

Chapter IX:

Environmental Consequences of Human Inventiveness

JUST AS THE CENTRAL role played by technology in the overall human drama was slow to be recognized, so has an understanding of the part played by technology in the degradation of the environment that has resulted from human activities. Since readers are surely accustomed to a never-ending barrage of news reports, commentaries, and debates concerning the effects of human beings and their technology on the natural environment, it may come as a surprise that public awareness of and concern for such matters is a quite-recent development. This is not to say, of course, that until recently no one had realized that his or her physical surroundings had deteriorated on a sufficient scale to signal a pervasive development rather than simply a local phenomenon. Quite to the contrary. The idea that deforestation and soil erosion had reduced Plato's native Attica to a "skeleton" of its former self is expressed in his *Critias* (111a–112a).

But it was only in the eighteenth century that the basic outlines of the impact that human beings were having on the natural environment began to emerge. This came about as the result, first of all, of systematic studies carried out by the

naturalist Georges-Louis Leclerc, comte de Buffon (1707–88). Buffon devoted himself to examining and describing in excruciating—but captivating—detail every aspect of constituents of the natural order. The focus of his work, however, was not on individual entities but on developing a complete description of the kinds of things which they exemplify—in the case of living things, species. For such creatures, a complete characterization needs to include habitat, water and nutritional requirements, pattern of growth, mode of reproduction, etc. Evidently, such accounts have a temporal dimension, hence the name “natural history” or, in French, as in the title of Buffon’s great forty-four-volume work, *Histoire Naturelle*.

The passage of time is also central to Buffon’s approach to geology, mineralogy, and geography (as these disciplines are currently understood). For example, he did not believe, as essentially everyone once did, that the mountains that dot the surface of the Earth have always existed, more or less the same. Buffon applied his systematic and (as far as possible) exhaustive method to the study of the land: the mountains, hills, plains, streams, rivers, lakes, marshes, forests, grasslands, deserts, etc. His investigations revealed significant differences between uninhabited or recently settled lands and those occupied since ancient times. The latter boasted less forest land, more bare mountains, fewer lakes and swampy areas, and soils of reduced fertility. Buffon’s work marks the beginning of Western scientific studies of the impact of human activities on the natural environment.

For some time thereafter, investigations focused on particular examples of such effects, e.g., the consequences of deforestation in the French and Austrian Alps: erosion, floods, siltation, alterations in the courses of streams, reductions in the water level of lakes, and other phenomena. Nothing like an overall assessment of the effects of human activities on the natural world appeared until 1864 when George Perkins Marsh’s *Man and Nature* was published. In the late nineteenth and early twentieth centuries, a number of important studies on the topic were made and issues pertaining thereto debated among a few geographers and related specialists. But these had very little influence outside these groups.

During this period, however, there was a growing public recognition of the desirability of preserving certain especially spectacular areas in their natural state, as evidenced by the creation of the first national parks: Yellowstone in the United States (1872) and Banff in Canada (1885). In the 1890s four more national parks featuring towering mountain peaks, waterfalls, and giant trees were created in the Pacific Coast region of the United States: Sequoia, Yosemite, General Grant (later Kings Canyon), and Mount Rainier. The conservation and preservation movements also began to pick up steam at this time. The Sierra Club, for example, was founded in 1892 and soon became embroiled in a hotly debated issue that

focused attention at the national level on the conflict between preserving the natural environment and developing it to serve human ends. Around the turn of the twentieth century, the rapidly growing city of San Francisco needed to make provisions for a reliable water supply to meet existing needs and anticipated future ones. The obvious source was the Sierra Nevada watershed 150 miles to the east. The city leaders focused upon a narrow, steep-walled valley through which the Tuolumne River flowed. There they proposed to create a reservoir by building a dam. Since the valley, known as “Hetch Hetchy,” lay within the boundaries of the newly-established Yosemite National Park, the city had to seek permission from the federal government to build the dam.

A bitter political battle ensued, separating the preservationists (people committed to saving wilderness areas in their natural state) from the conservationists (those committed to good stewardship of natural resources for the benefit of present and future generations). The former group opposed the project, the latter supported it, as did those who attached little or no importance to its environmental effects. Eventually, the view that seems to have prevailed was that San Francisco’s need for water outweighed any losses that might result from building the dam and flooding the valley. In 1913 Congress voted to let the project proceed. Although technology played a crucial role in this drama, it could hardly have been expected to focus attention on the difference that the availability of technologies can make in the impact that human activities have on the natural environment. After all, the Romans built dams to create reservoirs as well as long water conduits (“aqueducts”) some 2,000 years ago. The difference in the technologies involved in the two cases would seem to be of little significance.

By the 1960s, it was widely believed that there was an **“environmental crisis,”** and the question of its cause(s) received a lot of attention. One viewpoint, shared by a number of those in Europe and North America who addressed this issue, was that people once had lived—and some still did—in harmony with and as an integral part of nature. These thinkers, accordingly, sought to identify the “roots” of this crisis. Given the severity of the environmental degradation that followed in the wake of industrialization and the formation of the powerful science-and-technology partnership, it can hardly be surprising that more traditional ways of living would have seemed absolutely benign in comparison. Before long, however, it became clear to all who studied the matter thoroughly that modern ways of doing things are by no means the only type of human activity to have had a significant impact upon the environment. Indeed, as investigations have proceeded, it has become increasingly obvious that states of affairs once thought to be examples of human beings living in harmony with pristine nature are actually cases of people living in environments they had altered radically. Thus, the

first major section of this chapter explores evidence concerning how even early humans may have radically altered their environments and caused extinctions.

A more recent and well documented case concerning the negative impact of powerful new technologies on the natural order is what happened to the American Bison in the nineteenth century. Some 50 million of these huge beasts are believed to have ranged over central North America before the Europeans arrived with their horses, guns, and steel. Early explorers and trappers left reports of herds that stretched to the horizon. In 1850, despite a shrunk habitat and increased predation, an estimated 20 million bison roamed the Great Plains region just east of the Rocky Mountains from Canada's Great Slave Lake to the Rio Grande. But a dramatic change was in the works. In an incredibly short period of time, the vast, thundering herds of buffalo, which once forced steam locomotives to wait while they crossed the tracks, were completely gone! In 1889 only about 500 buffalo could be located anywhere in the US. How could such a thing have happened? Although new technologies played a crucial role, following the pattern discussed above (especially in Chapters VII and VIII), their effects were conditioned by a number of factors: demographic, economic, political, military, and socio-psychological. Because it illustrates this point so well and because the near-extinction of such an iconic species raised public awareness of the gravity of the threat of anthropogenic (human-caused) extinctions, the example of the buffalo is ideally suited for a case study, which occupies section B of this chapter.

This case study is followed by a discussion of four examples of environmental problems that prompted constructive action. The final section of the chapter is devoted to the mixed legacy of the powerful science-and-technology partnership: both wonders and unprecedented environmental degradation.

A. North American Mega-fauna Extinctions in the Late Pleistocene

Prior to the mid-1960s, the prevailing assumption was that people with meager technological resources were too few in number and too limited in weaponry to have contributed significantly to the **extinction of mega-fauna** (large animals). Consequently, the hypothesis that human beings were responsible for the abrupt extinction of most (perhaps 70 percent) of the large (adult weight of 100 lbs. or more) mammalian species of North America some 11,000 years ago was met with skepticism and with suggestions for alternative solutions to this long-standing puzzle. (Eleven thousand years ago is the date long used in most discussions of this phenomenon, but recent radiocarbon methods fix this date at about 12,700 years ago.) Keep in mind, however, that extinctions are a normal part of

the on-going life process. As new species arise and compete with existing ones for ecological niches, extinctions are inevitable. But that was not what happened in North America in the **Late Pleistocene Epoch**, a time when the continental ice sheet was retreating northward. Rather, the places in the ecological web once occupied by the extinct species were, by and large, simply left vacant.

A number of possible explanations for the extinction of the mega-fauna in North America were put forward, including the impact of an extraterrestrial body (an asteroid or comet), a deadly pandemic, climatic changes, and the activities of human beings. Nothing much ever came of the first two of these hypotheses, but the fourth one sparked an extended debate. The basis for the suggestion that human beings were responsible for the extinctions was (i) their occurrence relatively soon after the arrival of people in North America and (ii) the existence of clear evidence that these newcomers hunted the animals. Those who thought that this explanation lacked credibility tended to favor the view that climatic changes were the primary cause of the extinctions. They emphasized that many rapid changes in climate took place during the Late Pleistocene, which would have put animal populations under stress, and suggested that human beings may have done little more than finish off the remnants of species already under threat of annihilation. They also pointed out that human beings had coexisted with Africa's great variety of large animals for many thousands of years without there having been a wave of extinctions like that which occurred in North America.

Admittedly, it might seem that the existence of so many species of large animals in Africa, despite the presence of human beings for many thousands of years, would cast doubt on the suggestion that people were responsible for the abrupt extinction of such a high percentage of the mega-fauna in North America. But the matter is a bit more complicated than it might seem. First of all, there was a limited but significant number of extinctions among large-animal species in Africa during the (pre-modern) period in which human beings or other members of the ***Homo* genus** were present, with some indications of a transitory spike at the time when a new and better way of making stone tools made its appearance: the flake technology (discussed in Chapter III). Secondly, there are good reasons to expect extinction rates among mega-fauna to be less elevated even when human beings are present if certain conditions are met: specifically, if the animals have co-existed with people (or other members of the *Homo* genus) long enough to have learned or been programmed by natural selection to fear them and/or to follow other survival strategies. In Africa there was enough time for such defensive strategies to develop before members of the *Homo* genus were sufficiently numerous and possessed of sufficiently effective hunting weapons and

techniques to make an impact—but not in North America in the Late Pleistocene.

Of course, the wave of extinctions that swept North America would not be expected to have taken place immediately after the arrival of human beings but only after their numbers had grown and their hunting capabilities honed. Indeed, there is a growing body of evidence that the earliest human inhabitants of the Americas, who are believed to have arrived about 15,500 years ago, were not big-game hunters but hunter-gatherers who subsisted on such things as roots, nuts, crustaceans, fish, birds, small reptiles, and small mammals. Even so, that picture clearly had changed by about 13,000 years ago, a time when a very distinctive type of stone spear point, called a “**Clovis point**,” appears to have been used in the pursuit of large animals. The first of these to be found (near Clovis, New Mexico) were embedded in a cache of bones belonging to a sub-species of extinct giant bison. Typically around four inches long and one third of an inch thick, these (often) superbly fashioned points feature a shallow groove extending from the squared-off butt-end toward the tip, a characteristic that would have facilitated mounting the points on wooden shafts. Some 10,000 of these points have been found in locations scattered across most of North America. So distinctive are they that they must have been produced in essentially the same way, a technique that seems to have appeared quite suddenly and rapidly spread across the continent. Examinations of collections of Siberian artifacts have revealed no hint of a tool-making tradition of this kind. Thus, it seems reasonable to conclude that the Clovis point is an American invention. As remarkable as the sudden appearance and rapid spread of this new technology is, its abrupt disappearance some 400 or 500 years later, leaving only enticing artifacts, is even more so. At this point, one can only speculate as to what happened. In any case, this new technology certainly enhanced the hunting capabilities of the early Americans; and the close match between the dates of the Clovis phenomenon and that of the mega-fauna extinctions lends support to the argument for a human role in these extinctions.

If wholesale extinctions had occurred only in North America, and if small animals and plants had been similarly affected, the matter would have been more of a local puzzle than something of global significance. But such was not the case. Small animal and plant species generally did not become extinct at an abnormally high rate at those places and times when the numbers of mega-fauna species were in steep decline. Furthermore, reductions in mega-fauna species also took place in South America (roughly 1,000 years later than in North America), in Australia (much earlier, about 15,000 years ago), in New Zealand (much more recently, 900 years ago), and Madagascar (even more recently, about 800 years ago). In every case, these large-scale extinctions occurred after the arrival of human beings, in some instances within a relatively short period of time, in

others only after some time had elapsed, depending upon certain factors. The very nature of the habitats of some species of animals, small as well as large, renders them especially vulnerable to rapid extinction when human beings arrive upon the scene. As discussed above, isolated islands are a prime example of such states of affairs. Under some conditions, on the other hand, mega-fauna species may escape extinction, or the threat of it, because all or some of their range is inhospitable to human beings. But the viability of a region as a place for human habitation can change as a result of technological development, as is illustrated by the invention of the sewing needle together with the tanning of animal hides, which enabled people to establish themselves in central and northern Eurasia. Similarly, as discussed below, the introduction of the domesticated horse into the Americas made possible the “buffalo economy,” which in turn supported the rich Native American cultures of the Great Plains. Furthermore, the vulnerability of a species to extinction and the timing of it (if it happens) can be affected by climatic changes, as critics of the Pleistocene Overkill hypothesis have pointed out.

As more and more factors are identified that might affect the significance of the presence of human beings at times when meta-fauna extinctions took place, the more difficult it becomes to make headway regarding the matter. Especially problematic is the lack of precise information regarding the timings of extinctions as well as the size of human populations at a given time and place in the distant past. Rather than focusing upon the timings and possible causes of individual extinctions (or groups of them), a promising new approach involves making a country-by-country, worldwide comparison of the correlations between late Quaternary mega-fauna extinctions and (i) climatic changes and (ii) the arrival of archaic or modern human beings in a particular geographic location. During the period from 132,000 years ago to 1,000 years ago, the study found, 30 percent or more of large mammalian species became extinct (globally or continentally) in those places (North America, South America, and Australia) where the animals had not encountered members of the *Homo* genus until the relatively recent arrival of modern human beings. On the other hand, in Africa (where the *Homo* genus originated) and in southern Asia (which was populated by *Homo erectus* beginning as early as 1.8 million years ago), extinction rates among large mammals were relatively low during this same period. This difference is to be expected, as explained above. The one major exception to this pattern is southern and western Europe, which suffered losses of mega-fauna species during the timespan of the study comparable to those of the Americas and Australia even though *Homo erectus* had arrived there at about the same time as in southern Asia. During this period, Europe and the rest of the planet underwent extreme climatic changes. The last interglacial (the warm interval between

the most recent period of glacial formation, “ice age,” and the one preceding it) began about 132,000 years ago and lasted some 40,000 years. The cold period that followed it ended about 10,000 years ago. Changes in temperatures and precipitation as well as the rapidity with which these changes took place were analyzed in this study, which concluded that (overall) the severity of meta-fauna extinctions between 132,000 and 1,000 years ago are closely linked to the presence of modern (or archaic) human beings, and that only in the case of Eurasia is there even a weak connection between the extinctions and climatic change. Although these findings are sure to be challenged and many questions remain (for example, what accounts for the departure of southern and western Europe from the dominant pattern?), and even though the effects of human activities are heavily conditioned, it is becoming increasingly clear that the inventive and self-transforming human being is a disruptive presence on the face of the planet. Few cases make this point so clearly as the near-extinction of the buffalo in North America in the late nineteenth century.

B. Case Study: The Vanished Thundering Herd

The technological factors that played a more-or-less direct role in the complex drama that culminated in the decimation of the great herds of bison include **a domesticated animal (the horse)**, the **breech-loading rifle**, the **steam locomotive**, and **refrigeration**. Horses were introduced into North America by the Spanish. At some point, a wild population of the animals became established on the Great Plains, likely originating with horses that had escaped from or been abandoned by the Spanish. The Native Americans managed to capture and train some of these, and they learned to breed horses as well. The result was a transformation of Native American life on the Great Plains. To the hunter, buffalos represent a tempting supply of meat; but preying upon them on foot, armed only with stone-tipped arrows and spears, is not a very promising undertaking. One ingenuous stratagem employed by the Native Americans to get within bow-and-arrow range of the animals was to cover themselves with wolf pelts and to approach on hands-and-knees. Another effective technique was to stampede herds of the buffalo over cliffs or into ravines, killing them, crippling them, or otherwise rendering them more vulnerable. Opportunities to exploit this strategy, however, were limited, as were other sources of food, with the result that life on the Great Plains tended to be a matter of “feast or famine.” Consequently, the region remained sparsely populated prior to the arrival of horses. However, with the advantage of well-trained mounts (and iron arrowheads and spear points, when they became available, and

eventually guns), the Native American hunters were able to avail themselves of the food supply that the great herds of bison constituted. Bison became their primary source of nourishment, and they fashioned tents, robes, and other articles from their tanned hides and made good use of other parts of the carcasses. They even used dried buffalo droppings for fuel. So successful was the new “buffalo economy” that large numbers of the Native inhabitants of adjoining regions abandoned their traditional ways of living, which included growing crops, and took up the pursuit of the buffalo out on the prairie.

As seen in Chapter V, the domestication of animals and the development of ways of making use of them are an important part of the human technological repertoire. Of course the “wild horses” captured by the Native Americans were not “wild” in the same sense that zebras (which have never been domesticated) are wild. They were descendants of Eurasian horses that were domesticated some 5,000 years ago and bred selectively thereafter. And they had not been in a feral state long enough for natural selection to have resulted in significant changes in their genetic makeup. What the Native Americans did was to build on this foundation, developing the skills and practices that made them such superb riders.

A second technological contribution to the destruction of the buffalo herds was the invention of the **breech-loading rifle** with its pre-packaged ammunition in the form of metal-cased cartridges. These made it possible to reload and fire while riding a horse, a feat hardly imaginable with earlier muzzle-loading firearms. A lighter, shorter rifle, called a “**carbine**,” was produced specifically for use on horseback (see Figure 9-1 below). Cavalry units were armed with it during the American Civil War, but it was not generally available until after that conflict. The advantage of such a weapon for the buffalo hunter hardly needs explaining.

Yet another technological development that played an important role in the demise of the bison herds was the extension of the **railroads** west of the Mississippi



Figure 9-1. A Carbine Rifle. Pictured here is the Sharps carbine, an extremely popular breech-loading rifle produced in the mid-1800s, meant for use on horseback.

River following the Civil War. Prior to that, the construction of bridges across the Mississippi and Missouri rivers had been held up by engineering challenges, the cost, opposition from the steamboat operators and their allies, and overall poor prospects for a profitable enterprise. Most importantly, rail lines crossing the river into the sparsely populated region to the west simply could not be assured of generating enough revenue to justify building them. And without access to markets, few people were going to move into the region to carve out farms and ranches or to launch commercial, extraction, or manufacturing operations. The drive to overcome these obstacles drew support stemming from a variety of motivations: the desire to make a profit, the hope of having a better life by making a fresh start, the attraction of being a part of the fulfillment of the “manifest destiny” (discussed in Chapter VIII), the “itch” for adventure, the allure of a romanticized vision of “the West,” and so on. Believing that settlers would move into wilderness areas if transportation and access to markets were provided, government leaders and businesspeople worked out an arrangement whereby railway companies would be granted not only rights of way for the tracks but also blocks of land along the routes which they could sell, once the railroads were built, to recover the costs of their construction—and to turn a profit.

However, the first railroad land grant, authorized by the US Congress in 1850, was not for an east/west route but for a north/south one running through central Illinois. The last Native American group having been removed to the west by 1833, large numbers of settlers were flocking into the state and were soon demanding that something be done about the primitive state of the roads. The question, of course, given the relatively undeveloped condition of Illinois at the time, was how could the needed improvements be financed? The solution that eventually emerged was the formation of a railroad company which contracted to build a railway the length of the state on terms like those described above. But even with swarms of potential customers pouring into the state and with no great rivers to be bridged, there was much skepticism concerning the likelihood of a successful undertaking. Consequently, securing the stock subscriptions needed to get the project underway was not easy. Things worked out, however, and the rail line was completed on schedule in 1856. It quickly demonstrated not only its own economic viability but also the viability of the method employed in launching it: the railroad land grant.

As noted, however, railway construction financed this way did not really get underway west of the Mississippi until after the Civil War. Even so, developments that took place during the 1850s are relevant to the significance of the extension of rail lines west of the river after the war. During that decade, a wave of railroad construction swept the region from western New York, Pennsylvania, and

Maryland to the Mississippi River. Almost overnight, rail lines stretched without interruption from New York City, Philadelphia, and Baltimore to the “Father of Waters,” as Abraham Lincoln (1809–65) termed it. The region underwent an explosive growth in population, agricultural production, commerce, and industrial output, as evidenced by the city of Chicago, which quickly became a center of rail traffic without peer. From a population of less than 5,000 in 1840, it grew from about 30,000 in 1850 to some 112,000 in 1860. When the Civil War ended, there were reservoirs of people and resources just east of the Mississippi, poised for a surge across it onto the plains.

From 1865 to 1890, railroad construction west of the Mississippi proceeded at a frenetic pace, epitomized by the rate at which track was being laid as the Central Pacific/Union Pacific transcontinental railway neared completion: three miles of track per day, with a record ten miles laid one day on a bet. Of course, surveying parties, bridge builders, and graders had done their work well ahead of the track layers. The transcontinental railway, which was financed by the land-grant method, was completed in 1869. In Canada the first rail connection to the Pacific coast was completed in 1885. The extension of the rail lines westward was accompanied by an influx of adventurers, big-game hunters, prospectors, miners, and merchants as well as farmers and ranchers. As a way of realizing a return on their investments, rail companies went to great lengths to recruit people, sending agents as far as Russia to persuade them to come and establish farms and businesses along the rail lines.

However, the presence of more people needing food and the availability of breech-loading rifles and horses put more pressure on the buffalo, especially since very wasteful practices were followed in utilizing the animals killed. To make matters worse, buffalo robes were very much in demand back in the East, so that it became profitable to hunt the huge beasts just to obtain the hides. As a result, countless buffalo were slaughtered for that reason alone, with little use made of the rest of the carcasses, which were simply left to rot. The cattle farmers were another source of economic—and hence political—pressure on the buffalo herds. They wanted the open rangeland, then in the public domain and available for pasturage free of charge, for their cattle. The extension of the railroads into the region had made it possible to transport cattle over the immense distance that separated the grazing lands of the Great Plains from the markets in the growing urban centers of the northeastern US. Shipping operations of this kind had been underway from the Midwestern farming areas east of the Mississippi prior to the Civil War, but the greater distance that had to be traversed to move livestock from the Great Plains to the eastern markets took its toll on the cattle in the crowded rail cars and on the profits of the cattle farmers.

The invention of the **refrigerated railcar** (1877) led to dramatic changes (see Figure 9-2 below). Previously, it had been possible to ship dressed beef over significant distances only during the winter. Furthermore, the prevailing practice at the time—as it had been in centuries past—was for beef to be purchased at the local butcher shop, where the animals were slaughtered and carved up. All this was to change with the advent of refrigeration, greatly spurred by interest and investments from Gustavus Franklin Swift (1839–1903), founder of the Swift & Co. meat packing company, which gradually transformed the meat packing and shipping industries. At first this system relied upon bins of ice in the insulated rail cars, but this method of keeping beef cold soon was replaced by mechanical systems. Refrigeration made it possible to ship dressed beef over great distances. Thus, beef produced on the Great Plains could be brought to the dinner tables of the growing population centers of the East without the expense of shipping whole animals the entire distance. As a result, it could be sold at a lower price. That, in turn, led to increased sales and higher profits for the cattle farmers. Consequently, the practice of shipping beef “on the hoof” to the East soon came to an end. Chicago, the western terminus of the first refrigerator car operation, quickly became the center of the meat-packing industry, a development that contributed to its becoming the preeminent rail center of the central United States.

As the profitability of raising cattle on the rangelands increased, so did the political pressure to remove the buffalo from the Great Plains. The railroads also

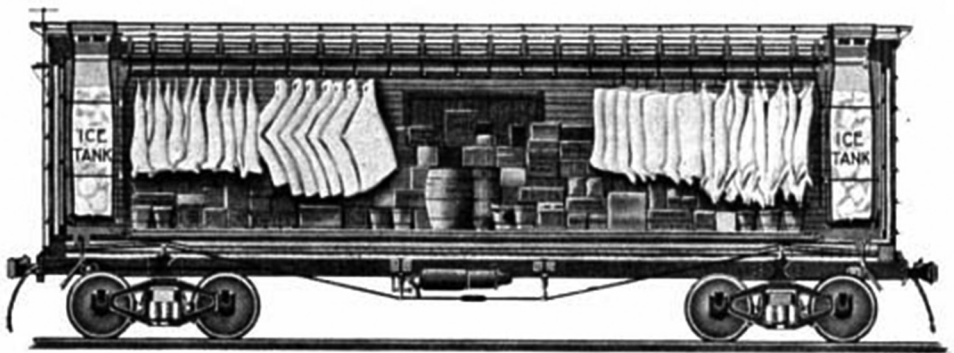


Figure 9-2. Early Refrigerated Railcar Design. This design uses ice to help cool the car and keep its contents from spoiling. Mechanical refrigeration technology (like that found in modern-day refrigerators) would not be widespread in railcars until the mid-twentieth century, though the technology itself had been developed decades earlier.

supported the assault on the bison herds because they held up the trains and damaged equipment. Even so, the buffalo faced an even greater threat deriving from the strategy employed by the US federal government and army in the struggle to subdue the “Plains Indians,” i.e., the Native peoples who had adopted the buffalo-hunting way of life described above. Inevitably, the westward movement of prospectors, miners, ranchers, homesteaders, etc. brought them into renewed and repeated conflict with the Native Americans. More often than not, hostilities resulted from infringements upon lands recognized in treaties as reserved for these Native peoples. Time and again, injuries, fears, and retaliations escalated into open warfare along the western frontier from the 1860s to the 1890s. Unfortunately for the buffalo, a core element of the basic strategy followed by the US Army in these “Indian Wars” was to destroy the economic basis of armed opposition to it. In the case of the conflicts with the Native Americans of the Great Plains, this meant the destruction of the bison herds. But the primary role of the army in this process was not actually slaughtering buffalo: it was supporting and defending those who did. Governmental involvement was less of a factor on the Canadian side of the border, in no small part because railroads and the ensuing population growth did not arrive west of the Great Lakes until the herds of plains bison had been decimated already. Even so, the hunters and hide merchants brought about a similar result there.

The destruction of the bison herds in the US was but part of a campaign of what has been called “total war,” i.e., military operations directed not only to defeating opposing combat forces but also to destroying utterly the enemy’s ability and will to offer resistance. Here, “enemy” is understood to include entire populations: men, women, and children. In such a context, avoiding casualties among non-combatants is not a priority. Rather, they are subjected to assaults and/or deprivations as part of an effort to weaken the opposition in every way possible. Of course, there had been a history of violence between European colonists and Native Americans as soon as the latter arrived in North America (though the colonists were responsible for much of it). And dwellings and resources of all kinds had been destroyed in attacks by both groups. But, in comparison, the campaigns to subdue the Native peoples of the western US during the latter part of the nineteenth century, taken together, were unprecedented, particularly in scope and systematic character. And this was not an accident. Both the architects and the executioners of the “total war” approach to subduing the Native Americans of the West were officers (or former officers) of the US Army, flush with victory in the Civil War. That victory was secured in no small part by the vigorous application of the principles of “total war” as set out in General Order No. 100, April 1863. The authors and chief proponents of

this policy were two Union generals, Ulysses S. Grant (1822–85) and William T. Sherman (1820–91).

By the early 1870s, the bison population was plummeting, awareness that extinction was on the horizon was growing, and movements to prevent it were getting underway. Meanwhile, Grant had been elected President; Sherman had succeeded him as Commanding General of the US Army; and General Philip H. Sheridan (1831–88), who had been Sherman's chief lieutenant when he was in command of the plains division, succeeded him in that position. In 1874, the US Congress passed a bill placing the buffalo under federal protection. Sherman and Sheridan urged Grant not to sign the bill on the grounds that the only way that the Plains Indians could be civilized, i.e., persuaded to settle down as peaceful farmers, was to eliminate the buffalo way of life as a possibility. They would then have to accept the terms of the government in Washington or starve. And if some of them did, the attitude seems to have been, so much the better. After Congress had adjourned, Grant allowed the bill to lapse without his signature, a maneuver known as a "pocket veto." When the matter came up again the following year, Sheridan carried the same message to a joint session of Congress and garnered enough support among the "hard liners" to forestall further action. The racist views prevalent at the time surely contributed to this result. Evidently, the complete loss even of such an iconic element of the natural environment as the American bison did not outweigh the benefits seen to accrue from an extreme military strategy. No effective action that benefited the buffalo was taken by the US federal government until the passage in 1894 of the Yellowstone Protection Act, which outlawed hunting, timber cutting, and extracting minerals in the park, established penalties for violations, and made provisions for enforcement—too late to have saved the buffalo.

Fortunately, ranchers and other individual citizens in Canada and the US had already taken steps that would insure the preservation of the bison species. They had established private herds of the animals by rounding up buffalo calves (strays, orphans, etc.) and raising them. As these herds grew, they were traded and divided. Because of their huge size and strength, managing and moving bison is a challenging undertaking. In 1906, the largest buffalo herd in North America, which had been assembled by two Montana ranchers, was offered to the US government, but Congress declined to appropriate funds for the purchase. A deal was worked out with the Canadian government, however, and the daunting task of moving the seven-hundred-strong herd north to Alberta began.

The example of the destruction of the bison herds clearly illustrates just how complex technology-and-the-environment subjects can be. All four of the technological innovations discussed above (domesticated horses, breech-loading

rifles, railroads, and refrigeration) were crucial to the confluence of factors that conspired to dethrone the buffalo. Equally important were the many demographic, economic, political, military, and sociological developments involved. Furthermore, the relations among these factors can be rather complicated. For example, absent the introduction of domesticated horses into North America quite some time in the past, there would have been (in the nineteenth century) no large population of Native Americans dependent upon the “buffalo economy” and hence no reason to support the slaughter of the bison herds as a means of forcing those fierce warriors to accept the terms demanded by Washington. Similarly, had it not been so fashionable to wear a buffalo robe or coat, there would have been much less economic motivation to venture onto the Great Plains to kill and skin buffalo and to tan the hides. And these are just two of many such examples.

C. Corrective Action Prompted by Over-Exploitation of Natural Resources

The Congressional approval of a bill to protect the buffalo in the 1870s and the founding of private herds during that period attest to a growing recognition of the harm to the natural order that human activities can cause and a willingness to do something about it. But such awareness and concern were not sufficient to prevent the complete removal of what was once another major feature of the North American scene: the enormous flocks of passenger pigeons that blackened the sky much as the buffalo had darkened the prairie. As late as 1800, the passenger pigeon was the most numerous species of North American bird. Highly sociable, they roosted in such incredible numbers that they broke large tree limbs. In nesting season, they gathered in huge colonies, building dozens of nests in a single large tree. Because they congregated so densely, whether feeding, flying, roosting, or nesting, they were an easy target for hunters. Given this behavior pattern and their enormous numbers, these pigeons were an important source of meat, not only for the Native Americans but also for the European colonists and their descendants, until the precipitous decline of the pigeon population in the latter part of the nineteenth century.

Among the wide variety of methods used to capture these birds were bombarding them with sticks and stones, snaring them in large nets, and knocking them from trees with long poles. (Juveniles not yet able to fly were especially vulnerable to this tactic.) As industrialization and urbanization proceeded during the nineteenth century, more powerful technologies were utilized and hunting and trapping pigeons became increasingly commercialized. Especially notable is

the introduction of the breech-loading shotgun. Using the double-barreled version, one could bring down a dozen or two birds with a single discharge of both barrels. Another important technological development was the construction of the railroad network that provided access to markets in major cities. Pigeons were shipped into New York and Chicago by the carload. As early as the 1850s, lawmakers in a number of states attempted to do something about the decline in the passenger pigeon population but got nowhere. A formidable barrier to effective state action was the migratory nature of the species. Efforts to breed the birds in captivity were unsuccessful as well, and the last known member of the species died in a zoo in 1914. Although public concern for the fate of the passenger pigeon failed to prevent its extinction, the attention it drew energized the movement to end the indiscriminate killing of birds. In 1918, following negotiations between Canada and the US, the Federal Migratory Bird Treaty Act went into effect in the US. It and a corresponding Canadian law were major milestones in the campaign to reduce the environmental degradation that all too often is associated with human technological and economic development.

The fate of the passenger pigeon and that of the American bison illustrate cogently what happens all too often when powerful new technologies become available for taking wild game or fish and for transporting the products obtained to distant, large-scale markets: the population of the targeted species collapses, wiping out its value as a natural resource and putting it on the road to possible extinction. A recent, even more disturbing example is afforded by the seismic changes that swept through marine fisheries around the world in the third quarter of the twentieth century. Early in that period an entirely new type of fishing vessel began to appear at those places where commercial fishing was concentrated because of the abundance of fish. These enormous “**factory trawlers**” (300 feet or more in length) were designed for fishing in waters far from their home ports. They towed huge trawl nets behind them which, when full, were hauled up their stern ramps. These leviathans could scoop up as many fish in an hour as older trawlers could hoist aboard in weeks. The catch was immediately processed on board and frozen. Since there was no immediate urgency about getting this frozen cargo to port, these factory ships could remain at a given fishing site for days or weeks—or until they were either fully loaded or ready to move on to another site. The Soviet Union, Germany, Poland, and Spain dispatched these giant trawlers to fisheries around the globe. And from the viewpoint of functionality and efficiency, they were a rousing success—so much so that they quickly put the very foundation of the marine fishing industry in jeopardy.

The problem was that the factory trawlers were doing such a thorough job of catching fish that not enough were being left to reproduce in sufficient numbers

to prevent the population from collapsing. Furthermore, since the best marine fishing sites were in international waters, lying outside the jurisdiction of individual countries, and since there was no international agency capable of overseeing and regulating the situation, there was nothing to restrain or even discourage the operators of the factory ships from taking every fish they were able to ensnare. Worse still, there would have been no point in any particular factory ship's limiting its catch at a given site, since any desirable fish left would have been scooped up by another of these huge vessels. This situation exemplifies what has come to be referred to as the "the tragedy of the commons," the destruction of a shared resource as the result of its over-exploitation in a context in which there is no framework for collective action and no reason to think that an individual's exercising restraint will have any effect on the long-term fate of the resource. Of course, it is theoretically possible in such situations for the interested parties to agree to an arrangement that protects the resource through agreed-upon limits to its utilization. In practice, however, such agreements are notoriously difficult to achieve and even more difficult to make work.

Not surprisingly, a resolution of the problem posed by the factory trawlers did not come about in this way. They were reined in—indeed, put out of business—by actions taken by individual nations taking advantage of the locations of the good fisheries of the world: shallow areas of the oceans relatively near landmasses. In response to the protests of established, land-based fishers regarding the factory trawlers' taking so much of the fish, countries with good fisheries near their shores (including the US and Canada), assumed jurisdiction over fishing operations in "exclusive economic zones" extending out two hundred miles from their coastlines. Once restricted by quotas, if not completely excluded from these fishing sites, the factory trawlers were no longer economically viable because it cost so much to operate them. By 1980, they were being taken out of service, bringing to an end another episode of the dark side of human inventiveness: the havoc wreaked on elements of the natural environment—all too often to the detriment of human beings themselves. An arresting aspect of this case is that the factory trawlers contained within themselves the seeds of their own destruction. Had no restrictions been placed on fishing in the exclusive economic zones, the factory ships would have quickly decimated the desirable species at the good fisheries and put themselves out of business. Unlike domesticated horses, breech-loading guns, locomotives, and refrigeration systems, factory trawlers had only one purpose, which they served efficiently only under a very narrow set of conditions.

Unfortunately, the arrival of the factory trawlers at the marine fisheries does not mark the beginning of the degradation of the fisheries from over-exploitation

nor does the disappearance of these giant fishing vessels mark the end of it. This point is illustrated powerfully by the fate of the Grand Banks and the Georges Bank, two of the richest fisheries in the world, which lie off the southeast coast of Canada and New England. Earlier technological innovations together with growing numbers of fishing operations were already having a negative impact on these sites before the factory trawlers arrived. During the nineteenth century, fishing vessels were wind-powered and fish were caught on baited hooks and hauled over the side rails by means of gaffs. Beginning around 1900, the marine fishing industry expanded worldwide and became more efficient with the development of more modern equipment. Especially significant was the introduction of diesel engines which made it possible for fishing boats to move about at will and thus to scoop up immense quantities of fish by towing huge trawl nets. These engines also made it possible to employ power-driven equipment to handle the enormous nets that came into use and to hoist the masses of ensnared fish aboard. The use of airplane spotters, radar, and sonar to locate schools of fish was also important, as were weather forecasting and communication by radio-telephone.

Of course, these innovations and the expansion of commercial fishing resulted in a dramatic growth in the total amount of fish brought in, as illustrated by the thousand-fold increase in the tonnage recorded by New England fishers between the middle of the nineteenth century and the middle of the twentieth. But there were clear signs of trouble ahead. One early signal was the downward trend evident in the size of the fish being caught. Another was that, despite increasing fishing capacity and activity, the moving average of the annual catch of the New England fishers began dropping about 1950, significantly before the factory trawlers started to make an impact in the mid-1960s. The underlying problem of more and more people going after a finite natural resource with ever more powerful technologies showed itself clearly when the huge vessels departed: the total catch brought ashore by the New England fishers continued to decline. By the early 1990s, it plunged so steeply that the US government declared a complete moratorium on fishing in part of the Georges Bank in order to give the population of desirable species a chance to rebound. For the same reasons, Canada shut down the Grand Banks fishery even though 40,000 jobs were at stake.

The contrast between the attitudes expressed and the actions taken when extinction threatened the American bison and the passenger pigeon and those evoked by the looming demise of the North Atlantic fisheries testifies to the depth of the changes in the attitudes and priorities that took place during the twentieth century. These changes were fueled in large part by a series of natural disasters, the impact of which was enhanced by best-selling books, iconic photography, and movies. An early, especially notable example is the “dust bowl” of the 1930s,

a drought- and wind-stricken area that included the panhandles of Texas and Oklahoma and adjacent parts of Kansas, Colorado, and New Mexico. The most horrendous feature of the dust bowl was the dust storms, monstrous clouds of wind-driven dust in which it was impossible to see or even breathe. Stripped of its native sod cover and loosened by cultivation, the soil was picked up by the fierce winds, resulting not only in dense dust clouds but also in severe soil erosion. In desperation, a third of a million farm workers pulled up stakes and made their way as best they could to California. This saga was portrayed in John Steinbeck's novel, *The Grapes of Wrath* (1939), and John Ford's Academy Award-winning (1940) movie based on it.

The dust bowl disaster prompted the recognition that land, like other natural resources, could not be exploited at will without painful consequences and that land use must be carefully managed if people are to reap the benefits which it is capable of providing. In 1933 the Soil Erosion Service (later the Soil Conservation Service) was established to advise and assist farmers in preventing soil erosion caused by wind and water. The agency set to work promoting such conservation strategies as check dams, crop rotation, contour plowing, and strip cropping. The dust bowl and soil erosion differ significantly from earlier examples of the negative effects of human technological activities and the responses elicited by them. In this case, (i) human life and health were affected directly and (ii) general features of the natural world (soil and air) were involved, not just a single species or type of resource.

The movement of environmental concerns toward center stage was interrupted by the Second World War but resumed with a vengeance when it ended. Indeed, because the war effort took precedence over nearly everything else, it can hardly be surprising that the state of the environment was considerably worse in 1945 than it had been in 1939. The first headline-grabbing postwar environmental disaster exemplified both characteristics noted above. It also exhibited another basic feature that was to be a central focus of environmental awareness and action: the indiscriminate dumping of wastes of all sorts into the air, streams, lakes, and oceans, and onto the land. It had been known for centuries that burning coal, smelting ores, and related activities release dirty and foul-smelling smoke and fumes into the air. And there were reasons to believe that breathing air thus polluted was not only unpleasant but also unhealthy. The severity of the threat posed by air pollution showed itself in starkest terms in late October 1948 in Donora, Pennsylvania (see Figure 9-3 below).

This small industrial city lies in a deep, narrow valley on a horseshoe bend of the Monongahela River. Humidity tends to be high and fogs are frequent, as is typical of river valleys in rugged terrain. Industrialization added coal smoke,



Figure 9-3. Pollution in Donora, Pennsylvania. This photograph shows the high level of pollution emitted by industry in Donora in 1910. This grew worse until a combination of pollution and meteorological factors resulted in the 1948 disaster.

automobile exhaust, and smokestack emissions. In the mid-twentieth century, the US Steel Corporation was operating a zinc works and a steel and wire mill at Donora. (Zinc is used to coat sheet metal, pipe, and other iron and steel products to prevent them from rusting.) Among the pollutants released by these plants were hydrogen fluoride and sulfur dioxide. When these gases are mixed with fog, the smog that results is thick, yellowish, and corrosive. In late October 1948,

meteorological conditions in Donora prevented the pollutants from being carried aloft and dispersed by air currents. The city had fallen victim to a thermal inversion, a reversal of the usual pattern of temperatures dropping with increasing altitude. In a temperature inversion, a layer of cold air lies under warm(er) air. The usual thermal process is for air to be warmed through contact with rocks, plants, bodies of water, etc. at the Earth's surface. Thus warmed, it is lighter and rises, while the un-warmed, cooler air above settles lower. The circulation thus set up serves to disperse everything from the smoke of campfires to industrial emissions. When cold air is somehow trapped under warmer air, this circulation does not take place and pollutants released at the lower level are not carried away but remain in the vicinity and can build up to toxic levels.

And that is what happened in Donora. By the second day of “the smog,” people were coughing and exhibiting other symptoms of respiratory distress. The situation worsened with each passing day. The healthcare resources of the city came under severe stress. Oxygen to bring relief to the worst cases was brought in from surrounding communities by emergency workers. The smog became so thick that visibility was essentially zero and driving automobiles was all but abandoned. By the time rain brought relief on the fifth day, twenty people had died and from one third to half of the population had been sickened.

The Donora incident is just one example of the disasters that focused attention in the postwar period upon the necessity of bringing air pollution under control. In 1952 an especially thick smog settled on London. Within a period of only five days, 4,000 people had died. In Tokyo during the postwar period the air became so polluted that despite wearing protective masks police were able to remain outside directing traffic only for short durations. The scope and complexity of the problem quickly elbowed its way into the public consciousness and has remained there as new aspects of it have come to light and more countries have become industrialized. In 1970 the US Congress passed the Clean Air Act and the Environmental Protection Agency was established.

D. The Promise and Perils of the Science-and-Technology Partnership: Genie Out of the Bottle

In the decades following the Second World War, public awareness and concern also became focused on the abysmal state of the rivers, lakes, and streams. At mid-century, human beings continued, as they had for thousands of years, to treat rivers as waste-disposal facilities. But by then populations were much larger and more urbanized. Industrialization, which involved an entire complex

of new technologies, had resulted in increased quantities and types of wastes being dumped into rivers and other bodies of water. And the arrival of the powerful partnership, science-and-technology (discussed in Chapters I, II, and VII), had ushered in a whole new range of toxic waste products that were released into the environment. Most notable in this regard are the chemical industry and, to a lesser degree, the electrical and electronics industries, the development of which—unlike earlier technologies—was heavily dependent upon basic science.

The petroleum industry, one of the main suppliers of raw materials to the chemical industry, was itself launched on the basis of analyses of crude oil carried out by chemists. One of these was performed at the request of Samuel M. Kier (1813–74), an entrepreneur who was trying to find a use for the dark, odoriferous fluid that was a by-product of his salt-production operations. Wells drilled to obtain brine often yielded crude oil along with it. Kier had used it, instead of expensive whale oil, to illuminate his salt works at night, but burning it produced much foul-smelling, black smoke, rendering it unsuitable for most purposes. In the late 1840s, Kier even tried marketing it as a medicinal product. The chemist, James C. Booth (1810–88), advised Kier that petroleum had potential as an illuminate but that it would have to be distilled or refined. Beginning in 1850, Kier began experimenting with the distillation of crude oil. This resulted in a fuel oil that burned without objectionable smoke or stench, which he called “carbon oil.” Right away, Kier entered into a partnership with John T. Kirkpatrick and they built a petroleum refinery in Pittsburgh, the first in the United States, but had to abandon the operation under pressure from fearful residents. In 1854, the Canadian doctor and geologist Abraham Gesner (1797–1864) was granted a patent for a distillation process that yielded kerosene (kerosine), a fuel oil suitable for lighting, from crude oil. He also found a way to obtain it from coal, hence the name “coal oil.” In 1858, another Canadian, James Miller Williams (1818–90), sank an oil well and set up a refining operation near what is now Oil Springs, Ontario. However, his achievement was soon dwarfed by developments in the United States.

Once again, interest in petroleum was stimulated by an assessment by a chemist, Benjamin Silliman Jr. (1816–85) of Yale University, who carried out an analysis of “rock oil” (the literal meaning of *petr-oleum*) in the 1850s at the request of a group of entrepreneurs. His report affirmed emphatically that excellent illuminants and lubricants could be obtained from it. By the late 1850s, it was generally recognized that petroleum held great promise, but sources of it remained extremely limited—usually to seepage in certain locales. At the time, there was no way anyone could have known that there were pools of petroleum deep in the ground that could be tapped.

In 1858 James Townsend (1825–1901), a New Haven banker, gained control of the company which had sought Silliman’s appraisal of petroleum and which had leased 100 acres of farm land and acquired the right to extract oil on an additional 12,000 acres near Titusville, Pennsylvania, where oil seepage was common. Townsend put Edwin L. Drake (1819–80) in charge of finding a way to obtain large quantities of oil from the properties and arranged financing for the undertaking. Although he had no geological expertise, Drake was convinced from the start that oil was trapped in rock cavities deep underground. He concluded that it should be possible to extract it by boring into the rock, just as was done to obtain brine for making salt. After various setbacks, Drake began drilling in the summer of 1859. At first he was able to achieve well-depths of only 16 feet or so. Mud and water rushed into the well shaft faster than it could be removed. In solving this problem, Drake may reasonably be said to have laid the foundation of the petroleum industry. Using steam power, he drove an iron pipe down the well and drilled down inside the pipe, while driving it deeper and deeper. (Later these pipes came to be referred to as “well casings.”) Solid rock was encountered at a depth of 39 feet, oil at a little over 30 feet more. The oil rose up the well shaft to within a short distance of the surface. Drake fitted the well with a pump and began extracting oil from it at the rate of about 500 barrels a month. Remarkably, Drake did not seek a patent for his invention but actually showed others how to replicate his success. Right away, oil derricks began popping up like daffodils in the spring. As a result, the price of crude oil plummeted and the whale-oil industry collapsed, granting a (brief) reprieve to these immense marine mammals.

The petroleum industry developed during a time that has come to be recognized as a watershed in human economic affairs, a time when a new dimension was added to the picture: energy. As can be seen retrospectively, some of the elements of this development had been around for a long time. What was new, in addition to more of these elements, was the discovery and exploitation of relations between them. People have gathered fuel to feed fires to provide heat and light about as long as there have been people. But the invention of the steam engine made it possible to derive motive power from heat. Prior to that, the suggestion that such might be possible or that heat could be generated by motion would have lacked credibility. But by the middle of the nineteenth century, a transformation had taken place: railroad construction was booming, and (as discussed in Chapter VII) Rumford had demonstrated that motion could make water boil (1789). Then (in the 1840s) James P. Joule had nailed down (empirically) the equivalence relation between electrical energy (wattage) and heat (Joule’s law) as well as that between mechanical energy and heat. At mid-century,

scientists were in the process of elevating conservation of energy to its status as a basic law of nature. Rudolph Clausius (1822–88) is credited with being the first to formulate it in general terms (in the 1860s).

Of course, the existence of this theoretical basis did not translate immediately into practical applications or into changes in the way (most) people thought about matters to which it was relevant. Initially petroleum was sought not as an energy source, with all that implies, but simply as a fuel for a flame to provide illumination. That it might have other uses was certainly contemplated, but only in concrete terms at first. Its ability to supply motive power was realized only with the invention of the internal combustion engine and the automobile. The invention of the incandescent electric bulb (1879) and a stream of other electrical devices created a growing demand for electricity. In response, quite a variety of generating systems were developed. These utilized steam engines, water wheels, windmills, diesel engines, turbines of various sorts, and (eventually) nuclear reactors. The use of diesel engines for this purpose provided the petroleum industry with a new customer.

Electricity-generating facilities became progressively more sophisticated and, taken together, more reflective of the implications of the law of energy conservation—i.e., that there are numerous ways of producing electric power. Because of the desire for the benefits of electricity at the lowest possible cost under a variety of conditions, much attention was focused on how best to utilize the available options. For example, hydroelectric power was often used to meet peak demands because it was easier and more economical to increase or decrease the wattage thus produced than to change the output of a fossil fuel plant. Public awareness of such matters became even more heightened following the Second World War as the environmental costs of expanding and intensifying human technological activity pressed for attention and people sought “environmentally friendly” sources of energy. The involvement of the petroleum industry in the creation of environmental disasters is illustrated powerfully by what happened in Cleveland, Ohio and its environs.

Stoked by the growth of the chemical industry and the invention of the automobile, the petroleum industry soon accounted for a major fraction of economic activity in the United States. Initially, extracting, refining, and transporting petroleum and petroleum products were in the hands of a large number of small-scale operators, and conditions in the industry were volatile and chaotic. Convinced that consolidation would bring order and efficiency to the petroleum industry and (of course) profits to himself, John D. Rockefeller (1839–1937) set about acquiring one small petroleum business after another in the years following the Civil War. Because of its location and transportation advantages, he chose

Cleveland, Ohio to be the center of his oil-refining operations. To achieve his goal of monopolizing the petroleum industry, he formed an alliance with a few other businesspeople which was incorporated in 1870 under the name “Standard Oil.” The corporation prospered handsomely during the ensuing decades as did the city of Cleveland, which continued to develop as a major center of the iron-and-steel and heavy-machinery industries. But this economic development was accompanied by environmental degradation that was, in the end, nothing less than spectacular.

Oil refineries, steel mills, factories, and warehouses lined the shores of the Cuyahoga River, which winds through Cleveland before emptying into Lake Erie. Industrial wastes dumped into the river and oil and its derivatives seeping into it from the refineries made it a poster child for polluted rivers. As incredible as it might seem, the Cuyahoga carried such a load of flammable fluids and other combustibles that it sometimes caught fire, putting bridges and ships in peril! The 1969 fire drew national attention—not because it was the worst ever (it wasn’t), but almost certainly because of the growing public awareness of and concern with the deteriorating state of the environment. This movement gained additional impetus from the highly visible effects of pollution on Lake Erie, which included massive fish kills that left its shores littered with dead fish. Not only was Lake Erie inundated with industrial waste from cities along its shores and from rivers emptying into it, but it was also befouled by great quantities of raw sewage from the cities and towns and agricultural run-off laden with fertilizer and pesticides. The resulting high levels of plant nutrients in the lake (a process known as “eutrophication”) fueled explosive growths of algae (known as an “algal bloom”). When algae die, they ordinarily sink to the bottom and rot, a process that removes dissolved oxygen from the water. If the concentration of dissolved oxygen in water falls below a certain level, fish suffocate. In the 1960s algal blooms in Lake Erie became so massive that wind-rows of rotting algae lined its shores, and in summer certain areas of it were carpeted with layers of algae up to two feet thick.

The “burning river” and the “dying lake” caught the media’s attention and fired the public’s determination that something be done. In short order, the US Congress passed the Clean Water Act (1972), which tightened restrictions on industrial waste disposal. In the same year Canada and the United States reached an accord, the Great Lakes Water Quality Agreement, which was focused primarily on reducing algal growth by controlling the amount of the plant nutrient phosphorus that was getting into the lakes. A revised version (1978) broadened the scope of the agreement to protecting the waters of the whole Great Lakes Basin Ecosystem. It emphasized preventing toxins from getting into the waters of

the basin. The reductions, achieved in ensuing decades, in algal blooms and in the presence of toxins in the Great Lakes demonstrated that effective action could be taken to repair anthropogenic damage to the natural environment.

Another example of environmental destructiveness stemming from human inventiveness that attracted widespread attention in the 1960s is the havoc wreaked by the indiscriminate use of the insecticide **DDT** (dichloro-diphenyl-trichloro-ethane). Indeed, it would not be too far off the mark to say that *Silent Spring* (1962) by Rachael Carson (1907–64), which brought the ill-effects of DDT forcefully to the attention of the public, did more than anything else to launch environmentalism as a major cultural force. This episode also illustrates very effectively the promise and the perils of powerful new technologies made possible by the science-and-technology partnership.

Dichloro-diphenyl-trichloro-ethane was first synthesized by a German doctoral student in the late 1850s, but no notice was taken of it until 1935, when J.R. Geigy, a Swiss chemical dye company, set about finding a preparation that could be used to protect woolens from moths. It assigned this task to a team of chemists led by Paul Hermann Müller (1899–1965). After testing various chemicals on houseflies, they found that DDT was not only effective but also persistent (continued to work without reapplication for days and even weeks). Furthermore, the product did not irritate the skin of test subjects as did other preparations. The Geigy chemists then tested DDT on cockroaches, mosquitoes, and other pests with excellent results. In 1940, the chemical company began marketing the product as an insecticide, which it called “**Gesarol**.”

When the United States entered the Second World War in 1941, people in the Office of Scientific Research and Development were aware that disease, particularly those forms spread by insects such as lice and mosquitoes, was one of the most formidable challenges that troops in the field would face. Accordingly, a program to find ways to deal with disease-carrying insects was launched in 1942. When the First Marine Division had to be pulled from combat in the Pacific because over half of its men had fallen victim to malaria, this effort took on new urgency. Thousands of products were tested, but none proved satisfactory—until a sample of Gesarol arrived from Switzerland in the fall of 1942. In repeated tests under a variety of conditions, DDT demonstrated its suitability for the task. Subsequent field trials dramatically confirmed its capabilities, whether in powder form applied by hand-operated blowers or in kerosene solution sprayed from airplanes. Lessons thus learned made possible DDT’s first major triumph: the suppression of an incipient typhus epidemic in Naples in the winter of 1943–44. When the city was liberated in October, people were living in deplorable conditions and as many as 90 percent of them were infested with body lice, the vehicle

of the bacterium that causes typhus. So impressive was this result that the British and American armies made DDT a regular part of their arsenal. The insecticide also played a vital role when German concentration camps were liberated, as typhus was rampant in them. But as important as it was, the part played by DDT in meeting the typhus/lice challenge was not as significant as its contribution to the fight against mosquitoes and malaria. This becomes clear if one considers not only what happened to the First Marine Division and the role of DDT in the Pacific campaigns but also its contribution to the ongoing, worldwide fight against malaria. It has been estimated that by 1950, DDT had prevented five million deaths from that disease.

Prior to the summer of 1944, information about DDT was kept secret because of its role in the war effort. But as hostilities wound down the following summer, restrictions on civilian access to the chemical were lifted. Since it was known from preliminary testing that DDT was effective against a variety of insects, it was quickly utilized to solve many different kinds of domestic and agricultural as well as public-health related insect problems. Accordingly, DDT was sprayed wherever flies congregated or were not wanted: in homes, businesses and public buildings, and large, open spaces outdoors. Airplanes sprayed the insecticide on potato crops, soybeans, and—most of all—cotton crops, which had been devastated by the notorious boll weevil. Elm trees threatened by Dutch elm disease (caused by a fungus spread by bark beetles) were treated with DDT, as was a large forested area in New Brunswick infested with spruce budworm. DDT was also the centerpiece of a worldwide anti-malarial campaign. The entire island of Sardinia was subjected to four years of saturation spraying in a failed effort to eradicate mosquitoes.

In retrospect, this indiscriminate use of DDT may seem irresponsible. Even so, it exemplifies one of the basic ways that technological innovation takes place. As seen above, especially in Chapters V and VII, once a substance, mechanism, or procedure has been devised (for whatever purpose), someone can be counted on to try using it in some other way. Unfortunately, in the case of DDT, additional applications greatly magnified the harm it caused. Hence a second feature of technological innovation that is very much in evidence in the case of DDT is unanticipated side-effects. Since DDT is a broad-spectrum insecticide (it kills all kinds of insects), such unintended side effects are especially problematic. For example, declines—even decimations—of fish populations have resulted from aerial spraying because the insecticide wiped out the food supply of the fish, even when the insects the fish fed upon were not the target of the spraying! Another unintended side effect of the wholesale use of DDT is that it not only provides an opportunity for resistant strains of a pest to flourish but also facilitates their

success by wiping out the organisms that prey upon the pest. This was forcefully demonstrated by the failed attempt to completely eradicate mosquitoes on Sardinia.

A third feature of technology exemplified by DDT is that it is often a double-edged sword: the very characteristics that make a technology so useful for one purpose are often the source of the problems it causes. The broad-spectrum nature of DDT makes it effective against fleas and mosquitoes as well as body lice (and thus an extremely valuable weapon against diseases spread by biting insects), but this very characteristic also makes it a menace to fish in affected bodies of water. The persistence of DDT is a great advantage in combating typhus. (It remains effective against lice for days and even weeks after application.) However, because it degrades slowly and is not soluble in water (and thus is not eliminated by the kidneys) but is soluble in fats and oils, DDT tends to accumulate in the bodies of animals that ingest it. This accumulation increases the higher up a creature is in the food chain. The result can be devastating for a species, depending upon the chemistry of its reproductive processes. Birds of prey seem to be especially vulnerable in this regard, as is evidenced by the steep decline in their populations in the years following the Second World War (when the use of DDT exploded) and the rebound in their numbers following the (1972) ban of its use.

One might think that once it becomes clear that the use of a substance is causing significant, perhaps irreversible harm to the environment, the appropriate action would be to prohibit it. Unfortunately, dealing with environmental problems is not always simply a matter of eliminating “harmful” substances. Certainly, the Lake Erie algal booms and fish kills were caused by phosphates that were getting into that body of water. But an influx of phosphates can be very beneficial. Phosphates are essential to the growth of algae, whether their presence is a problem or a key element of an ecosystem. Without the phosphates that are supplied continuously to the waters of the Georges and Grand Banks by upwelling, nutrient-rich ocean currents, the phytoplankton (tiny plant-like eukaryotic organisms that are the foundation of the food chain) would not flourish there and these massive shoals would never have been prime fishing sites. Phosphates are also needed by the plants that supply food for human beings and their animals.

The challenge at this point is to develop and implement ways of producing food that inflict less damage on the natural order than is being done currently. Even with the continued use of chemical fertilizers and pesticides, there are ways to reduce the percentage that gets into lakes, rivers, and streams. Some of these methods are simply good farming practices (contour plowing, strip-cropping, and crop rotation) that slow run-off, reduce erosion, and pay dividends to the farmer.

Others, such as leaving a buffer zone between cultivated land and rivers, lakes, and streams, have an economic cost. So does the abandonment of methods of applying insecticides, such as crop-spraying with airplanes, that deliver only a small fraction of the material to the intended target. Similarly, curtailing the use of broad-spectrum pesticides may require costly and time-consuming efforts to find alternatives with no guarantee of even partial success. The unavailability of acceptable replacements for environmentally-destructive products often triggers probing discussions and debates concerning the relative weights to be accorded the needs of human beings, on the one hand, and the integrity of the environment, on the other. One example is the controversy surrounding the flooding of the Hetch Hetchy Valley to create a water-supply for San Francisco, as discussed above.

Discussions and debates of this kind took place as the effort to ban DDT got underway. Although the insecticide was soon outlawed in industrialized countries where the threat posed by malaria was minimal, its value in the fight to suppress the disease where it was a major scourge weighed heavily against a total ban. After all, its use inside homes (for example, on mosquito netting) requires only a tiny fraction of the amount used in the applications that caused so much harm. The only problem with allowing such limited uses would seem to be ensuring that they remain thus limited, which is important, given the emergence of DDT-resistant strains of mosquitoes. For that reason, DDT could never be more than a small part of the answer to the malaria menace.

All of these cases and more contribute to the ongoing threat of anthropogenic (human-caused) climate change. The burning of fossil fuels continues to increase atmospheric concentration of carbon dioxide (CO₂), the primary cause of global warming, at an alarming rate. In 1940, approximately 5 billion metric tons of CO₂ were released into the atmosphere—by 2025, that figure had increased to approximately 38 billion metric tons. Clearing land for industrial development or agricultural use reduces trees that serve as CO₂ sinks—naturally reducing the amount of atmospheric CO₂. Though DDT is no longer used in the US, other pesticides continue to pollute the environment while paving the way for the increased grain production necessary for farming beef on an industrial scale, which contributes large quantities of the greenhouse gases methane and nitrous oxide to the atmosphere.

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The snowballing effects of technology are not always positive. The exploitation of fossil fuels has increased humanity's ability to harness energy in ways undreamed of in earlier centuries—at the expense of the Earth's atmosphere.

Likewise, pesticides allow for controlling disease and enhancing agriculture, providing more food for Earth's growing population, but at the cost of polluting the environment and causing unintended harm to other ecosystems. Railroads across the Great Plains and refrigerated rail cars increased supplies of beef through much of the United States and lowered its price for consumers, but also increased pressure to exterminate buffalo that might block train routes. When contemplating the havoc wreaked, it is difficult to quarrel with the slogan, "We have met the enemy, and he is us," from the cartoon strip "Pogo" by Walt Kelly (1970), which appeared on a 1971 Earth Day poster. Clearly, this situation calls for human beings to stop and reflect upon the effects of their actions, to re-examine their priorities, and to re-think their place in the scheme of things. Issues of this kind, which involve ethics and values, that are raised by the impact of technology on the environment are addressed in the following chapter along with other normative questions raised by technological innovations.

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