



The Evolution of Humans and Their Economies

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The first four chapters focused mostly on economics, that is, the procedures by which we study our economies. This chapter focuses more about the economies themselves, including their historical and biophysical basis.

6.1 The History of Formal Thought on Surplus Energy

Many natural and social scientists from different disciplines have thought deeply about the long-term relation of humans and wealth production. Many of them have concluded that the best general way to think about how societies evolved over time is from the perspective of surplus energy. Human history, including contemporary events, is essentially about exploiting energy and the technologies to do so. This is not the perspective taught in our schools, and the role of energy is essentially missing from our dominant history. Instead, human history usually is seen in terms of generals, politicians, and other personalities. But the options and successes and failures of these generals, politicians, and others are extremely dependent upon the energy and other resources available to them for undertaking whatever they undertake.

This chapter will develop the alternative perspective that the fates of past civilizations and other events of the past can be better understood from the perspective of energy availability and in particular surplus energy. *Energy surplus* (or net energy) is defined broadly as the amount of energy left over after the costs of obtaining the energy have been accounted for. The energy literature is quite rich with papers and books that emphasize the importance of energy surplus as a necessary criterion for the survival and growth of many species, including humans and the development of science, art, culture, and indeed civilization itself. While each acknowledges that other issues such as human inventiveness, nutrient cycling, and entropy (among many others) can be important, each is also of the opinion that it is energy itself, and especially surplus energy, that is key. The issue is not simply whether there is surplus energy but how much, what kind (quality), and at what rate it is or was delivered. The interplay of those three factors determined the flow of net energy and hence the ability of a given society, whether modern or ancient, to divert

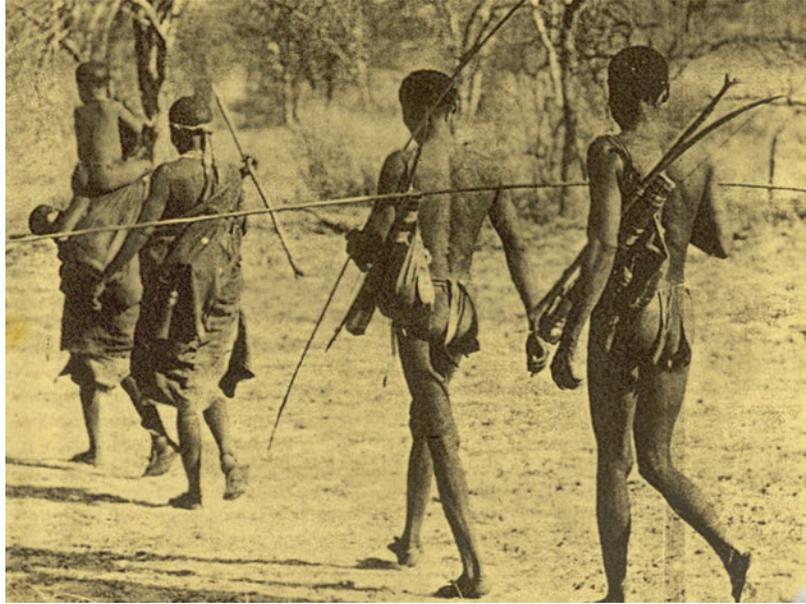
attention from growing sufficient food or the attainment of water toward trade, warfare, or luxuries, including art and scholarship. Indeed, humans could not possibly have made it this far through evolutionary time, or even from one generation to the next, without there being some kind of net positive energy, and they could not have constructed such comprehensive cities and civilizations or wasted so much in war, without there being substantial surplus energy in the past.

6.2 The Prehistory of Human Society: Living on Nature's Terms

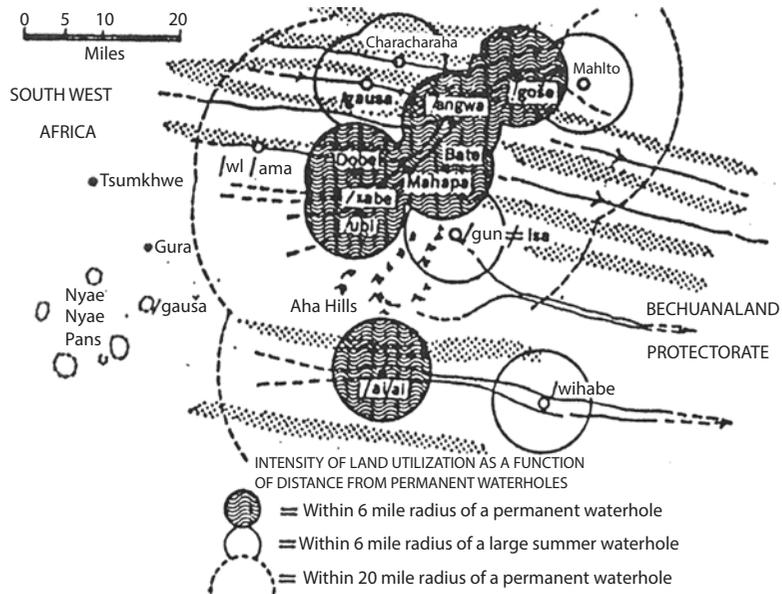
Human populations must first feed themselves and after that generate sufficient net energy to survive, reproduce, and adapt to changing conditions. While a moderately small percentage of people in industrial societies today worry about getting enough to eat, for many in the less industrialized global South, getting sufficient food is still a major concern. The focus on food acquisition has also occupied much of humanity's time throughout history. For at least 98% of the 2 or so million years that we have been recognizably human, the principal technology by which we as humans have fed ourselves has been that of hunting and gathering. Contemporary hunter-gatherers—such as the !Kung of the Kalahari Desert in Southern Africa—probably live as close to the lifestyle of our long-term ancestors as we will be able to understand. Studies by anthropologists such as by Lee and Rapaport confirmed that indeed present-day (or at least recent) hunter-gatherers and shifting cultivators acted in ways that appeared to maximize their own energy return on investment.

Richard Lee studied the energetics of the !Kung while they were relatively unaffected by modern civilization [1]. A charming, although romanticized, view of their culture is readily accessible in the movie “The Gods Must be Crazy.” Life for a hunter-gatherer is basically about taking nature as it is found and finding ways to survive on those resources. The key challenge was gaining the needed food energy. For the !Kung, this was undertaken by women gathering mongongo nuts and men hunting antelope and other animals. Mongongo nuts are the most abundant resource that provides the largest part of the energy and

■ **Fig. 6.1** !Kung people, modern-day hunter-gatherers, probably represent how all of our ancestors lived their lives for far more time than even the time since the start of agriculture (Source: Science Magazine)



■ **Fig. 6.2** Map of the various waterholes in the Kalahari desert that the !Kung migrate from and to over the seasons. The exhaustion of easy food in the region of one waterhole necessitates movement to another (Source: Lee 1973)



protein consumed by the !Kung, although game is very much appreciated and gives needed additional protein to the diet. Life is good for the !Kung, at least before their major contact with civilization (■ Fig. 6.1). According to Lee's studies, the !Kung spent far fewer hours working each day than do people living in industrial societies; a lot of their time was spent in leisure activities. Young women tended to be sexually active (which was considered normal) from as early as age 9, but tended not to get pregnant until about age 18,

when they had sequestered enough body fat so that the pregnancy was possible (i.e., it appears that the human body protects young women from pregnancy when they do not have enough energy surplus to carry a fetus) [2]. Life for the !Kung was not always simple, however, for they lived in a desert and were constrained by their need for water and food. In their homelands of Botswana, there are only a relatively few waterholes, and it is essential to set up camp near one of these waterholes (■ Fig. 6.2). Mongongo trees are spread ran-

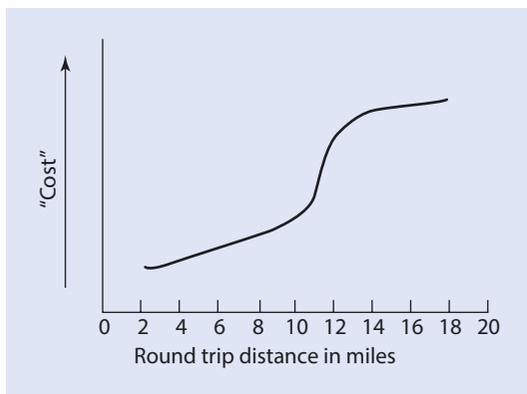


Fig. 6.3 Determinants of !Kung EROI. At a distance of about 11 miles, energy cost increases greatly because an additional day is needed. When the !Kung have exhausted the mongongo nuts within 1 day's walk, they have to make a substantial investment in walking 2 days to get a new supply of nuts (Source: Lee 1973)

domly around this part of the Kalahari Desert so initially the !Kung can derive all the food they need from relatively short excursions from their camp. As time goes on, they deplete the nuts (and game) within easy reach, so that each day they must make a longer and longer trip to gather enough mongongo nuts to feed their families. At some point, they have gathered all the mongongo nuts within a day's hike. Then they must make much longer, overnight trips to get them. Since they eat a lot of food both going and coming back, they consume a substantial portion of the food they went out to get! This greatly increases their energy investment and lowers what we call their energy return on investment or EROI (■ Fig. 6.3; see ► Chap. 13). This makes it desirable at some point to make the additional investment of moving to a new waterhole.

According to Lee, the !Kung lifestyle, under normal circumstances, generates a quite positive energy return on investment (i.e., generates a large surplus) from their desert environment, perhaps an average of some 10 Kcal returned per one of their own Kcal invested in hunting and gathering. New studies indicate that hunting may have an even higher EROI than gathering [2]. In normal times, these cultures had plenty to eat, and the people tended to use the surplus time made available from their relatively high EROI lifestyles in socializing, childcare, and storytelling. The downside was that there were periodic tough times, such as droughts, during which starvation

was a possibility. It is probable that our ancestors had a fairly positive EROI for much of the time, although periodic droughts, diseases, and wars must have occasionally, or perhaps routinely, taken a large toll. Thus even though the !Kung, and by implication other hunter-gatherers, had a relatively high EROI, perhaps 10:1, human populations tended to be relatively stable over a very long time, barely growing year to year from millions of years ago until about 1900. Thus, even this relatively high energy return was not enough to generate much in the way of net population growth over time.

It is increasingly clear that our Stone Age hunter-gatherer ancestors, as hunter-gatherers today, tended to be quite good hunters. This hunting prowess resulted in an enormous environmental impact on the large birds and mammals of the earlier world. As humans spread about the world, they encountered in each new place large, naive herbivorous animals of the sort we do not see anywhere on Earth today. For example, the new arrivals in North America found giant beavers, rhinoceros, two species of elephants, camels, and so on. Human arrivals in Australia found giant flightless birds, while the first humans into Italy found large turtles no longer extant and so on. None of these large animals are there today, and except in Africa, there are few animal species larger than 100–200 kg left. These large animals were abundant prior to human arrival (■ Table 6.1). (Of course, bison, bears, moose, and elk are large and still with us, although in greatly reduced ranges.)

What caused their extinction? There are two competing hypotheses. First, since the climate was warming rapidly 10,000 years ago, it is possible they succumbed to some effect of climate change. The second hypothesis is that humans hunted these animals to extinction. These large animals had no previous reason to be afraid of anything as small and puny as a human being, or that humans could simply walk up to these animals and stick a spear into their side. Africa still has many, many very large herbivorous species, probably because the animals coevolved with humans as they slowly became more proficient hunters with better weapons. All around the world where humans came later, most or all the larger animals disappeared within 2000 years of human arrival. This certainly supports the idea that it was humans who did them in [3]. The fact

Table 6.1 Megafaunal extinctions

	Extinct	Living	Total	% Extinct	Landmass (km ²)
Africa	7	42	49	14.3	30.2 × 10 ⁶
Europe	15	9	24	60	10.4 × 10 ⁶
North America	33	12	45	73.3	23.7 × 10 ⁶
South America	46	12	58	79.6	17.8 × 10 ⁶
Australia	19	3	22	86.4	7.7 × 10 ⁶

Late Quaternary (last 100,000 years) extinct and living genera of terrestrial megafauna >44 kg adult body weight) of five continents. Adapted after [3]. Data for extinct and living European megafauna from Martin (1984). For Australia, it may be that as many as eight genera were already extinct before human arrival (Roberts et al. 2001). If so, this reduces both the number and percentage of megafaunal extinctions that could conceivably be attributed to human activity
Source: Wroe et al. [32]

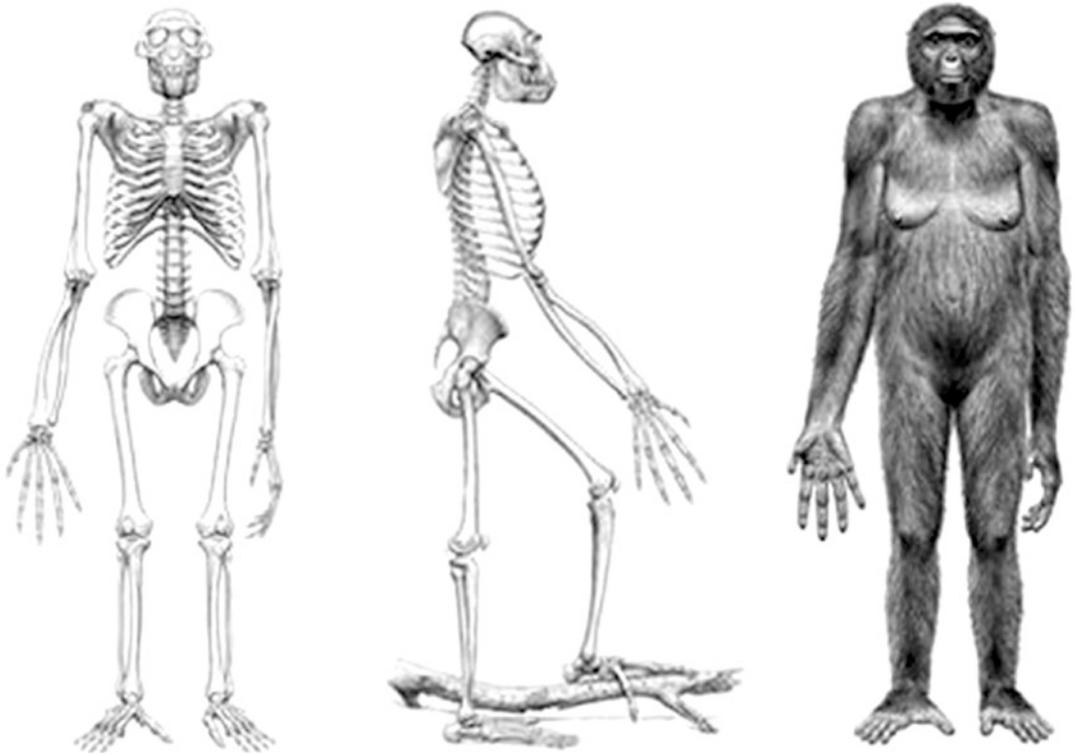
that these same animal species had survived many previous climate changes lends support to the human-caused extinction idea. Thus, significant environmental impact from humans is hardly new.

6.2.1 African Origin and Human Migrations

All available evidence suggests that humans and their predecessors evolved in Africa, which is the only place we have found human fossils or evidence dating to roughly 1.7–1.8 million years ago [4]. Take a mental time trip to East Africa about 2 or 2.5 million years ago. You would be in the cradle of the evolution and development of all that makes us human. Remarkably you would find not one but perhaps half a dozen types of early humans (or hominids), each group as distinct from one another as chimpanzees from gorillas. Most of these protohominids were found in small migratory bands at the transition of forests to drier savannas. We continue to learn more about our ancestors. The finding in the 1990s of the fossils of what appears to be the ancestor of humans that lived some 4–6 million years ago is cause for great excitement among those who are determining our lineage. This creature, named *Ardipithecus ramidus* (Ardi for short), walked upright but still spent much, perhaps the majority, of its time in trees (■ Fig. 6.4). There was strong natural selection for developing hands with opposable thumbs

that could grasp branches more firmly than with all digits on one side, preadapting humans for our present hands, very useful for the coming agricultural and industrial environments as well as such amenities as musical instruments.

Recent research has found that a human uses only about one quarter as much energy to walk 100 m as a same-sized chimpanzee, so there obviously has been a tradeoff favoring more energy-efficient walking over the ability to both walk and climb trees well, as Chimpanzees can. Probably most of the Ardis made, or at least used, tools of some sort, for we understand now that even chimpanzees have a rather astonishing ability to make many different types of tools, including stone anvils. Most of their tools were made from organic materials and hence are not well preserved, so we know little about the past of tool making of either chimps or protohominids. By about 2.5 million years ago, our ancestors had developed quite sophisticated methods for making stone knives and spear points by striking or stroking one rock on another in repeated and often sophisticated patterns. There are even a number of ancient “industrial complexes” in, for example, Kenya’s Olduvai Gorge, a rich hunting ground for information about our ancestors (■ Fig. 6.5). Spear points and knife blades are actually energy technologies—energy (force)-concentrating devices that allow the strength of a human arm to be multiplied many times when concentrated on a line or point (■ Fig. 6.6). This allowed humans to exploit many new animal resources and eventually



■ Fig. 6.4 Ardi, *Ardipithecus ramidus*, is a new found fossil that is neither man nor ape but probably represents our human ancestors some 4 million years ago (Source: Science Magazine, Jay Matternes)



■ Fig. 6.5 Olduvai Gorge (from Shunya website). Many very early human remains have been found here as well as early “industrial” sites, where stone tools were manufactured

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the colonization of cooler lands. Our ancestors were using stone tools for roughly two and a half million years, which is equivalent to about 100,000 human generations.

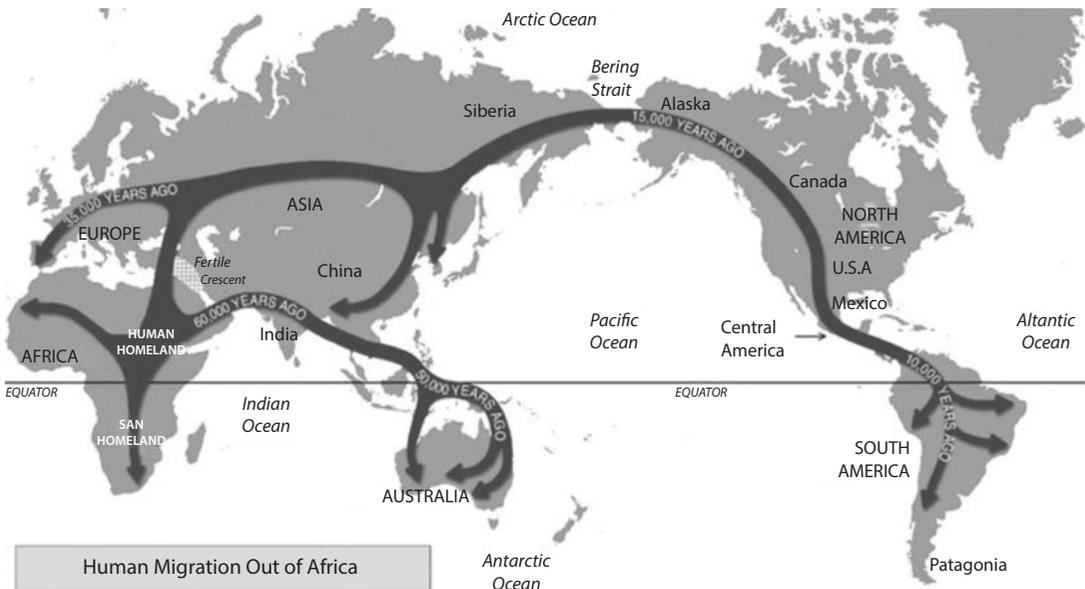
These stone spear points and knife blades were more or less the first in a long series of technological advances that helped increase the flow of energy to humans, thus greatly expanding the ability of humans to exploit the energy available in the various plant and animal resources in their environment. It also greatly increased the climates in which they could live because of their ability to kill large animals and use their skins for clothes (■ Fig. 6.7). Another important new energy technology was fire,



■ Fig. 6.6 Spear heads

which allowed people to stay warm in cooler climates but more importantly increased the variability and utility of plant foods, as cooking broke down the tough cell walls that plant (but not animal) cells have. Many humans left the relatively benign climate of Africa probably a little less than 2 million years ago. The remains of both humans and their tools of that era have been found in present-day Middle East, Georgia, and Indonesia [5]. By a million years ago, human remains were common all through Asia, but curiously humans did not appear to colonize Europe until roughly 500–800 thousand years ago. The first humanoid colonists of Europe do not appear to be our direct ancestors, for morphologically modern humans (popularly known as “Cro-Magnons” as distinct from the earlier “Neanderthal” stocks) appear to have left Africa in a separate migration only about 100,000 years ago. There are very strong debates in the anthropological literature as to whether all of these groups of people are our ancestors or just the “Cro-Magnon” variety of a large suite of early humans. Modern DNA analysis seems to favor the separate stock concept with some mixing that ended 35,000–40,000 years ago, leaving, it seems as of 2015, a few of their genes mixed with those of Cro-Magnon stock.

One of the many changes that took place as humans moved out of Africa was that humans tended to lose their melanin, a protective pigment



■ Fig. 6.7 Human migration patterns. All humans originated in Africa but then took various routes to establish new groups of people

that helped people living in Africa avoid various skin diseases such as skin cancer. When humans were exposed to much less sun for long winter periods, while in the meantime covering their skins with animal hides, they did not get the benefit of the sun producing vitamin D within human skin. This made humans much more susceptible to rickets, a debilitating vitamin deficiency disease that results in easily broken bones, obviously a great problem for hunter-gatherers. Since the dark pigment melanin protects the skin, but also decreases its ability to make vitamin D, darker skin is less advantageous in areas with less year-round intense sun. Hence skin color, something of often egregiously misplaced cultural importance, is simply a reasonable evolutionary response to humans leaving or not leaving the tropics.

6.2.2 The Dawn of Agriculture: Increasing the Displacement of Natural Flows of Energy

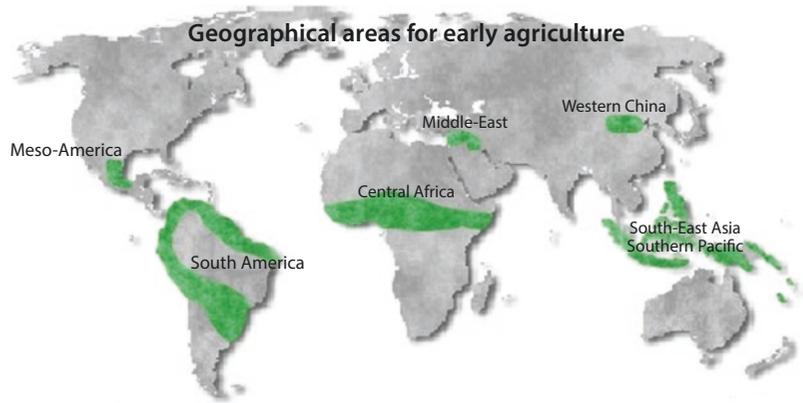
Sometime about 10,000 years ago, in the vicinity of the Tigris and Euphrates river valleys of present-day Iraq, a momentous thing happened [6, 7]. Humans previously had been completely constrained by their limited ability to exploit entirely natural food chains, due to the low abundance of edible plants there. They found that they could increase the flow of food energy to themselves and their families enormously by investing some seeds into more food for the future. How this happened is lost to antiquity, but as described by Jared Diamond in “Guns, Germs and Steel,” [8] it probably happened as people observed that their own kitchen middens (garbage areas) produced new crop plants from the seeds that had been deliberately or inadvertently discarded. This caused hunters and gatherers to experiment agriculturally, and as the climate warmed, more of the experiments were successful.

The implications for humans were staggering. The first, seemingly counterintuitive, is that human nutrition, on the average, declined. One of the best studies to document this was by Larry Angel, who studied the bones of people buried over the past 10 thousand or so years in Anatolia, roughly the border region of modern-day Turkey and Greece [9]. Angel dated the bones he found in ancient burial grounds and could learn many things about the people who once lived there from the bones themselves. For

example, their height and general physical condition, as well as functions of the quality of nutrition, could be determined by the length and strength of the bones. Bones could also show the number of children a woman had by the scars on the pubis, whether that person had malaria by the appearance of the bone marrow-producing regions of the bone, and so on. The data indicate that the people became shorter and smaller with the advent of agriculture, indicating a *decrease* in nutritional quality. In fact, the people of that region did not regain the stature of their hunter-gatherer ancestors until about the 1950s. Although agriculture may have given the first agronomists an advantage in terms of their own energy budgets, that surplus energy was translated relatively quickly into more people with only an adequate level of nutrition as human populations expanded. Or perhaps, as outlined below, more of the farmers’ net yield was diverted to artisans, priests, political leaders, and war, leaving less for the farmers themselves. One of the clear consequences of agriculture was that people could settle in one place, so that the previous normal pattern of human nomadism was no longer the norm. As humans occupied the same place for longer periods of time, it began to make sense to invest their own energy into relatively permanent dwellings, often made of stone and wood, in which to store the surplus. This left more durable artifacts for today’s archeologists.

A second major consequence of agriculture was an enormous increase in social stratification as economic specialization became more and more important. For example, if one individual was particularly skilled at making agricultural implements or understood the logic and mathematics (i.e., best planting dates) of successful farming, it made sense for the farmers of the village to trade some of their grain for his implements or knowledge, initiating, or at least formalizing, the existence of markets. From an energy perspective, relatively low-quality (because so many people had the necessary skills) agricultural labor was being traded for the high-quality labor of the specialist. The work of the specialist can be considered of higher quality in terms of its ability to generate greater agricultural yield per hour of labor. Considerable energy had to be invested in training that individual through schooling and apprenticeship. The apprentice had to be fed while he or she was relatively unproductive, anticipating greater returns in the future. Thus, we can say that the energy return on investment (EROI) of the artisan was higher

■ **Fig. 6.8** Origins of early agriculture (Source: Wroe et al. [32])

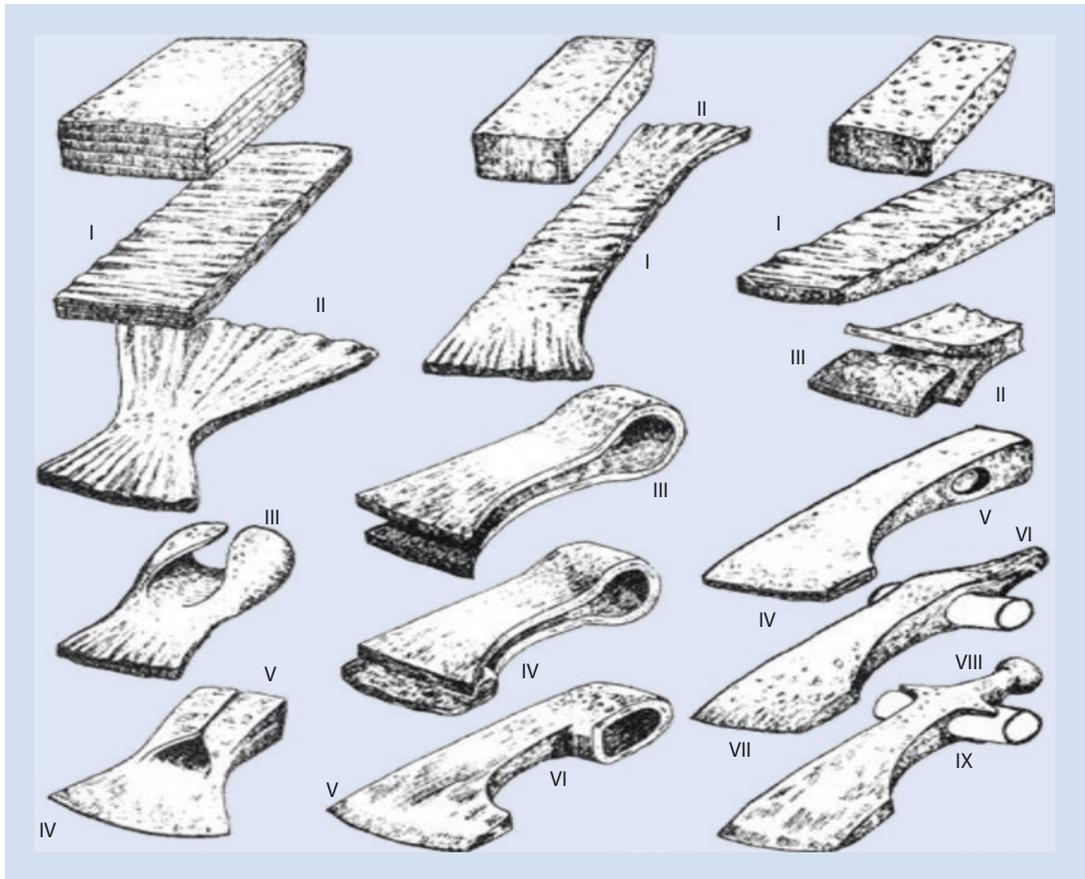


than that of the farmer, even if less direct, and often his pay and status as well. High agricultural yield led to surpluses that could be stored, leading to the concentration of political power by those who built and controlled the granaries.

Eventually, the concept of agriculture spread around Eurasia and Africa (■ Fig. 6.8). A new phenomenon appeared with the development of agriculture, the large net surpluses from the farmers and the permanent settlement of certain regions: cities and other manifestations of urbanization. The first place this occurred appears to be in the Tigris and Euphrates valleys, and one of the first cities was known as Ur, from which we derive the word urban. Today we call that ancient civilization Sumer and the people Sumerians. There were many great cities of that time (roughly 4700 years ago) and region, including Girsu, Lagash, Larsa, Mari, Terqa, Ur, and Uruk. These cities grew up in what had been at first a heavily forested region, as can be understood from the massive timbers in remaining ruins, although today there are essentially no trees and no cities in that region. In fact, the forests were gone by 2400 B.C., the harbors and irrigation systems silted in or required increasing amounts of work to maintain, the soil became depleted and salinized, barley yield dropped from about 2.5 tons per hectare to less than one, and by 2000 B.C., the Sumerian civilization was no longer extant. The world's first great urban civilization, in fact its first great civilization, used up and destroyed its resource base and just disappeared over a span of 1300 years.

The interaction of people with cultivars (plants that humans cultivate) also changed greatly the plants themselves. All plants are in constant danger of being consumed by herbi-

vores, from bacteria to insects to large grazing or browsing mammals or, formerly, herbivorous dinosaurs. The evolutionary response of plants to this grazing pressure was to derive various defenses, including physical protection (such as spines, especially abundant in desert plants) and more commonly chemical protection in the form of alkaloids, turpenes, tannins, and so on. These compounds, usually derived at an energy cost to the plant, place a heavy burden on herbivores or potential herbivores by discouraging consumption or by extracting a high energy cost on those specialized herbivores that can eat them, for the energy cost of detoxifying poisonous compounds is very high [13, 14]. Humans do not like these frequently bitter, poisonous compounds either and for thousands of years have been saving and planting the seeds from plants that taste better or have other characteristics that humans like. Partial exceptions are, e.g., mustards, coffee, tea, cannabis, and other plants whose bitter alkaloids are poisonous if that was all we ate but an interesting dietary supplement in small doses. Consequently, our cultivars are, in general, quite poorly defended against insects and have led to the invention and use of external pesticides, with complex consequences. Many of our cultivars would not survive in the wild now and have coevolved with humans into systems of mutual dependency. A visitor from outer space might conclude that the humans have been captured by the corn plants who use us for their slaves to make their lives as comfortable and productive as possible! Meanwhile all kinds of pests were themselves adapting to the concentration of humans and their growing and stored food, often with disastrous impacts on humanity [15]. For



■ Fig. 6.9 Early metallurgy (Source: National Geographic)

example, crowding is a major factor in the transmission of diseases with epidemic potential such as acute respiratory infections, meningitis, typhus, cholera, and scabies.

At roughly the same time that agriculture was spreading around the world, humans made another extremely important discovery: metallurgy. Prior to the advent of metallurgy, essentially all tools used by humans were derived directly from nature: stone, going back perhaps 50,000 years (■ Fig. 6.6) fashioned with increasing sophistication, wood, bones, antlers, and so on. According to Ponting [16], the first evidence of the smelting of copper is found in Anatolia in about 6000 B.C.E., although the near contemporaneous existence of residuals of smelting from all continents at only slightly later in time implies that probably many groups of people had roughly the same idea by about 5000 B.C.E. (■ Fig. 6.9).

Eventually very specialized furnaces were developed, as is indicated by archeological digs from 5 to even 10 thousand years ago in Africa, Europe, South America, and Asia. Early copper and bronze tools were replaced over time with iron as people learned to make hotter fires using charcoal. We have been using metal tools for roughly 8000 years, or about 400 generations. So, most of our history as a species is without metal tools. An important component of the transition is that the stone tools could be made with only a very small energy investment, essentially all as human muscle power, whereas the metal tools required a much larger investment in terms of cutting trees, making charcoal, and of course the energy of the wood itself. Early smelting was probably technically inefficient but had the advantage, at least initially, of the availability of very high grades of ore.

Smelted metals had many advantages compared to materials derived directly from nature: metals were harder and could take a sharper edge, increasing the cutting work that could be done by human muscles, and the sharper knife blades and spear points concentrated energy onto a smaller surface and enhanced the process of humans exploiting nature, for example, by accelerating the rate that people could cut trees (and of course each other) with bronze vs. stone axes. Perlin [10] has chronicled the tremendous increase in human cutting of forests in a wonderful book “A Forest Journey.” He makes the point in this book that massive deforestation is an old phenomenon and that India, China, and most of the Mediterranean were pretty thoroughly deforested by the time of Christ. In most cases, the most severe deforestation was to get fuel for metallurgy.

The scenario often went something like this (with Crete as a good example). A group of people would find and develop a rich ore deposit of, for example, copper. This metal would be very valuable in trade and the people would become prosperous. Cutting of trees for smelting also cleared land for agriculture, and the wealth and well-being of the people increased not only from the trade in metals but also from the substantial increase in the area under agriculture in the rich forest soils where the trees had been cut. Things would tend to go very well for roughly a century. But once rich forest soils were exposed to agriculture and rain, they would tend to erode, and the agricultural yields would decline. That civilization would decline as ore deposits and soils wore out, until they collapsed: meaning that the number of people being supported decreased dramatically. According to Perlin (and many others [10, 12, 16, 17]) this process has occurred again and again and again throughout history. India and Greece have had three separate major deforestations, with the forests growing back each time human populations became lower. The great works of literature, for example, Thucydides *The Peloponnesian Wars*, were written about events enormously impacted by large resource and environmental events (i.e., the exhaustion of sufficient forests for Athenians to smelt silver or make ships) although such resource issues were rarely considered by historians until recently [10].

■ **Table 6.2** Evolution of power outputs of machines available to humans

Machine	Horsepower
Man pushing a lever	0.05
Ox pulling a load	0.5
Water wheels	0.5–5
Versailles water works (1600)	75
Newcomen steam engine	5.5
Watt's steam engine	40
Marine steam engine (1850)	1000
Marine steam engine (1900)	8000
Steam turbine (1940s)	300,000
Coal or nuclear power plant (1970s)	1,500,000

*Cook, E. 1976. *Man, Energy, Society*, W. H. Freeman

Other important energy-related events were occurring in these prehistorical times. Perhaps most important was the domestication of useful animals, some of which predated agriculture, while some occurred simultaneously. The domestication of animals and the increased sophistication of animal husbandry were important in increasing energy resources for humans in at least two ways. First, since these animals ate plant material that humans did not, this greatly increased the amount of energy that humans could harvest from nature, especially in grasslands. Second, oxen and especially horses as draft animals greatly increased the power output of a human (■ Table 6.2). This power was useful for transport, for agricultural preparation (which came later), and for war. A horse, however, did not necessarily increase the speed of communications because over a day, a fit human can outrun a horse!

The story of how the use of animal technology was passed throughout Eurasia has been developed elegantly by Diamond [8]. Most of the important domestic animals came from Eurasia and could thrive more easily at the same latitude. Our most important animals, the sheep, cow, horse, pig, and chicken, were “corralled” in Eurasia and developed into today's domestic animals. The increasing familiarity with beasts of burden and

the development of roads and caravan technology in turn allowed for the development of long-distance trade [11]. Meanwhile, sailing and navigational skills were developed and passed on, and Cottrell writes well about the importance of using wind power in ships to greatly enhance the amount of work (carrying goods) that one person could do. Trade between cultures enriched the knowledge and the biotic resources of many human groups.

As agriculture, settlement, and commerce expanded, there became a greater need for maintaining records, and some time about 3000 B.C., formal writing was developed, apparently simultaneously in Egypt, Mesopotamia, and India (and perhaps other places). Writing allowed for technologies to be maintained from one generation to another and transferred among cultures. Cumulatively, these new technologies increased the energy flow to the human population, which slowly but relentlessly increased. These old records have allowed us to estimate some earlier patterns of human population changes (■ Fig. 6.10). They suggest that the human population record is hardly one of the continuous regular growths but rather one of the periodic growth and decline. Sometimes this is manifested as catastrophic decline and the virtual or absolute cessation of that population or, more commonly, the political structure that once held them together. Edward Deevy [18] has suggested that there were three main increases in human populations associated with first the corralling of animals, then the development of agriculture, and then the industrial revolution. We are still experiencing the latter as global human population growth continues strongly, although at a somewhat lower rate than a few decades ago.

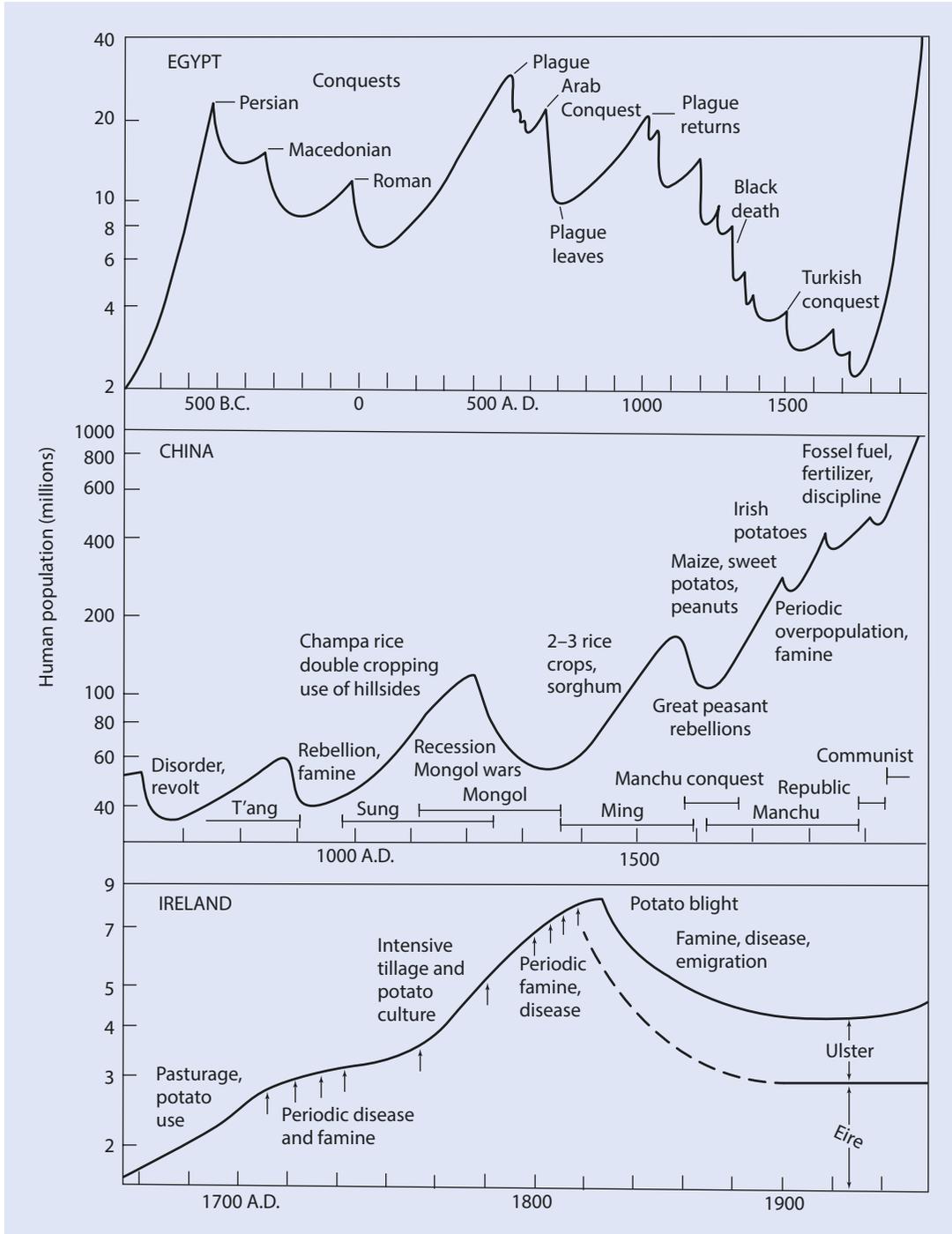
6.2.3 Human Cultural Evolution as Energy Evolution

As we keep pointing out, most of the major changes that occurred in the ability of humans to exploit more and more of the resources around them were either directly about or clearly associated with increased use of energy. Spear points and knives are energy-concentrating devices, fire allows greater availability of plant energy to humans, agriculture greatly increases the productivity of land for human food, and so on. These evolutions of the ability of humans to control more and more energy, for example, the evolution of wind and water

power, are probably best told in Fred Cottrell's wonderful book *Energy and Society*, published more than half a century ago [19]. Cottrell was a railroad man for most of his life and then a college professor near the end. Always impressed, like us, with the energy that undergirds all that humans do, Cottrell's focus was on the development of what he called "converters," which are specific technologies for exploiting new energy resources.

Cottrell's early chapters focus on herding and agriculture as a means of exploiting biotic energy and then on water and wind power. He shows the historical importance of a city being located relatively downstream on a river, so that the natural flow of the water would allow that city to exploit easily all upstream resources, such as timber, agricultural products, game, and ores. Of course, there was always a problem with this: barges had a one-way trip so it had to build a new barge at the top of the watershed for each new trip. Also, crews had to walk or otherwise get themselves back upstream. Nevertheless, a barge could carry a much larger load compared to a single individual, who can carry only about 25 kg at a maximum for any serious distance, or a pack animal such as a horse that can carry about 100 kg. Thus, the use of a barge carrying, say, 10 tons of goods and with a crew of four increased the efficacy of each person by a factor of 25–100. This process continued well into the nineteenth century on the Mississippi River until the age of steamboats. Raftsmen simply broke up the rafts and barges for lumber at the end of the journey (Taylor [33]).

The development of a sailing ship likewise increased the energy that subsidized a human porter enormously. According to Cottrell's calculations, an early sailing ship such as used by the Phoenicians (more or less the equivalent of modern-day Lebanon) increased the load that a human could carry by some factors of 10 and by late Roman times as much as a factor of 100. The Romans needed to import large quantities of grain from Egypt because, in part, they had depleted their own soil. But, according to Cottrell, the Romans were not the only ones who had an eye on this grain, and initially the Romans lost a lot of grain to pirates. This required the Romans to transport the grain in heavily guarded narrow warships, and a significant part of the grain was consumed by the soldiers on board. Thus, one further energy investment had to be made by the Romans—clearing the Mediterranean



■ **Fig. 6.10** Human population changes in Egypt, China, and Ireland, regions that had relatively well-developed bureaucracies and hence good data (Source: [34])

of pirates. Once this was done, proper wide-beamed sailing merchant vessels could be used, and Egypt finally became a large net energy source for the Romans. Cottrell gives many other examples of the

increasing use of energy by humans over time, including very interesting chapters on the growth of railroads in England, steam power, and industrialized agriculture.



■ Fig. 6.11 Ruins of ancient city of Ur

6.2.4 The Possibility, Development, and Destruction of Empire

Agriculture and its greatly increased yield brought with it the possibility of the concentration and storage of food, specialization, and, through greater populations, military-political power. These concepts are again ably reviewed in Diamond, Tainter, Ponting, and others. From our energy perspective, agriculture allowed for huge energy surpluses as a result of high return ratios (EROIs) from large energy investments. Thus, agriculture allowed a massive increase in the ability of people to generate culture and cultural artifacts. We have bare glimpses of these in the remaining artifacts of ancient cultures such as the main building at Ur (■ Fig. 6.11), temple complexes, and the great wall of China. What we see of these ancient civilizations today are beautifully shaped and carefully put together stones, and, as we dig more carefully, more sophisticated ornamentation, pottery, and metal household implements. By digging a little deeper, we can find other impressive artifacts of past civilizations: irrigation systems to bring water over large distances and large pyramids of stacked stones. These artifacts imply huge energy surpluses relative to hunter-gatherers, probably much of its vast public works programs to keep farmers occupied during non-planting or harvesting seasons.

In hunter-gatherer cultures, there was normally relatively little differentiation in what different people did, except for divisions by sex and age. Agricultural surpluses allowed a greater division of labor and with it a greater difference in wages, status, and social power. This division of labor led

in time to extreme differences in political power. This power was enhanced as professional military men became increasingly common, exemplified in the ancient Assyrian cultures. Most people had very little status or wealth and tilled the soil or took care of domestic matters. Only a very small proportion, large land owners, merchants, technocrats, and political leaders, lived lives of increasing affluence and luxury. Over time, the difference between rich and poor increased drastically.

As the concentration of wealth and power increased, as central granaries became more important and as military power and war became increasingly institutionalized, there were increasing opportunities for the development of empire. An *empire* is defined as large geographic areas under the rule of a central place and chief and maintained through what we might call civil servants or bureaucrats (although “lieutenants” are probably more accurate). Tainter and others [12] have developed the concept of a pattern that they believe has occurred again and again through history. One city or local culture becomes very successful through effective agriculture, mining, or trade and the resultant growth in population and economy. Often it becomes increasingly wealthy, allowing it the surplus energy to support soldiers and expropriate larger and larger areas of land around its periphery while exploiting the subjugated people’s energy surplus. Since war is expensive, it becomes increasingly important for the central city to impress others with their wealth, a sign of surplus energy available to be used, potentially, against others. Therefore, huge public investments are made in public structures, temples, administrative centers, markets, roads, food storage facilities, and so on. If they are successful, outsiders decide it makes sense to become aligned with this most powerful culture, even at the expense of tribute in the form of agricultural products, precious metals, or other materials. Thus, the culture expands, often many times over.

At some point, the culture, through its growth, begins to exhaust the initial resources that made it rich. Another problem is that as cultures increased in linear dimensions, the energy cost of moving resources (e.g., taxation grains) to the central city became greater and greater. If the provinces sensed difficulties in the central city, they might become a bit more restless, requiring increasing investments in military forces or status symbols in the central city. According to Tainter, eventually the citizens of

both the central city and the provinces become tired of paying the high taxes for what is mostly “maintenance metabolism,” that is, the food, roads, and armies needed to maintain the central city. Due to diminished revenues, the physical and social infrastructure is not maintained, leading to the collapse of the empire. Tainter, an archeologist, ecologist, and historian, says that this has occurred repeatedly (he gives more than 20 examples in his first chapter) through prehistory and history. Ponting develops a similar scenario in many detailed examples and with a bit more emphasis on resource depletion, as does Charles Redman.

6.3 Mediterranean Cultures

There are some quite detailed assessments of the rise and collapse of earlier civilizations from the perspective of the energy and other resources required for development and maintenance. Mediterranean cultures are a good place to start thinking about these questions for a number of reasons. First, many of the most important ideas for the contemporary world, including democracy as a form of government, mathematics as we know it, and concepts in art and culture, originated in this region. Second, the Mediterranean world offers a well-documented, well-studied suite of examples for us to explore and to understand the importance of energy and other resources in helping to shape the events that many of us recognize from traditional historical accounts. Third, this region remains today a vibrant and sometimes contentious region with many issues going way back in time. Many of the readers of this book will have been educated on the history of the region, which allows us an opportunity to examine familiar territory through our different lens of energy-based analysis.

6.3.1 Greece

Contemporary Western democracies usually trace their ancestry back to ancient Athens and neighboring cities in what is now Greece. Twenty-five hundred years ago, these were vibrant, dynamic, frequently wealthy cities with some truly remarkable accomplishments, including defeating significantly larger Persian forces and producing some of humanities’ still greatest architecture, sculpture,

literature, and ideas about government. Athens and its sister city-states were also venal, domineering, and frequently squabbling cultures, squandering remarkable opportunities for “the good life” on pointless wars. The most important city-states were Athens and Sparta. Today we remember Athens as an incredible caldron of art, ideas, and famous men and Sparta as a culture completely dominated by preparing its young men for war (hence, “Spartan conditions” is a term used today for harsh, uncomfortable, and arduous conditions). Athens too was a militaristic and imperialist culture and excelled in maritime combat. Athens and Sparta lived for many years in an uneasy truce which eventually ended in distrust and shifting alliances. From 431 to 404 B.C.E., these states and their allies initiated more than 25 years of intense combat that has been elegantly told by Thucydides [20]. Thucydides was once one of Athens’ generals, but the price of losing even one battle in Athens, which had happened to Thucydides, was dismissal from the army. This gave him the time to write a comprehensive history (*The Peloponnesian Wars*, a classic of history) of what ensued during this war, which was a stalemate for decades.

One interesting energy-related analysis of the Peloponnesian Wars, from which the following is borrowed, is found in Perlin’s book *A Forest Journey*. Perlin surveys the Peloponnesian Wars from the perspective of the forests and forest-derived energy required for the military activity and generation of the wealth required to finance the war. Anyone visiting Greece today is impressed by the nearly total absence of extensive and robust forests, so that it is quite curious to think of Greece and its southern part, the Peloponnesian peninsula, as heavily forested. Plato, as late as the sixth century B.C., remarked that not long before his own time, the hills surrounding Athens provided the huge building timbers he could still see in the buildings of Athens and that these hills even contained forest-dwelling wolves that were a threat to livestock. Perlin believes that these abundant forests probably saved Greece from Persian domination as they provided timber to construct the Athenian fleet that defeated the Persian monarch Xerxes at Salamis. This was followed by the construction of an even larger 200 ship navy so that ambitious Athens could become the mightiest marine force in Greece. The Athenians were running into timber shortages, however, because of intense demand for fuel and construction wood

in the city (including for immense wooden cranes to build the Parthenon) and because of an immense vein of galena ore that had been discovered in the nearby town of Laurion. The ore could be smelted using charcoal as an energy source to produce silver, which was then spent on the new fleet, public works such as the Parthenon, and personal luxuries. While this immense ore deposit made Athens extremely wealthy and powerful, it was at the expense of many of the forests of the region. This became a large problem because the Persians still controlled the timber supply regions to the east and north, including especially the Strymon valley. Ten thousand Athenians sent to colonize the mouth of that river, to insure a timber supply for Athens, were slaughtered by the locals. A second invasion was somewhat more successful resulting in the capture, at least for several years, of the port city of Amphipolis. When that city was lost later, (this was the battle Thucydides lost) Athens struggled for timber throughout the ensuing decades and centuries.

The Peloponnesian War that followed was principally between Athens and Sparta but also included other Greek city-states. It was ruinous to all the participants. Due to wood being used for all instruments and means of war, it depleted the remaining forests of southern Greece and then consequently soil eroded. The war spread even to Sicily, which the Athenians attacked unsuccessfully in a vain attempt to seize the forests to build a giant armada. In the meantime, Sparta had seized the forest reserves on the peninsula that belonged to Athens and other states. Sparta then turned to Macedonia, made a new alliance, and built a new fleet. Meanwhile, plague had entered Athens, greatly decreasing their number of soldiers. The Spartans made an alliance with their former Persian enemies and constructed a new fleet from Persian forests. They caught the Athenian fleet on shore with their crews foraging for dinner, and Athens was finally and permanently defeated, leaving the city destitute and without fuel or too much in the way of food. Thus, although we learn of the war in terms of battles, generals, and so on, much of the background was about energy (to smelt silver to pay the armies and for obtaining timber and metal for weapons and armor) and other resources (e.g., wood for ships), the depletion of which contributed to the eventual outcome. The golden age of Athens was over, as was the city's contribution to our present culture.



■ Fig. 6.12 Maximum extent of Roman Empire (Source: Tylecote [35])

6.3.2 Rome

Rome, founded in about 750 B.C.E (according to myth by the abandoned twins Romulus and Remus, who were supposedly nurtured by a female wolf), was initially a group of neighboring hill towns that increasingly became incorporated into a city. Rome kept expanding through trade and military conquest until it comprised much of the world known to Romans. The Romans learned early on that wealth could be gained much more easily through conquest and subsequent taxation than through other means and thus kept expanding its boundaries. Subjugation and taxation were of course not especially popular among those subjugated, but the *Pax Romana* (Roman peace) imposed by the strong Roman military force actually decreased local conflict for many. The city was ruled by a series of kings until about 400 B.C.E, when it was changed to a Republic ruled principally by a senate of patricians.

The Roman Empire lasted 500 years from roughly 44 B.C.E, when Julius Caesar appointed himself emperor, to 476 C.E., although the eastern portion at Constantinople lasted for 1000 years more. The Empire reached its maximum extent about 117 C.E., when it encompassed essentially all areas around the Mediterranean, including all or most of the present countries of Italy, France, Spain, England, Greece, and Egypt, as well as the North African coast, Syria, the Middle East, and the regions around the Black Sea (■ Fig. 6.12). Rome had at its height about 1,000,000 people (of which only about 10% were citizens), and the entire Empire contained as many as 70,000,000 people. This Empire was carved out, maintained, and governed essentially by human energy—by citizen

soldiers on foot who traveled on campaigns each year, utilizing wonderfully engineered stone roads that spread throughout the Empire (hence “all roads lead to Rome”), although ships were used over the Mediterranean itself. Imperial Rome was probably the most populous city in the world until the eighteenth century. The task of feeding roughly 1,000,000 people was a great undertaking, especially following the passage of a law that guaranteed free grain to Roman citizens. The Roman invasion and subjugation of Egypt were not simply about Caesar’s lust for Cleopatra but also about shoring up Roman food supplies after the soils of Italy had been depleted by Roman farmers. Fortunately for the Egyptians, and for the Romans, the annual flooding of the Nile replenished the Egyptian soils. This occurred every year until the closing of the Aswan Dam in the 1960s. The concentration of artisans in Rome, and the *Pax Romana* that existed within the Empire, brought unprecedented economic prosperity to many, many people, while Roman engineering and architecture (borrowed heavily from the Greeks and others) generated massive and often wonderful public works throughout the Empire. Swamps were drained, creating new agricultural land and ending malaria. While Rome is mostly thought about as a militaristic imperial force, and it certainly was, day-to-day life and influence were probably more a function of extensive and very effective trade, engineering, and agriculture.

Although Roman emperors were often venal, cruel, and corrupt, the best of them espoused very noble ideas about civilization and citizenship. There were a succession of good and bad emperors and other leaders, often representing different classes of people. For example, Julius Caesar although an aristocrat by birth, represented especially the interests of the common citizen class, although those who killed him also claimed to represent more the interests of the general Roman citizen. Either way, like the period when Athens was at its height, this was a remarkable period for civilization. Some of the leaders, including Marcus Aurelius, appear in history’s lens as quite enlightened. Edward Gibbon, the eighteenth-century historian who wrote *Decline and Fall of the Roman Empire*, described the period best or at least most eloquently [21]. Gibbon believed that Rome in the second century might have been the greatest time of all for humanity.

» In the second century of the Christian Era, the empire of Rome comprehended the fairest part of the earth, and the most civilized portion of mankind. The frontiers of that extensive monarchy were guarded by ancient renown and disciplined valor. The gentle but powerful influence of laws and manners had gradually cemented the union of the provinces. Their peaceful inhabitants enjoyed and abused the advantages of wealth and luxury. The image of a free constitution was preserved with decent reverence: The Roman senate appeared to possess the sovereign authority, and devolved on the emperors all the executive powers of government. During a happy period of more than fourscore years, the public administration was conducted by the virtue and abilities of Nerva, Trajan, Hadrian, and the two Antonines.

» If a man were called to fix the period in the history of the world, during which the condition of the human race was most happy and prosperous, he would, without hesitation, name that which elapsed from the death of Domitian to the accession of Commodus. The vast extent of the Roman empire was governed by absolute power, under the guidance of virtue and wisdom. The armies were restrained by the firm but gentle hand of four successive emperors, whose characters and authority commanded involuntary respect. The forms of the civil administration were carefully preserved by Nerva, Trajan, Hadrian, and the Antonines, who delighted in the image of liberty, and were pleased with considering themselves as the accountable ministers of the laws. Such princes deserved the honor of restoring the republic, had the Romans of their days been capable of enjoying a rational freedom.

Nevertheless, there were always economic troubles, generally related to natural resources, including grain and wood, and the failure to maintain the solar-based systems that generated them. The general consumption of the Romans always exceeded the revenues. Common and necessary raw materials, such as wood, became more and more difficult to obtain as forests increasingly far from Rome were cut and turned to agricultural land, whose productivity tended to decrease over time. To meet its expenses, the government

increasingly debased the gold and silver currency, causing extreme inflation, a fascinating story told in detail by Walker [22]. The Roman denarius was adulterated from being 98% silver in 63 C.E. to zero percent (i.e., all copper or other such metals) by 270 C.E. as the main silver mines at, for example, Rio Tinto, were depleted. As the denarius was adulterated, its purchasing power decreased proportionally.

Lead may have had an impact too, as the bones of ancient Romans have very high levels of lead, probably reflecting its use in pipes and in wine making. Nevertheless, it is quite remarkable what humans can do based on essentially solar energy plus their own (or slave) muscle power alone. Perhaps it is better to conclude that the energy that built and maintained Rome was hardly the muscle power of Romans and the agriculture of Italy but rather that of the millions of subjugated people in the provinces (and their land) who grew the necessary grain and cut the necessary wood to maintain the level of concentrated wealth in Rome. Perlin calculates that to run the baths at Caracalla for 1 year, 114 million tons of wood was required, a truly prodigious quantity that had to be transported from tens to hundreds of miles by human or horse power.

Over time, the Romans “became soft,” hiring or forcing others to do their military service and grow their food. Vast expenditures went into public buildings and sports (if that word can be used) complexes, the most important of which is the Coliseum, where thousands of exotic animals were brought in and put into combat with slaves. They even staged naval battles in the Coliseum by flooding the interior with water. Clearly Hollywood has had its precedents. But by 200 C.E., the Empire began to be nibbled away by soil erosion, plagues, crop failures, and the Germans and Asians who desired the wealth that was within. Ultimately the city itself was successfully stormed by the Goths, Visigoths, and Vandals, with the full fall generally agreed to be in 476 C.E. Of course, Rome, the city, is still there, with many artifacts from earlier times, although it is hardly the center of an empire.

The most interesting and, from our perspective, insightful analysis of the decline and fall of Rome (other than Gibbon’s monumental books) is that of Joseph Tainter [12], who examined the entire process from the perspectives of the energy cost and gain of each activity. The main way that the ancients

gained wealth was through conquest. Whatever wealth had accumulated in a region was the result of the slow accumulation of solar energy. This included mineral wealth, for the metals had to be mined by solar-powered human activity and then smelted using wood for fuel. Obviously, this was hard work, and many preferred the much easier (although possibly fatal) path of conquest. As the Roman Empire became larger and more powerful, it also became more complex to maintain and defend the provinces and eventually Rome itself. According to Tainter, increasing complexity is usually how problems are solved. But there is a high energy cost to complexity that makes its use eventually counterproductive. Tainter develops in a very compelling narrative how complexity, for example, through the maintenance of distant governmental administration and bureaucracies, garrisons, communications, and so on and the import of grain from ever more distant provinces, imposed an ever-increasing energy drain on the Empire and how this led eventually to its susceptibility to decay and invasions. Basically, the necessary investments into maintaining centralized administrative and military control become increasingly expensive and counterproductive, especially as the limits of an empire are pushed further and further from the centralized control, necessitating increasing energy costs for transport and to maintain the compliance of other people. Combining the language of Tainter and that of economists, we might consider this decreasing marginal return to complexity, which Tainter shows us occurred again and again and eventually led to the collapse of most empires.

We know less about the next 500 years in what had been the Roman Empire, partly because few historians have given us as comprehensive assessment of the subsequent events as we have for the years of the Roman Empire. These years are often called the “Dark Ages” or “the Middle Ages” and are left at that. It is important to remember that life went on, Romans or Italians or whatever we wish to call them continued to live in Italy (as French did in Gaul and so on), solar energy was used through agriculture and forestry to maintain people as they had been for millennia, and people lived, loved, fought, and died, while populations grew and sometimes declined from plague. Sometimes they left stone or occasionally literary artifacts but more usually leaving behind only more depleted soils and forests. What was left of knowledge and culture and civilization tended to

be kept alive in monasteries and in civilizations further to the East.

6.3.3 The Rise of Islam [23]

The prophet Mohammed, originally a merchant but eventually a political and religious leader, united the Arabian Peninsula in the seventh century AD. His followers expanded the empire under his influence so that within a hundred years after his death they controlled a large area stretching from Central Asia through the Middle East and along North Africa to Spain. The empire expanded again in about 1200 to become what was probably the largest land empire ever. Although the empire, including the political administration, was quite ethnically diverse and far from centralized, the people were united in their devotion (or subjugation) to Islam and in their use of the Arabic language, in which the Muslim holy book, the *Koran*, was written. Known in the West for their fierceness, once subjugation occurred, the Muslim leaders tended to be relatively tolerant and left others within their administrative units (including Christians and Jews) to their own devices as long as they paid their taxes. At that time, most of the economies of the Muslim empire were either agricultural or grazing animal based. Likewise, conquest was generally through foot soldiers or cavalry, so that we can assume that both the economy and expansion was nearly completely based on a solar and biomass base for energy.

The Muslim world was increasingly focused in Cairo following the Arabic conquest of Egypt in the seventh century AD. Originally, Muslims eschewed naval warfare and even sea-based trade, focusing on land-based expansion by trade or voluntary conversion or sometimes conquest. Day to day, the main events were much more likely to be about trade than conquest. For example, Muslims had regular overland trade to China along the very lengthy “silk road.” Eventually, they became seafarers, focusing initially on the Sea of Arabia and then the coasts of India and Africa. Their long presence in Africa is reflected in, for example, the name Swahili, which means coast in Arabic, which remains as the principle language in Kenya. Arab traders brought coffee, originating in Ethiopia, to the rest of the world, and this is reflected in the scientific name for the best coffee, *Coffea arabica*.

Increasingly the Byzantines, as the residuals of the Eastern Roman Empire were called by the early Middle Ages, attacked Egypt and other Arabic possessions using ships and caused great destruction. Again, the use of solar energy to make timbers for ships and wind energy to move large quantities of people and goods by ships gave enormous power to those who were able to exploit it. In response, the great Arab leader Caliph Abd al-Malik in the late seventh century initiated a great program of ship building. This program was based in Egypt, but Egypt had few trees and none of a size to allow the construction of strong ships. Large cedars, many 170 feet in length, were imported from Lebanon, although that was very expensive. Consequently, the ship-building had to be moved to what is now Tunisia, which at that time was heavily forested. A very strong fleet was constructed which captured Sicily (with its huge forests) and established a beachhead in Spain. In time, the Mediterranean became essentially an Arab Lake, as it had been previously a Roman one. The only ones to challenge this were the Venetians, who had access to the forests of the Po and Adige river basins. Thus, the exploitation of wind energy allowed the Muslims to conquer and hold on to huge new land holdings and to generate great wealth through trade. They were the masters of the Mediterranean world for nearly a thousand years (or more, considering that today most of North Africa is Muslim).

Among the many who accepted Islam as their religion were the Turkic peoples of Central Eurasia, who established a very strong empire beginning near present-day Constantinople and eventually spreading under the Ottoman group influence through much of the Islamic world. They also spread into the West and were finally stopped at Vienna in 1683. According to Rondo Cameron, although this was not a tightly integrated empire, it persisted and spread for a very long time because it did not subjugate those it conquered but only asked for taxes which were not excessive. This approach to Empire seems to be a relatively successful one compared to brutal repression. Arabic influence spread through European culture, leaving, for example, its imprint in the English language with words such as “arsenal” (construction house, originally), “algebra,” and “algorithm,” both reflecting the great advance made in mathematics within the Muslim world

during what we now call “the Dark Ages” in Europe. More recently, an important GIS tool, IDRISI, was named after the great twelfth-century Arabic-Sicilian geographer.

The Muslim world, Ottomans, often found themselves in direct competition with the Christian world. Several specific events stand out. The Christian invasions of Muslim-controlled Jerusalem, known as the great Crusades (1095–1099, 1147–1149, 1188–1192, 1202–1204, 1217–1221, 1228–1229, 1248–1250), reflected the growing wealth, power, and some would say arrogance of Europe and represented not only a chance for the faithful and adventurous to attempt to wrest the “Holy Land” from the “infidels” but also opportunities for plunder, rape, trade, and extension of commercial influence. The first Crusade caught the inhabitants of Jerusalem by surprise, and an enormous blood bath of mostly Muslims (but also Christians) by Christians followed as the city was wrested from “infidels.” None of the subsequent Crusades were as successful militarily. Some of the related events were especially pernicious. On the fourth Crusade, the European knights and their camp followers (tinkers, blacksmiths, prostitutes, and so on), tired of walking and riding horses, stopped in Venice to attempt to purchase passage by ship to the Holy Land. The Venetians, crafty businessmen and politicians, took their gold for passage, loaded the heavily armed men onto ships, and set off for what they said was the Holy Land. The Venetians had some old scores to settle with the inhabitants of Constantinople, then a Christian remnant of the old Holy Roman Empire. On the journey, a detour was taken, and the unsuspecting knights were deposited before the city of Constantinople which the Venetians claimed was Jerusalem. When they asked their Venetian ship captains why the city was adorned with crosses, they were told that this was a Muslim trick. So, they attacked the city, eventually subduing the inhabitants, and looted, raped, and pillaged for several months. The Venetians received not only payment for ship passage but insured that Constantinople would no longer be a threat to their commercial interests in the Aegean and Adriatic Seas, for example, for wood in the region, at least for a while. In the long term, the plan perhaps backfired as the weakened Christian City of Constantinople fell later to Islamic invaders from the East in 1453, and the importance of the

Venetian Empire and Christianity in that region faded. Those who wish might say that indeed God works in mysterious ways.

Thus, the enmity of much of Islam today toward the West for the exploitation of the region’s oil resources is hardly new and lives on today as a great distrust by many Muslim cultures for the motives of the West. As the West has become so dependent upon oil from the Muslim world, it is hardly surprising that many view the relation with great suspicion.

6.3.4 The Lasting Legacies of Ferdinand and Isabella

Another place that Muslims and Christians clashed was in Spain. Muslims came to Spain from the south across the Mediterranean and from the ninth to the thirteenth century controlled most of the Iberian Peninsula. While there they developed very sophisticated agricultural and horticultural systems and, essentially, tolerated diverse other cultures. Christian influence filtered in from the north beginning about the tenth century, culminating in the expulsion of both Moors and Jews by King Ferdinand and Queen Isabella, whose names are familiar to most Americans because they also supported Columbus, both in 1492. The result was disastrous for the Spanish economy because the Moors were much more sophisticated agriculturists than the Christians, at least for the southern part of Iberia, and because many skilled Jewish people were forced to leave. Many of these Moors and Jews probably went as Colonists into the Americas, feeling no longer welcome in Spain. The wealth of Spain, originally based on sophisticated agriculture and trade, was partially restored only by the brutal exploitation by Spain of the inhabitants of the New World as they extracted gold, silver, and other minerals with the aid of slaves, wood fuel, and wind power for their sailing ships. The food production system exported to the New World by the Spanish was one based on cattle raising, as this was the system favored by the Christian Spanish. The often sophisticated agricultural systems (e.g., extensive terracing) in place in Central and South America were displaced, even destroyed, by the very crude cattle-based *latifundia* system brought from Spain. In both southern Spain and Central America, the cattle were turned out to graze in the much more productive Native

American gardens that were often highly terraced, representing generations of careful investments of human energy. Since cattle return much less food per hectare per year than crops, the overall productivity of these systems for food energy was greatly lowered. Thus, in a sense, the actions of Ferdinand and Isabella destroyed two great agronomical systems and replaced them with unsophisticated grazing systems with perhaps one-tenth or one-twentieth the capacity to produce usable food energy for humans but with a greater capacity to produce money income for *haciendas*.

Entire forests, such as in southern Bolivia, were cut to supply timbers for mines and provide energy for smelting. Much of the Tarija region of southern Bolivia, for example, was deforested to support the silver mines in Potosi, and the timbers were transferred nearly a thousand kilometers horizontally and thousands of meters vertically on the backs of mules and slaves [24]. The deforestation resulted in some of the most extensive erosion found on the face of this Earth, which covers nearly 5 million hectares. Spain grew rich on the imported gold, but a curious phenomenon happened. The Spanish efforts in the New World doubled the quantity of gold in the old, but it decreased its value to less than half! What had happened was no different from what happens when a modern country prints too much money: inflation. Gold has little utilitarian value but is rather a medium of exchange. The real wealth of Europe came from the fields, forests, fisheries, and artisans, that is, the investments of solar and human (and occasionally wind and water) energy into the process of turning raw materials into real wealth: food, clothes, shelter, tools, utensils, and so on. Much of that gold ended up eventually in the great cathedrals of Europe.

6.3.5 Other Regions of the Earth

While Europe was living in the “Dark Ages,” independent and often very sophisticated cultures were developing in China, India, and the Americas, each of which had much greater and often more sophisticated human populations than did Europe. Again, these were solar-powered agrarian cultures for the most part and depended year after year on intensive human labor and of course the sun as a source of energy. Several grass-based nomadic civilizations, including that in

Mongolia led by Genghis Khan, also established very extensive empires that in his case reached nearly to Europe. In the Americas, very extensive city-states developed, flourished, and eventually collapsed. For example, the Olmecs and Maya of present-day Mexico and the Inca in Peru followed such fates long before the arrival of Europeans but more commonly after that. But, as we said at the beginning of the Mediterranean section, these cultures are not our focus here.

6.4 The Energetics of Preindustrial “Modern” Societies: Sweden and the Netherlands

There have been several especially comprehensive analyses of preindustrial solar-powered economies in the Netherlands and Sweden by De Zeeuw [25] and Ulf Sundberg [26]. These analyses indicate that it was possible to generate a very significant energy-based economic machine on plant material alone. The longer view, however, is that eventually these “renewable” systems tend to become depleted, and they require relatively low population densities (compared to the present) to be successful.

In the period 1640–1740, the Dutch had created a very profitable ceramics industry in the vicinity of the city of Delft, near Rotterdam. Even today, it is possible to purchase very fine China by the name of Delft. Making pottery is energy intensive, as the raw material (basically clay with metal decorations—in the case of Delft characteristically blue) must be heated to high temperatures. The fuel for this in the Netherlands was originally peat, partially decomposed Sphagnum moss, which was abundant in the low-lying areas of the Netherlands. To this day, large rectangular holes, called polders, remain where the peat was extracted four centuries ago.

A particularly thorough energy analysis of the economy of that time has been undertaken for Sweden by Sundberg. In 1550, Sweden was overwhelmingly rural and very poor. Most of Sweden is too cold for much agriculture, which was concentrated in the south of the country. Most of the citizens lived scattered throughout the vast forests where they cut trees for charcoal, which was used for a variety of purposes, most importantly for smelting the abundant silver, copper, and especially iron ore. Thus, Sweden had at that time two particular assets in terms of natural resources: vast

forest areas and rich iron ore. In order to make iron, high temperatures (above 1000 °C) must be used. This is not possible from timber alone but can be done with charcoal, which is basically wood heated in the absence of oxygen so that it is nearly pure carbon. Charcoal is made by taking trees and piling them into a large earth-covered structure containing from dozens to hundreds of trees. Then the pile is fired and allowed to smolder for days.

In 1600, approximately 15–20% of all Swedes lived in small family groups scattered throughout the forest. Their houses were quite small and simple, and most men worked making charcoal. The resulting charcoal was taken to regional metal processing centers, and the iron and copper ore turned into metallic implements. The principal products of Swedish iron factories in the period 1600–1800 were very good cannons. The Dutch were the first to take full advantage of these cannons and mounted them in warships that made them rulers of the European seas for about 100 years, until the English became better at the game. The Dutch invested in cannons because they allowed them, essentially, to steal whatever they wished from other nations. This was considered fair game, at least by the rules of the newly emerging mercantile capitalist economy (although not by the conquered and colonized).

Over time, more and more of the Swedish forest was cut and burned, and since trees grow slowly in the cold climate, eventually the vast Swedish forests were destroyed in almost their entirety. The Swedes faced an extreme energy crisis, and many froze in the winter because they had insufficient fuel and insufficient food. Starting in about 1850, vast numbers of Swedes moved to the United States, especially to the Northern Midwest, where they felt right at home among the snow and the pine forests.

Crosby [27] has commented upon the particular aggression and greed of Europeans compared to others about the world. By 1641, the Dutch trade and military empire extended as far away as Malaysia, where a Dutch fort and windmill can still be found in Malacca. If other nations wanted to trade in waters where the Dutch ruled, they had to either pay tribute to the Dutch or suffer the loss of some of their ships and ports. Consequently, the Dutch got very rich. Thus, the energy of photosynthesis of Swedish forests was translated into dominance of the seas by the Dutch using wind-driven ships to carry far more Swedish cannons than land armies could muster. These energies

also generated a very high level of comfort for Dutch burghers and the leisure to generate some of the world's greatest art. Then as now, affluence had a source somewhere in extensive use of energy. But that affluence for the Dutch did not last either, for it was the British defeat of the Dutch at the Straits of Malacca in 1647 that catapulted the British into prominence as a mercantile power. Then the bulk of the eighteenth century was spent in British conflict with the French. Finally, at the end of the Seven Years' War in 1763 and the great British naval victory at Trafalgar in 1805, British hegemony was established over the world's seas, and the long period of Pax Britannica began.

Throughout world history, however, most people remained very poor. Societies often adjusted to these mean circumstances by generating limited social expectations and mechanisms that allowed people to be comfortable with only these very limited economic circumstances and opportunities. One's rewards would be found (they said) after death, or in serving God modestly, or in leisure (in many societies, men hardly worked but spent much of the day in cafés or smoking cigarettes or hashish, while the women tended the fields or shops as well as the children). Fortunately, death rates were high, and the population did not expand greatly beyond the means of the land to support the people who were there. People may have been as happy as, or even happier than, today. We don't know, but the economic circumstances for most were barely above what it took to remain alive and to have and raise children. Some very few adventurous souls would join armies going to faraway places to exploit new resources and peoples (i.e., the rampant European colonialism of one, two, three, and four centuries ago and the crusades long before that). When the Americas opened, massive numbers of Europeans were ready to move to the new "empty" continents to try to better their fortunes, sometimes paying little respect to the fact that the continents were already heavily peopled with Native Americans. In other words, once material opportunities opened, there were plenty of Europeans ready to give it a try to improve their own personal financial situation. Even so for almost all individuals, it was extremely hard to make a living. This was normally accomplished through hard physical labor to chop down trees or to farm or work a mine or in a factory. Records of colonial Americans, for example, show that people spent almost all their

time and money just surviving, although they may have done that in reasonable comfort. The concept of spending money for recreation simply did not exist for most, as there was relatively little surplus wealth or surplus energy in these solar-based societies.

Throughout history in many societies, it was deemed just fine to attack another city or nation and simply steal whatever wealth they had accumulated. While this may sound offensive to us in fact, it was highly regarded by many in antiquity. Great writers of past times chronicled approvingly again and again the stories of a leader of one state who plunders another state, bringing glory and treasure to himself and his own state. Vikings, living in Northern lands of very low productivity, sought wealth in raiding parties that terrorized much of Europe for 1000 years. Wooden Viking ships with charcoal-derived iron nails and weapons and woolen sails were constructed and equipped entirely using solar energy. Europeans stole entire continents from Native Americans on solar power (again winds and charcoal plus genocide and settlement), with God as well as gunpowder and European germs on their side [8, 27]. Today this process continues through the economic principle of “globalization,” which is viewed by many principally as a means by which the more developed world legitimizes its extraction of resources and cheap labor from the less developed world. Others believe that trade benefits all.

We stop our history here for we treat the history of industrial society in more detail in ► Chaps. 8–10. Meanwhile we provide some additional references for those who want to think more deeply about energy and the “progress” of civilization [29–31].

6.5 A Somewhat Cynical View of Human History

It is very impressive to examine from today’s perspective the views of the ancients with relation to war. Plutarch’s *Lives* [28] is a book about famous ancient Greeks and Romans, written several thousand years ago by a distinguished Roman historian. One of your authors (Charles Hall) tackled this book with vigor, wanting to better himself since his classical education, once the signature of a well-educated person, was limited to two undistinguished high school years of Latin under the

fierce eye of Miss Meservey. He was also interested in what might be the characteristics of leaders whose reputation had lasted thousands of years. He was quite surprised by what he found: the largest group of the people singled out for praise by Plutarch made their mark by plundering other culture’s cities. Plutarch recounted with favor and apparently without irony how these people brought fame and riches to their own cities or regions. These great leaders of the past appeared to be simply robbers and plunderers of accumulated solar-based profits. Human history has been in large part about mustering armies to rape and plunder and about the efforts of others to counter these robbers. Modern Italy, Scotland, and many other European landscapes are full of ancient stone fortifications that must have taken an enormous portion of the time and energy reserves of the ancient citizens to construct. The evolution of more powerful cannons reduced the effectiveness of these fortifications until they were reconstructed to stronger specifications.

America too is constructed on conquest and plunder, from the obvious example of early English and Spaniards stealing the lands of Native Americans to a US military expedition taking what is now California and the rest of the US southwest from the Mexicans in the time period from 1820s to the 1850s by force. When the United States somehow “forgot” to claim the low passes through the Southern Rocky Mountains, they bought them from Mexico in the Gadsden Purchase of 1853. Classic empires seem to have receded during the twentieth century as a new form of imperialism called globalization has advanced, spawning nationalism and ethnic conflict among the world’s hungry and disposed.

Occasionally, we can get a quantitative glimpse of the enormous inputs required to fuel the expansion of empires and also the misery suffered by the common person during both the times of the expansion and the collapse of empires. Little was known about energy during most of history, but we can get some glimpses and make some rough calculations. Napoleon was famous for his “cannon park” of 366 cannons, each capable of hurling a 6- to 12-pound iron ball. He took this formidable machine with him to Russia, an incredible and ultimately disastrous campaign that resulted in the death of most of his army. The Russian army under Kuznetsov chose not to stand up to Napoleon’s well-oiled military

machine but instead retreated before him, stopping only briefly at Borodino to give some serious resistance before melting away, leaving Napoleon to be defeated later by “General Winter.” Military historian John Keegan has calculated the energy requirements to feed that cannon park. The 300 plus cannons required 5000 horses to pull them along plus soldiers and teamsters to handle the horses and man the cannons. The men required about 12 tons of food a day and the horses 50 tons of hay, so many additional horses were required to bring along the fuel for men and horses pulling the cannon. One of Keegan’s main points is that Nelson’s fleet at Trafalgar carried six times the fire power at one-fifth the logistic cost by exploiting wind energy. This indicates the importance of being able to exploit a relatively large energy resource, in this case the wind.

In three successive summers, one of your authors (Charles Hall) happened to read three historical books on European history and some important military invasions in search of empire: the first Peter Massey’s on Peter the Great and his attack south into the Crimea in 1696, the second Phillipe De Segur’s (a nobleman in Napoleon’s army) record of Napoleon’s Russian Campaign in 1804, and the third Antony Beevor’s Stalingrad, the story of the furthest point that Nazi Germany had penetrated into Russia in 1942–1943. Each of these books is a masterful summary of enormous military campaigns. But it came as a shock when the first map in the third book turned out to be essentially the same map, with nearly the same national borders, in each of the two previous books, centered on the regions of the Baltic, the Black Sea, Moscow, and the Caspian. Each of the books tells of initial tremendous success and enthusiasm for the “glory” of conquest by the invading armies, but in each of them, the invading armies were humbled eventually by the peasant armies, climate, and lack of enough fuel within the devastated invaded regions to support horses, tanks, and soldiers. The suffering of the soldiers, officers, and the commoners caught in the middle in each was immense, and in each, the tales of massacre and barbarous behavior on all sides were appalling. No additional territory was gained by any of these campaigns, despite the enormous expenditure of resources. Educated

German officers in 1942 knew well of Napoleon’s appalling retreat in Russia and watched day by day as General Winter imposed the same horrible fate on their own army. At the end, it all seemed so stupid. Except for the massacre and displacement of Native Americans (and other aborigines) by Europeans, it seems that since 1800 (and probably long before) most land has remained in the hands of those who were there first. But that certainly has not stopped many invasions as ambitious generals and leaders attempt to conquer other’s land.

Thus, much of history can be seen as times of very limited abilities to do much more than survive on one’s own resources and that the main path to personal or national wealth was through exploiting others through warfare. Much of history can be viewed as a series of attempts by one group to exploit or dominate others, either by directly stealing their wealth (represented as the long-term gradual accumulation of net solar energy in precious metals, jewels, and edifices) or by gaining access to their resources. We end our brief historical review at a point before the fossil fuel era gave a tremendous boost to our ability to both generate wealth at home and to inflict carnage and misery upon each other [23]. We do note an optimistic pattern: the long age of arrogant European colonization, empire by conquest, and continuous international conflict appears to be behind us following the end of Second World War. With the rise of industrialization and the enormous ability to increase wealth that fossil fuels and their technologies allowed, plus a growing appreciation of the cultures of others and the costs of war, the concept of empires and subjugation of others seems to have largely stopped. But war and its misery continue for all kinds of other reasons, and exploitation of others continues through economic means.

6.5.1 The Repeated Collapse of Empires

There are several dictums of history that are important here. The first is that “history is written by the winners,” and the second is that most human endeavors of the past are barely or not at

all recorded. The scholars who think the most about this are archeologists, and the archeologist (and anthropologist, historian, and energy analyst) who has the most to say about this issue is Joseph Tainter. Tainter's magnum opus is *The Collapse of Complex Societies* (although we have found his 1992 paper "Evolutionary Consequences of War" to be equally cogent). Both are incredibly good reading. Tainter lists a minimum of 36 once-great civilizations that exist today only as a series of rocks and other hard materials, often under desert sands. The list goes on and on. One has only to visit the great museums of anthropology in, for example, Mexico City or Jalapa, to get a perspective on what incredible civilizations there were in the past and how so many have crumbled.

Why do most military invasions fail, and how did it come to pass that so many once proud and powerful civilizations fell apart so completely and, often, so quickly? There are probably many reasons, but we believe that the energy-based mechanisms put forth by Tainter and summarized above offer the best clue.

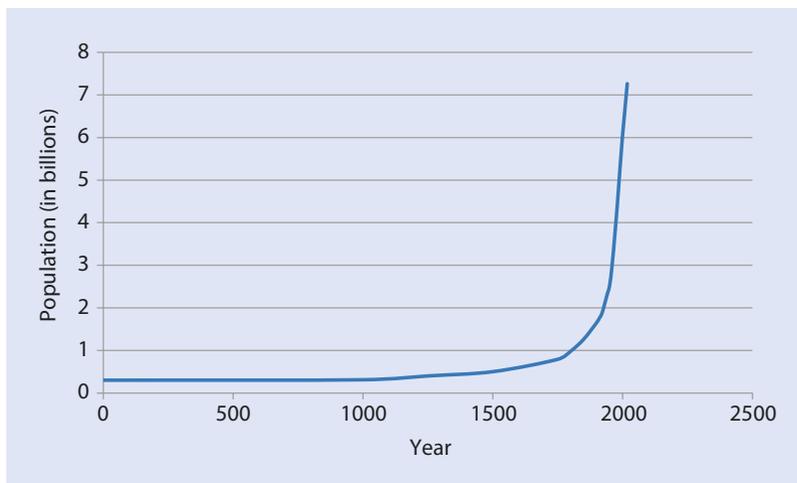
6.6 Summary

All of life, including human life in all of its manifestations, runs principally on contemporary sunlight that enters the top of our atmosphere at approximately 1.4 kW/m^2 ($5.04 \text{ MJ/m}^2/\text{h}$). Roughly half that amount reaches the Earth's surface. This sunlight does the enormous amount of work that is necessary for all life including all economic activity. The principal work that this sunlight does on the Earth's surface is to evaporate water from that surface (evaporation) or from plant tissues (transpiration) which in turn generates elevated and purified water that falls back on the Earth's surface as rain, especially at higher elevations. The rain in turn generates rivers, lakes, and estuaries and provides water that nurtures plants, animals, and civilizations. Differential heating of the Earth's surface generates winds that cycle the evaporated water around the world, and sunlight of course maintains habitable temperatures and is the basis for photosynthesis in both natural and human-dominated ecosystems. These basic resources have barely changed since the evolution of humans (except for

the impacts of the ice ages) so that preindustrial humans were essentially dependent upon a constant although limited resource base. Over time, humans increased their ability to exploit larger parts of that natural solar energy flow through technology, initially with spear points, knives, and axes which could concentrate human muscular energy, and then with agriculture, metals, dams, and now with fossil fuels.

The development of agriculture allowed the redirection of the photosynthetic energy captured on the land from the many diverse species in a natural ecosystem to the few species of plants (called cultivars) that humans can and wish to eat or to the grazing animals that humans controlled. Curiously, the massive increase in food production per unit of land brought on by agriculture did not, over the long run, increase average human nutrition but mostly just increased the numbers of people. Of course, it also allowed the development of cities, bureaucracies, hierarchies, the arts, and more potent warfare. For most of humanity's existence, most of the energy used was animate—people or draft animals—and derived from recent solar energy. Often humans themselves did most of the work, often as slaves but more generally as physical laborers which, in one way or another, most humans were. For thousands of years, from the period of the beginning of empires 5000 or more years ago until the widespread use of coal for steam power in about 1850, the principal source of energy for any large-scale agriculture or public works was masses of human power, principally but not always as slaves or near slaves (i.e., serfs). By one account, the Cheops pyramid represents essentially the entire energy surplus of the Nile civilization of about 3 million people at that time and required the labor of 100,000 people over 20 years. A second very important source of solar energy was from wood, which has been recounted in fascinating detail in books by Perlin, Ponting, and Smil. Massive areas of the Earth's surface—Peloponnese, India, parts of England, and many other locations—have been deforested three or more times as civilizations have cut down the trees for fuel or materials, prospered from the newly cleared agricultural land, and then collapsed as fuel and soil become depleted. Archeologist Joseph Tainter recounts the general

Fig. 6.13 Global human population (Source: United Nations)



tendency of humans to build up civilizations of increasing reach and infrastructure that eventually exceeded the energy available to that society.

Both the natural biological systems subject to natural selection and the preindustrial civilizations that preceded our own were highly dependent upon maintaining not just a bare energy surplus from organic sources but rather a substantial energy surplus, or large net energy, that allowed for the support of the entire system in question—whether of an evolving natural population or a civilization. Most of the earlier civilizations that left artifacts that we now visit and marvel at—pyramids, ancient cities, monuments, and so on—had to have had a huge energy surplus for this to happen, although we can hardly calculate what that was. An important question for today is to what degree does the past critical importance of surplus energy apply to contemporary civilization with its massive although possibly threatened energy surpluses.

6.6.1 Surplus Energy and Contemporary Industrial Society

Contemporary industrial civilizations are dependent on fossil fuels in addition to solar energy. Today fossil fuels are mined around the world, refined, and sent to centers of consumption thousands of miles away. These fuels have allowed for accelerated exploitation of solar energy and for the huge increase in food production, water transport, and

sanitation that has allowed the human population to grow enormously over the past 100–200 years. For many industrial countries, the original sources of fossil fuels were from their own domestic resources. The United States, United Kingdom, Mexico, and Canada are good examples. Since many of these initial industrial nations, however, have been in the energy extraction business for a long time, they tend to have both the most sophisticated technology of both production and use and the most depleted fuel resources, at least relative to many countries with more recently developed fuel resources. For example, as of 2017, the United States, originally endowed with one of the world's largest oil provinces, was producing only about half of the oil that it used, Canada had begun a serious decline in the production of conventional oil, and Mexico recently was startled to find that its giant Cantarell Field, once the world's second largest, had begun a steep decline in production at least a decade ahead of schedule. Although new sources of oil are being developed (see ► Chap. 13), these are from relatively low-yielding and expensive wells. Meanwhile, the global human population continues its upward course, although at a decreasing rate (► Fig. 6.13). The next chapter examines the role of oil in our society in much greater detail.

? Questions

1. Discuss several examples of how preagricultural humans exploited solar energy and the relation of the energy they obtained to their own personal energy investments.

2. How are spear points related to energy?
3. How does agriculture concentrate energy for humans? How does this process support a larger population?
4. The human use of fire assisted in opening a huge new food resources of agriculture for humans. Can you explain what the connection might be?
5. What was the relation of agricultural surplus to human specialization?
6. Many former dominant human cultures have collapsed. Can you give an example and the reasons thought likely for that happening?
7. Name at least two important legacies of the reign of Ferdinand and Isabella.
8. What does surplus energy mean to civilizations?

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- ¹ Dedicated to chemists Frederick Soddy and William Ostwald, anthropologist Leslie White, archeologist and historian Joseph Tainter, sociologist Fred Cottrell, historian John Perlin, systems ecologist Howard T. Odum, economist Nicolas Georgescu-Roegen, energy scientist Vaclav Smil and a number of others in these and other disciplines.

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