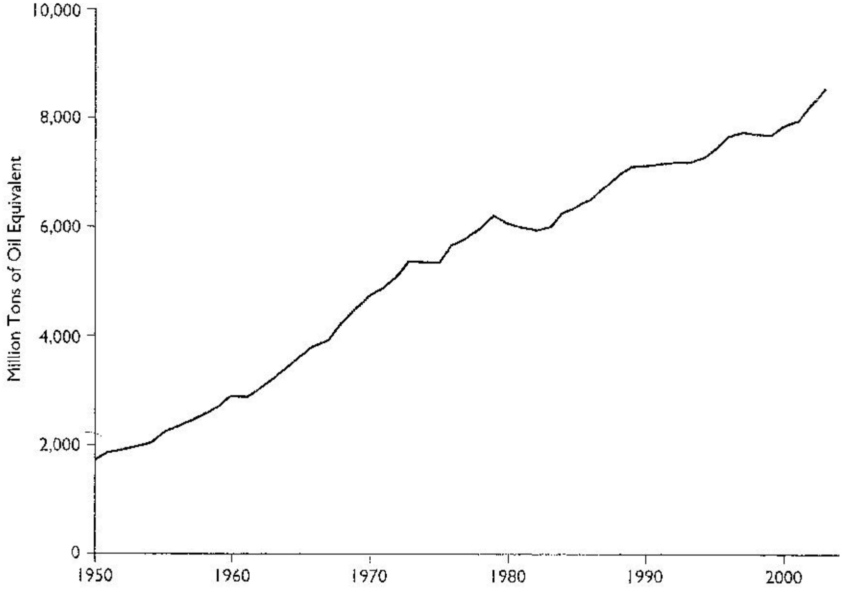

FIGURE 2.3.
World fossil-fuel consumption, 1950–2003. *Source:* Worldwatch Institute.

now in service. Nuclear power provides 7 percent of the world's energy and 17 percent of its electricity.[34] France, which closed its last coal mine in April 2004, currently produces more than 80 percent of its energy from nuclear reactors, making it the world leader in nuclear-energy consumption. The United States produces about 20 percent of its energy from nuclear sources.

Viewing human history in terms of energy consumption allows us to recognize the basic ecological trade-offs involved in choosing energy sources. It also provides a basis for reevaluating the significance of the Industrial Revolution and the current energy bottleneck in which humanity finds itself. Can we draw on our collective learning to find a solution? The environmental and energetic balance is not reassuring. Certainly the rest of the planet cannot increase its levels of energy consumption to match the levels of Europe, North America, Australasia, and Japan; nor can these levels be sustained indefinitely. Indeed, viewed against the background of all of human history, present levels of energy consumption appear deeply aberrant.

Is it possible to devise a sustainable fossil-fuel strategy?[35] Most experts agree that the discovery of additional quantities of petroleum on the scale of the oilfields of Saudi Arabia is most unlikely. Although coal reserves are larger, current methods of using coal do not hold out great hope for the long run. Most of the other remedies proposed (such as shale oil or alternative sources, such as solar, wind, and nuclear energy) have significant limitations. No single solution to the current impasse is apparent. But then the discovery of fossil fuels was itself improbable and at first stoutly resisted: other solutions may emerge that are implausible or unimaginable today.

Thomas Malthus (1766–1834) observed that the four human needs—food, clothing, shelter, and fuel—were in direct competition. An increase in one need necessitated reducing consumption of the others, and as population increased, difficult trade-offs were the inevitable result. These trade-offs had constrained the possibilities for economic growth since the early agrarian age and could be deferred only for brief periods. Although the enormous economic growth of the early nineteenth century impressed Malthus and his contemporary Adam Smith, both men were haunted by fears of a return to the cycles of demographic growth, overshoot, and population crash that had been the pattern throughout human history. Neither man ever recognized that he lived at the dawn of the Industrial Revolution and that the exploitation of fossil fuels had shattered the old limits on growth.[36] The current moment is freighted with a similar indeterminacy. So Malthus and Smith were wrong about the future. Or, in view of the new circumstances, prematurely pessimistic—by two and a half centuries. Today, with global population levels approaching seven billion human beings, although there are some grounds for guarded optimism, we can for the first time begin to contemplate the end of the age of fossil fuel. Some authorities suggest that given current rates of population increase and consumption patterns, we may actually be entering the down phase of a modern Malthusian cycle.[37]

NOTES

1. Richard Feynman, *The Feynman Lectures on Physics* (Reading, MA: Addison-Wesley, 1988), 4.2.

2. David Christian, *Maps of Time: An Introduction to Big History* (Berkeley: University of California Press, 2004), appendix 2.

3. Stephen J. Pyne, *World Fire: The Culture of Fire on Earth* (New York: Holt, 1995). See also, by the same author, *Vestal Fire: An Environmental History, Told through Fire, of Europe and Europe's Encounter with the World* (Seattle: University of Washington Press, 1997); *Fire in America: A Cultural History of Wildland and Rural Fire* (Princeton: Princeton University Press, 1982); and *Burning Bush: A Fire History of Australia* (New York: Holt, 1991).

4. Johan Goudsblom, *Fire and Civilization* (London: Penguin, 1992).

5. Vaclav Smil, *General Energetics: Energy in the Biosphere and Civilization* (New York: John Wiley and Sons, 1991). See also his *Energies* (Cambridge, MA: MIT Press, 1999).

6. Rolf Peter Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution* (Cambridge, U.K.: White Horse Press, 2001).

7. For a convenient summary of the new chronology for the settlement of the Americas, see Charles C. Mann, *1491: New Revelations of the Americas before Columbus* (New York, Alfred A. Knopf, 2005).

8. On the origins of agriculture, the best guide is B.D. Smith, *The Emergence of Agriculture* (New York: Scientific American Library, 1995). See also Jared Diamond, *Guns, Germs and Steel* (New York: Vintage, 1998).

9. An excellent summary of the debate on the origins of agriculture can be found in Christian, *Maps of Time,* chapter 8.

10. Stephen Boyden, *Patterns in Biohistory* (Oxford: Oxford University Press, 1987), 196. See also Charles A. S. Hall, Cutler J. Cleveland, and Robert Kaufmann, *Energy and Resource Quality: The Ecology of the Economic Process* (New York: John Wiley and Sons, 1986).

11. John R. McNeill, "Woods and Warfare in World History," *Environmental History* 9, no. 3 (2004): 388–410.

12. Infrahistorical factors such as bolide impacts, earthquakes, floods, droughts, volcanism, and El Niño and La Niña events, are also nontrivial sources of environmental change. They are not considered here because they lie outside the realm of human causality.

13. Christian, *Maps of Time,* 316–24.

14. For one approach, see Jason W. Moore, "The Modern World System as Environmental History: Ecology and the Rise of Capitalism," *Theory and Society* 32 (2003): 307–77.

15. Peter Christensen, *The Decline of Iranshahr: Irrigation and Environments in the History of the Middle East, 500 B.C. to A.D. 1500* (Copenhagen: Museum Tusculanum Press, 1993), 65–70.

16. Andrew Watson, *Agricultural Innovation in the Early Islamic World* (Cambridge: Cambridge University Press, 1983).

17. Mark Elvin, *Patterns of the Chinese Past* (Stanford, CA: Stanford University Press, 1973), chapter 9. The classic work remains Joseph Needham et al., *Science and Civilization in China,* vol. 6, part 2, *Agriculture* (Cambridge: Cambridge University Press, 1984).

18. On the environmental history of India, see Madhav Gadgil and Ramachandra Guha, *This Fissured Land: An Ecological History of India* (Berkeley: University of California Press, 1993). See also the introduction to Richard Grove, Vinita Damodaran, and Satpal Sangwan, eds., *Nature and the Orient: An Environmental History of India and Southeast Asia* (Delhi: Oxford University Press, 1998).

19. Colin McEvedy and Richard Jones, *An Atlas of World Population History* (New York: Facts on File, 1978).

20. On the Great Dying and the Columbian exchange, Henry F. Dobyns, "Estimating Aboriginal American Population: An Appraisal of Techniques with a New Hemispheric Estimate," *Current Anthropology* 7 (1966): 395–415, is fundamental. Mann provides some recent population estimates in *1491*.

21. Jason W. Moore, "Environmental Crisis and the Metabolic Rift in World-Historical Perspective," *Organization and Environment* 13, no. 2 (2000): 126.

22. John F. Richards, *The Unending Frontier: An Environmental History of the Early Modern World* (Berkeley: University of California Press, 2005).

23. For an overview of global deforestation in this period, see the magisterial study by Michael Williams, *Deforesting the Earth: From Prehistory to Global Crisis* (Chicago: University of Chicago Press, 2006), chapters 6–8. See also Richards, *Unending Frontier*.

24. John U. Nef, *The History of the British Coal Industry* (London: Cass, 1932), 2 vols.

25. Patrick O'Brien, ed., *Railroads and the Economic Development of Western Europe, 1830–1914* (New York: St. Martin's, 1983).

26. Henry Fry, *The History of North Atlantic Steam Navigation* (London: Sampson, Low, Marston & Co., 1896); James Croil, *Steam Navigation* (Toronto: William Briggs, 1898).

27. Vaclav Smil, *Energy in World History* (Boulder, CO: Westview Press, 1994), 160. Wolfgang Schivelbusch, *Disenchanted Night: The Industrialization of Light in the Nineteenth Century* (Berkeley: University of California Press, 1995), provides a convenient history of gas lighting.

28. For example, Eric Jones, *The European Miracle: Environments, Economies and Geopolitics in the History of Europe and Asia*, 3rd ed. (Cambridge: Cambridge University Press, 2003).

29. E.A. Wrigley, *Continuity, Chance and Change: The Character of the Industrial Revolution in England* (Cambridge: Cambridge University Press, 1988), 54–55.

30. Smil, *Energy in World History*, 156, 138. Five kilograms of wood are equivalent to one kilogram of charcoal.

31. Ian G. Simmons, *Environmental History: A Concise Introduction* (Oxford: Blackwell, 1993).

32. On the fossil-fuel revolution, see Clive Ponting, *A Green History of the World: The Environment and the Collapse of Civilizations* (London: Penguin, 1993), chapter 13. On the European dimensions, see Williams, *Deforesting the Earth*, chapter 6.

Table 2.3 masks a huge divergence between richer, industrialized societies and poorer, nonindustrialized societies worldwide and similarly impressive differences between rich and poor within individual societies. Indeed, what is striking about the last century of energy use is the massive advantage it has offered to the favored few, whether in rich or poor societies, at the expense of the poor. By 1900, the United States was consuming more than 50 percent of all of the energy used in the world. In 1950, despite the industrialization of other parts of the world and a global increase in energy use, U.S. energy consumption was still 30 percent of total world consumption. Because the U.S. population then represented 3 percent of the global population, this decline reflects its decline relative to other countries.

33. Worldwatch Institute, *Vital Signs* 2004, www.worldwatch.org

34. Worldwatch Institute, *Vital Signs*, 2004, www.worldwatch.org

35. See Mark Jaccard, *Sustainable Fossil Fuels* (Cambridge: Cambridge University Press, 2005).

36. Wrigley, *Continuity*, 47–51, 66–67.

37. Christian, *Maps of Time*, 471–81, especially 471. See also David Kennedy, *Preparing for the Twenty-First Century* (London: Fontana Books, 1994).

PART THREE LANDSCAPES, CONQUESTS, COMMUNITIES, AND THE POLITICS OF KNOWLEDGE

FIGURES, MAPS, AND TABLES

FIGURES

MAPS

TABLES