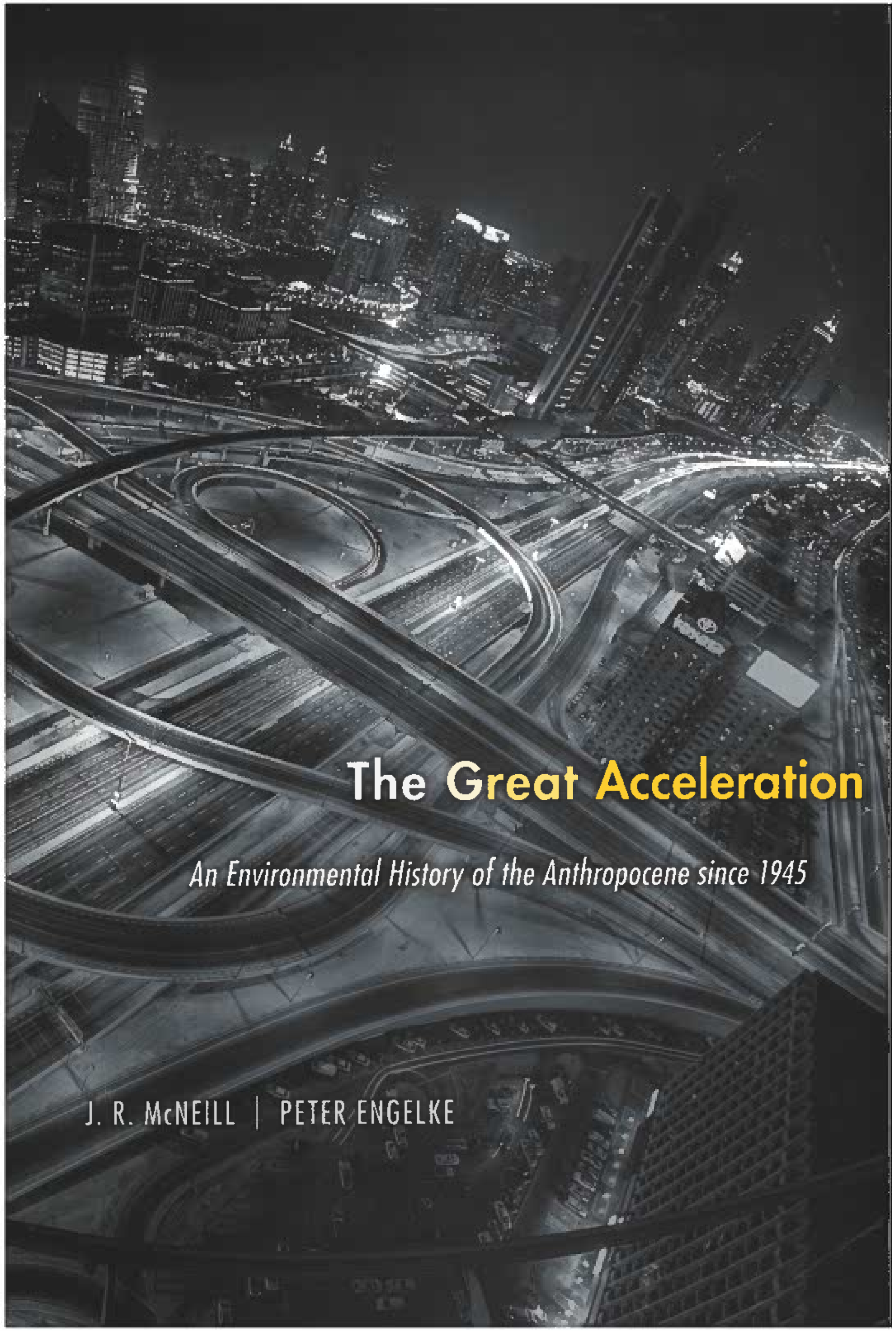

The Great Acceleration

An Environmental History of the Anthropocene since 1945

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Introduction

> Whosoever is writing a modern History, shall follow truth too neare the heeles, it may haply strike out his teeth.
>
> —Sir Walter Ralegh, 1614

Since the nineteenth century, geologists, earth scientists, evolutionary biologists, and their colleagues have divided the history of the Earth into a series of eras, periods, and epochs. These are based, in a loose sense, on the environmental history of our planet, especially on the twists and turns in the evolution of life on Earth as revealed in the fossil record. We are (and have been for a long time) in the Cenozoic era and, within that, the Quaternary period. And within the Quaternary period, we are in the Holocene epoch, meaning the last 11,700 years or so. The Holocene is defined above all by its climate, an interglacial moment that has been agreeably stable so far compared to what came before. All of what is conventionally understood as human history, the entire history of agriculture and of civilization, has taken place in the Holocene. Or perhaps one should say it all *took* place in the Holocene.

This book takes the view that a new moment in the history of the Earth has begun, that the Holocene is over and something new has begun: the Anthropocene. Beginning in 2000, the idea of the Anthropocene was popularized by the Dutch atmospheric chemist Paul Crutzen, who won a Nobel Prize in 1995 for his work on depletion of the ozone layer in the stratosphere. The changing composition of the atmosphere, especially the well-documented increase in carbon dioxide, seemed to Crutzen so dramatic and so potentially consequential for life on Earth that he concluded that a new stage had begun in Earth's history, one in which humankind had emerged as the most powerful influence on global ecology. The crux of the Anthropocene concept is just that: a new period (whether epoch, period, or era in geologists' parlance) in which human actions overshadow the quiet persistence of microbes and the endless wobbles and eccentricities in the Earth's orbit, affecting the governing systems of the Earth, and therefore define the age.[1]

Crutzen argued that the Anthropocene began in the late eighteenth century, with the onset of the fossil fuel energy regime. By the 1780s, the use of coal was becoming integral to economic life in Britain and would thereafter play an ever-larger role in the world economy. New technologies and new energy demand led to the exploitation of other fossil fuels, oil and natural gas. By the 1890s, half of global energy use came in the form of fossil fuels, and by 2015 that share had climbed to nearly 80 percent. Modern history unfurled in the context of a fossil fuel energy regime and, as we shall see, of exponential growth in energy use.

Of less concern to Crutzen, modern history also played out amid runaway population growth. In 1780, about 800 million to 900 million humans walked the Earth. By 1930 there were some 2 billion, and by 2011, 7 billion. People at the time did not detect it, but in the middle of the eighteenth century a long-term surge in human numbers began. It started slowly and (as we shall see) built to a crescendo after 1950. No other primate, perhaps no other mammal, ever enjoyed such a frenzy of reproduction and survival in the history of life on Earth. There is nothing in the demographic history of our species anything like the modern rise of population—nor will there be again. Its chronology can support Crutzen's notion of an eighteenth-century origin for the Anthropocene. Both these twin surges, of energy use and population growth, started in the eighteenth century and continue today. How they will evolve in the future is anyone's guess—and from time to time in the pages that follow we will hazard a guess. In any case, since the late eighteenth century the human species has embarked on a bold new venture with no analogues anywhere in its history or biology.

An Indian coal miner carrying a basket-load of coal, ca. 1950. Coal and other fossil fuels, such as oil and natural gas, powered the world's economy after 1945 but entailed major public health and environmental costs associated with extraction and use. (Getty Images)

Since 2000 and Crutzen's first formulation of the concept, rival versions of the Anthropocene have sprung to life. Depending on the criteria one wishes to emphasize, one can find reasons to date the Anthropocene to 1610, 1492, some 7,000 years ago, 12,000 to 15,000 years ago, or back as far as the human control over fire, which might be as much as 1.8 million years ago.[2] Or one can find reasons, as this book does, to prefer a more recent date for the beginning of the Anthropocene. Those reasons, in brief, are, first, that since the mid-twentieth century human action (unintentionally) has become the most important factor governing crucial biogeochemical cycles, to wit, the carbon cycle, the sulfur cycle, and the nitrogen cycle. Those cycles form a large part of what is now called the "Earth system," a set of interlocking global-scale processes.[3] The second reason is that since the mid-twentieth century the human impact on the Earth and the biosphere, measured and judged in several different ways (some of which we will detail), has escalated.

The escalation since 1945 has been so fast that it sometimes goes by the name the Great Acceleration.[4] Within the last three human generations, three-quarters of the human-caused loading of the atmosphere with carbon dioxide took place. The number of motor vehicles on Earth increased from 40 million to 850 million. The number of people nearly tripled, and the number of city dwellers rose from about 700 million to 3.7 billion. In 1950 the world produced about 1 million tons of plastics but by 2015 that rose to nearly 300 million tons. In the same time span, the quantities of nitrogen synthesized (mainly for fertilizers) climbed from under 4 million tons to more than 85 million tons. Some trends of the Great Acceleration are still in high gear, but others—marine fish capture, large dam construction, stratospheric ozone loss—have now begun to slow down.[5]

This period since 1945 corresponds roughly to the average life expectancy of a human being. Only one in twelve persons now alive can remember anything before 1945. The entire life experience of almost

everyone now living has taken place within the eccentric historical moment of the Great Acceleration, during what is certainly the most anomalous and unrepresentative period in the 200,000-year-long history of relations between our species and the biosphere. That should make us all skeptical of expectations that any particular current trends will last for long.

The Great Acceleration in its present form cannot last for long. There are not enough big rivers left to dam up, enough oil left to burn, enough forests left to fell, enough marine fish left to catch, enough groundwater left to pump up. Indeed, there are several indications that the accelerations are tapering off, and in a few cases reversing for one reason or another—as this book will explain. At root, it will probably come down above all to the character of the energy system and the size of the human population. If, as seems likely, we will craft an energy system in the decades to come in which fossil fuels play a much smaller role than they have recently, then our impact on Earth systems and the environment generally will abate sharply. And if the fertility declines among human populations around the world continue, as seems likely, then that will reinforce any future deceleration. One cannot say when the Great Acceleration will end, and one cannot say just how, but it is almost certainly a brief blip in human history, environmental history, and Earth history.

But the Anthropocene, barring catastrophe, is set to continue. Human beings will go on exercising influence over their environments and over global ecology far out of proportion to our numbers and far overshadowing that of other species. Our numbers are not likely to fall drastically. Nor are our appetites for energy and materials. Our powers to alter ecosystems will only increase, given the pace of change in biotechnology. Just how, and how long, humans will exert an outsized impact on the Earth and its systems in times to come is uncertain. But actions already taken, mainly between 1945 and now, assure a human imprint on the Earth, its climate, its biota, the acidity of its oceans, and much else that will linger for many millennia yet to come.

Before venturing any further into the temptations of futurology, it is well to remember the words of Sir Walter Ralegh quoted in the epigraph. Only some of the future is already determined (there *will* be lots of plastic and concrete lying around and buried under sediments). Much of it will be the result of choices and accidents yet to come. So it is best to return to the firmer ground of the past, to try to see how the present came to be what it is, how the Great Acceleration jump-started the Anthropocene. That will not allow us to know the future—nothing will, not even the most sophisticated modeling exercises—but it may help us to imagine the range of possibilities or, as Saint Paul put it, to see through a glass, darkly.

CHAPTER ONE

Energy and Population

Energy is a vexingly abstract concept. The word is derived from a term apparently invented by Aristotle to signify movement or work. Modern physicists have gotten only a bit further than the venerable Greek. They believe that energy exists in finite quantity in the Universe but in several different forms. Energy can be neither created nor destroyed, but it can be converted from one form to another. For instance, when you eat an apple, you convert chemical energy (the apple) into bodily heat, into muscular motion, and into other forms of chemical energy (your bones and tissues).[1]

The Earth is awash in energy. Almost all comes from the Sun. For human purposes, the main forms of energy are heat, light, motion, and chemical energy. The Sun's payload comes chiefly in the form of heat and light. A third of this is instantly reflected back into space, but most lingers for a while, warming land, sea, and air. A little of the light is absorbed by plants and converted into chemical energy through photosynthesis.

Every energy conversion results in some loss of useful energy. Plants on average manage to capture less than 1 percent of the energy delivered by the Sun. The rest is dissipated, mainly as heat. But what plants absorb is enough to grow, each year, about 110 billion tons of biomass in the sea and another 120 billion tons on land. Animals eat a small proportion of that, converting it into body heat, motion, and new tissues. And a small share of those new animal tissues is eaten by carnivores. At each of these trophic levels, well under 10 percent of available energy is successfully harvested. So the great majority of incoming energy is lost to no earthly purpose. But the Sun is so generous, there is still plenty to go around.

Until the harnessing of fire, our ancestors took part in this web of energy and life without being able to change it. The only energy available to them was what they could find to eat. Once armed with fire, probably more than 1.5 million years ago, our hominin ancestors could harvest more energy, both in the form of otherwise indigestible foods that cooking now rendered edible, and in the form of heat. Fire also helped them scavenge and hunt more efficiently, enhancing their access to chemical energy in the form of meat. This low-energy economy remained in place, with some modest changes, until agriculture began about ten thousand years ago.

Growing crops and raising animals allowed ancient farmers to harvest considerably more energy than their forebears could. Grain crops are the seeds of grasses such as rice, wheat, or maize, and are packed with energy (and protein). So, with farming, a given patch of land provided far more usable energy for human bodies than it could without farming, perhaps ten to one hundred times more. Big domesticated animals, although they needed huge quantities of feed, could convert the otherwise nearly useless vegetation of steppe, savanna, or swampland into usable energy, helpful for pulling plows (oxen, water buffalo) or for transport (horses, camels). Farming slowly became widespread, although never universal.

Eventually, watermills and windmills added a little more to the sum of energy available for human purposes. Watermills might be two thousand years old and windmills one thousand. In suitable locations, where water flowed reliably or reasonably steady winds blew, these devices could do the work of several people. But in most places, wind and flowing water were either too rare or too erratic. So the energy regime remained organic, based on human and animal muscle for mechanical power, and on wood and other biomass for heat. The organic energy regime lasted until the eighteenth century.

Then in late eighteenth-century England the harnessing of coal exploded the constraints of the organic energy regime. With fossil fuels, humankind gained access to eons of frozen sunshine—maybe 500 million years' worth of prior photosynthesis. Early efforts to exploit this subsidy from the deep past were inefficient. Early steam engines, in converting chemical energy into heat and then into motion, wasted 99 percent of the energy fed into them. But incremental improvements led to machines that by the 1950s wasted far less energy than did photosynthesis or carnivory. In this sense, culture had improved upon nature.

The enormous expansion of energy use in recent decades beggars the imagination. By about 1870 we used more fossil fuel energy each year than the annual global production from all photosynthesis. Our species has probably used more energy since 1920 than in all of prior human history. In the half century before 1950, global energy use slightly more than doubled. Then in the next half century, it quintupled from the 1950s level. The energy crisis of the 1970s—two sharp oil price hikes in 1973 and 1979—slowed but did not stop this dizzying climb in the use of fossil sunshine. Since 1950 we have burned around 50 million to 150 million years' worth of it.

The fossil fuel energy regime contained several phases. Coal outstripped biomass to become the world's primary fuel by about 1890. King coal reigned for about seventy-five years, before ceding the throne to oil in about 1965. Lately natural gas has grown in importance, so that in 2013 the world's energy mix looked as shown in Table 1.

These data do not include biomass, for which figures are sketchy. But the best guess is that it accounts for perhaps 15 percent of the grand total, fossil fuels for about 75 percent, and hydroelectricity and nuclear power together for about 10 percent. King oil's reign, now fifty years in duration, will likely prove as brief as coal's, but that remains to be seen. We have used about one trillion barrels of oil since commercial production began around 1860, and now use about 32 billion barrels yearly.[2]

The global totals belie tremendous variation in energy use around the world. In the early twenty-first century, the average North

TABLE 1
Global commercial energy mix, 2013

Type of energy	%
Oil	33%
Coal	30%
Natural gas	24%
Hydroelectric	7%
Nuclear	4%

Data source: BP Statistical Review of World Energy, June 2014.

American used about seventy times as much energy as the average Mozambican. The figures since 1965, in Table 2, speak volumes about the rise of China and India, and about the distribution of wealth within the world.

In 1960, most of the world outside of Europe and North America still used little energy. The energy-intensive way of life extended to perhaps one-fifth of the world's population. But late in the twentieth century that pattern, in place since 1880 or so, changed quickly. In the fifty years after 1965, China increased its energy use by 16 times, India by 11, Egypt by 10 or 11. Meanwhile US energy use rose by about 40 percent. The United States accounted for a third of the world's energy consumption in 1965, but only a fifth in 2009; China accounted for only 5 percent in 1965, but a fifth in 2009, and in 2010 surpassed the United States to become the world's largest energy user.

In sum, the burgeoning rate of energy use in modern history makes our time wildly different from anything in the human past. The fact that for about a century after 1850 high energy use was confined to Europe and North America, and to a lesser extent to Japan, is the single most important reason behind the political and economic dominance these regions enjoyed in the international system. Since 1965 the total use of energy has continued to climb at only slightly diminished rates, but the great majority of the expansion has taken place outside of Europe and America, mainly in East Asia.

TABLE 2
Annual energy consumption, 1965–2013
(in millions of tons of oil equivalent)

Year	World	China	India	USA	Japan	Egypt
1965	3,813	182	53	1,284	149	8
1975	5,762	337	82	1,698	329	10
1985	7,150	533	133	1,763	368	28
1995	8,545	917	236	2,117	489	38
2005	10,565	1,429	362	2,342	520	62
2010	11,978	2,403	521	2,278	503	81
2013	12,730	2,852	595	2,266	474	87

Data source: BP Statistical Review of World Energy, June 2010, June 2012, 2014.
Note: Amounts are for commercial energy only, not biomass, which might add 10 to 15 percent.

Fossil Fuel Energy and the Environment

The creation and spread of fossil fuel society was the most environmentally consequential development of modern times. Part of the reason for that lies in the direct effects of the extraction, transport, and combustion of coal, oil, and (to a much lesser extent) natural gas. These were (and are) mainly a matter of air, water, and soil pollution. The other part resides in the indirect effects of cheap and abundant energy: it enabled many activities that otherwise would have been uneconomic and would not have happened, or perhaps would have happened but only much more slowly.

Extracting fossil energy from the crust of the Earth has always been a messy business. Coal, mined commercially in over seventy countries since 1945, had the most widespread impacts. Deep mining brought changes to land, air, and water. Carving galleries out from beneath the surface honeycombed the Earth in coal districts such as South Wales, the Ruhr, eastern Kentucky, the Donetsk Basin, and Shaanxi Province. Occasionally underground mines collapsed, as in the Saarland (Germany) in 2008, producing a small earthquake. In China, as of 2005, subsidence due to coal mines affected an area the size of Switzerland. Mine tailings and slag heaps disfigured the landscape around coal mines. In China (by 2005) coal mine slag covered an area the size of New Jersey or Israel. Everywhere tailings and slag leached sulfuric acid into local waters. In some Pennsylvania and Ohio waterways, acidic liquids from mine drainage had killed off aquatic life by the 1960s, although in some spots life has since returned. Deep mining also often put extra methane in the atmosphere, adding perhaps 3 to 6 percent on top of the natural releases of this potent greenhouse gas.

Deep mining has always put people in dangerous environments. In China, for example, where roughly one hundred thousand small mines opened up during the Great Leap Forward (1958–1961), mining accidents killed about six thousand men annually at that time, and at least that many yearly in the 1990s. In the United Kingdom in 1961, about forty-two hundred men died in mine accidents. In the United States, the most dangerous year for coal miners was 1907, when more than three thousand died; since 1990, annual deaths have ranged from 18 to 66. Early in the twenty-first century, accidents killed a few thousand miners each year in China, several times the figure for Russia or India. Black lung disease, a consequence of years spent underground inhaling coal dust, killed far more wherever coal was mined.[3]

Surface mining, often called strip mining in the United States, was far safer for miners. It began with simple tools centuries ago, but steam technology made it more practical in the early twentieth century. After 1945, new excavation equipment and cheap oil ushered in a golden age of strip mining. Today it accounts for about 40 percent of coal mining worldwide, and outside of China is usually much more common than deep mining. In surface mining, which is practical to

depths of nearly 50 meters, big machines claw away earth and rock above coal seams, destroying vegetation and soils. In the United States it aroused fervent opposition in many communities, which provoked federal regulation after 1977. Since that time, mining companies have been legally obliged to fund landscape restoration.

One particularly unpopular variant of strip mining was "mountaintop removal," practiced especially in those parts of Kentucky and West Virginia that had low-sulfur coal. High energy prices in the 1970s made these procedures lucrative as never before. Tighter air pollution laws in the 1990s, which made using high-sulfur coal more difficult, added to the economic logic of mountaintop removal. Blasting the tops off the Appalachians had many environmental consequences, none so important as the filling in of streams and valleys with waste rock ("overburden"), which buried forests and streams and led to accelerated erosion and occasional landslides.

Mountaintop removal, and surface mining generally, aroused spirited opposition from the 1930s onward and made environmentalists out of ordinary rural people throughout Appalachia. Their farms, fishing streams, and hunting grounds were sacrificed for coal production. In the 1960s and 1970s, opposition to strip mining reached its height in Appalachia, proving divisive in communities where mining companies offered most of the few jobs around. But the practice of mountaintop removal remained economic, and lasted into the twenty-first century.[4]

Drilling for oil brought different environmental issues but no less discord. In the early twentieth century, oil drilling occurred in many heavily populated places, including East Texas, southern California, central Romania, the city of Baku, and the then-Austrian province of Galicia. Gushers, spills, and fires menaced hearth and home. But by midcentury the technologies of drilling and storage had improved, so that oil fields were no longer necessarily the oleaginous equivalent of the Augean stables. And production increasingly shifted to places where people were few, such as Saudi Arabia and Siberia, so the consequences of oil pollution became less costly—at least in economic and political terms.

But the hike in energy prices of the 1970s inspired oil drilling in new and often challenging environments, including the seafloor, tropical forests, and the Arctic. Leaks, accidents, and blowouts became more common, thanks to Arctic cold and deep-sea pressures. Crude oil except in small concentrations is toxic to most forms of life and is extremely hard to clean up. By 2005 the world had some forty thousand oil fields, none of them free from pollution. Routine drilling involved building new infrastructure, moving heavy equipment sometimes weighing thousands of tons, and splashing vast quantities of oil and contaminated water into the surrounding environment. In the decades after 1980, about 30 million tons (or 220 million barrels) of oil dripped and squirted into the environment every year, about two-fifths of it in Russia.[5]

Offshore drilling, pioneered in California waters in the 1890s, remained confined to shallow waters for many decades. In the 1920s the practice spread to Lake Maracaibo in Venezuela, and to the Caspian Sea—both enduringly polluted as a result—and in the 1930s to the Gulf of Mexico. Technological advances, and the huge pools of investment capital available to oil companies from the 1940s on, opened new offshore frontiers in deeper waters. By the 1990s deepwater platforms dotted the North Sea, the Gulf of Mexico, and the coasts of Brazil, Nigeria, Angola, Indonesia, and Russia, among others. Big platforms stood over 600 meters above water, rivaling the tallest skyscrapers.

Offshore drilling operations were inherently risky. When hit by tropical storms or errant tankers, rigs splashed oil into the surrounding seas. The worst accidents occurred in the Gulf of Mexico. In 1979 a rig operated by the Mexican state oil company suffered a blowout and spewed oil for more than nine months before it was successfully capped. Some 3.3 million barrels escaped (equivalent to about six

hours' worth of US oil use in 1979). It resulted in a surface oil slick roughly the size of Lebanon or Connecticut that ruined some Mexican fisheries and damaged Texan ones.[6]

In April 2010 the *Deepwater Horizon*, an oil platform leased by BP, exploded and sank, killing eleven workers and springing a leak some 1,500 meters below the waves on the seafloor off the Louisiana coast. It defied all containment efforts for more than three months. Some five million barrels in all spewed into the Gulf, the largest accidental oil spill in world history. The coastal wetlands ecosystems and what in previous years had been tourist-filled beaches of the Gulf Coast sopped up some of the wandering oil. Tar balls and oil washed up on the coasts of Louisiana, Mississippi, Alabama, and Florida. Fisheries ceased operations, and dead and damaged birds began to pile up. One of the victims was the Louisiana brown pelican, once brought to the edge of extinction by DDT in the 1950s and 1960s. Conservation work had given the brown pelican second life to the point where in 2009 it migrated off the federal endangered species list. In the first two months of the BP spill, 40 percent of the known population of brown pelicans died oily deaths. Some forty-eight thousand temporary workers and an armada of vessels not seen since D-Day tried to limit the ecological damage. Oceanographers and marine biologists will be assessing the spill's impacts for years, and lawyers will be kept busy for decades ascertaining who will be held responsible and just how tens of billions of dollars will change hands.[7] In the Gulf of Mexico, small spills occurred daily, huge ones every few years, but nothing yet matches the *Deepwater Horizon* disaster.

Drilling for oil in the forests of Ecuador presented different challenges from offshore environments. In the remote upper reaches of the Amazon watershed, in northeastern Ecuador, a Texaco-Gulf consortium struck oil in 1967. Over the next half century, the region yielded over two billion barrels of crude oil, most of it sent by pipeline over the Andes, making Ecuador the second largest oil exporter of South the Ijaw, Igbo, and Ogoni. Unlike Oriente, it is densely populated, home to several million people. Shell and BP began oil operations here in the 1950s, happy to find a low-sulfur crude that is easy to refine into gasoline. Other companies followed, creating some 160 oil fields and 7,000 kilometers of pipelines. For decades, tankers filled up on crude where centuries before wooden ships had loaded slaves.

The Nigerian government, in what could well be an understatement, recorded about seven thousand oil spills between 1976 and 2005 in the Delta, involving some three million barrels of crude.[10] Some of the spills resulted from routine accidents, normal in the industry but especially frequent in the Delta due to poor maintenance and challenging conditions, both geographic and political. Others were acts of sabotage undertaken by locals, some of whom were seeking revenge for something, others of whom sought extortion or compensation payments from oil companies. The Niger Delta was, and remains, one of the poorest parts of Nigeria despite the several billions of dollars' worth of oil pumped out. For most residents, oil production made life harder. Dredging canals for oil exploration eliminated much of the mangrove swamp in which fish spawned, which together with oil pollution undercut a long-standing source of sustenance in the Delta. Air pollution and acid rain, largely from gas flares at oil wells, damaged crops. In the early 1990s the United Nations declared the Niger Delta the world's most ecologically endangered delta. Locals felt (and feel) that their natural wealth has been either destroyed or stolen by foreign companies and the Nigerian state, whose leadership has shown remarkable persistence in skimming off oil wealth. Resulting frustrations fed both liberation movements of local minorities and criminal syndicates. Lately Nigeria and its multinational partners have emphasized drilling offshore, where there is no local population to consider.[11]

The quest for oil led to new drilling in the chilly latitudes of Siberia and Alaska as well as in rainforests. The Soviet Union developed the huge oil and gas fields of western Siberia beginning in the 1960s (the Soviets used nuclear explosions to help in seismic explorations between 1978 and 1985, so some Siberian oil is slightly radioactive).[12] The much more modest fields of northern Alaska opened up in the 1970s. Both regions, but especially Siberia, had their normal accidents and intentional releases of oil, "produced water," and other toxic substances. In high-latitude wetlands, taiga, and tundra, where biological processes move slowly, the ill effects of spills as a rule lingered longer than in the tropics, as we shall see.

Oriente and the Niger Delta are extreme examples of sacrifice zones, where the cost of energy extraction included pervasive ecological degradation. Among local species, only oil-eating bacteria benefited from the fouling of the soils and waters of these regions. But people far away also benefited, in the form of cheap oil for consumers, tidy profit for the companies involved, and luxurious revenue streams for state officials. The world enjoyed great benefits thanks to oil extraction, but specific places paid a high price. People living near strip mines would likely say the same of the history of coal extraction.

Coal and Oil Transport

While extraction of coal and oil exacted an environmental price upon a fixed archipelago of mining districts and oil fields, the transport of fossil fuels had a scattered impact. Coal transport took place mainly in rail cars and barges. Very few accidents occurred, and when they did what coal toppled out onto land or into canals and rivers led to minimal consequences.

Oil was a different matter. Part of the appeal of oil over coal is the ease of transport. As a liquid, oil (except for the heaviest varieties) can ooze through pipelines. Even more glided over the seas in tankers. After 1950 oil increasingly was drilled in one country and burned in another, a reflection of the emergence of the Persian Gulf giant fields. So tankers plied the high seas in ever greater numbers. Today oil makes up half the tonnage of maritime cargoes, and there are more miles of pipeline than of railroad in the world.[13]

Pipelines and tankers proved remarkably susceptible to accident. One reason tankers had so many accidents is that they became too big to stop. In 1945 a big tanker held 20,000 tons of oil, in the 1970s about half a million, and today 1 million tons. Supertankers are 300 meters in length and the least nimble vessels on the seas. They need several kilometers in which to slow to a stop.

Fortunately, in the same decades tankers became harder to puncture. In the 1970s most new tankers had double hulls, which sharply reduced the likelihood of spills resulting from collisions with rocks, icebergs, and other ships. But when spills occurred, they could be large, and they always happened near shore where oil could foul rich ecosystems and valuable property.

Though small tanker spills happened almost every day, most of the escaped oil came in a few big accidents. The English Channel witnessed two giant tanker spills, in 1967 and 1978. The biggest spill of all occurred off of Cape Town in 1983, leaking more than six times as much oil as did the famous *Exxon Valdez* in 1989. Tanker spills could happen almost anywhere, but they were most numerous in the Gulf of Mexico, in Europe's Atlantic waters, in the Mediterranean Sea, and in the Persian Gulf.[14] The most recent big tanker spill, in 2002, occurred when a single-hulled vessel broke up in a storm off the northwest coast of Spain.

Pipelines carried a smaller, but growing, share of the world's oil after 1945. Their builders intend them to last fifteen to twenty years, but many, perhaps most, pipelines are asked to serve beyond that span. They corrode and crack, especially when subject to extreme ranges of climate. By and large, pipeline design improved over time, but accidents increased because the world's network of pipelines grew so quickly.[15]

The most affected landscapes were in Russia. The most serious single pipeline leak occurred near Usinsk, in Komi Republic, Russia,

about 1,500 kilometers northeast of Moscow in 1994. Outsiders estimate the leak at six hundred thousand to one million barrels. Officials initially denied any leaks, a position they soon had to abandon.[16] Another large one occurred in 2006. Altogether, about 7 to 20 percent of Russian oil production leaked out of faulty pipelines in the 1990s, a reflection of oil's low price, a business culture that put scant value on routine maintenance, especially in an economically disastrous decade, and the challenges of both remoteness and climate. Thousands of leaks and spills, large and small, happened every year in the 1990s. The subzero winter cold of regions such as the oilfields of Komi Republic—most of which lie north of the Arctic Circle—was hard on pipelines and other components of oil infrastructure.[17] Some indigenous Siberians, not surprisingly, tried to organize themselves against oil and gas development. Pipeline leaks imperiled their hunting, fishing, and reindeer herding. On at least one occasion some attempted armed resistance, which succeeded no better than the efforts of Ecuador's Huaorani.[18]

In human terms, the worst oil pipeline accident occurred in the Niger Delta in 1998 when a line maintained by Shell and the Nigerian state oil company sprang a leak. As villagers gathered to help themselves to free oil, an explosion and a fireball incinerated more than a thousand people. Two villages burned to cinders. In 2006 two additional oil pipeline fires elsewhere in Nigeria killed about six hundred people. As a means of ferrying energy from point of extraction to point of use, oil tankers and pipelines were both more economical and more hazardous than coal transport.[19]

Fossil Fuel Combustion and Air Pollution

Coal mine accidents and oil pipeline explosions took many thousands of lives in the decades after 1945, but nowhere near as many as the routine, peaceable combustion of fossil fuels. Air pollution, mainly from coal and oil burning, killed tens of millions of people.

To get an idea of the air pollution resulting from coal combustion, consider the annual pollution output of an average coal-fired American power plant about 2010, after decades of regulation and technical improvements. The average plant annually released millions of tons of carbon dioxide, the main greenhouse gas, and thousands of tons of sulfur dioxide, the main ingredient in acid rain. It put a few dozen kilograms of lead, mercury, and arsenic into the air as well. This was part of the price of turning coal into electricity, and forty years ago the price was much higher because coal combustion was much dirtier. And this does not include ash and soot.

Urban air pollution has a long history. In the twelfth century, Maimonides—no doubt justly—complained about air quality in Cairo, a dung- and straw-burning city. A century later London enacted the first recorded ordinances aimed against air pollution. The adoption of coal as a basic fuel made matters much worse, never more so than in London in the second week of December 1952.

When a cold air mass settled over the Thames valley in early December, bringing temperatures below freezing, Londoners added more coal to their hearths. Each day their million chimneys spewed out a thousand tons of coal soot and nearly 400 tons of sulfur dioxide. People could not see to cross the street at noon. Natives who knew the city like the back of their hand got lost on daily errands. A few walked into the Thames and drowned. During December 5–9, some forty-seven hundred people died, about three thousand more than normal. Over the next three months mortality remained well above normal for London winters, so that epidemiologists now attribute twelve thousand deaths to pollution during the December episode.[20] In the winter of 1952–1953, coal smoke, soot, and sulfur dioxide killed Londoners at roughly twice the rate the Luftwaffe managed during the blitz of 1940–1941. Undertakers ran out of caskets.[21]

The public and press raised a hue and cry, prompting one cabinet minister, Harold Macmillan, to write in a memo he wisely kept secret during his lifetime: "For some reason or another 'smog' has captured the imagination of the press and people. . . . Ridiculous as it appears, I suggest we form a committee. We cannot do very much, but we can be seen to be very busy."[22] Macmillan, whose insouciance about air pollution and its effects was characteristic of his time, went on to have a distinguished political career, including a stint as prime minister from 1957 to 1963. Pea-soupers, as Londoners called their densest fogs, persisted in London for a few more years. But between 1956 and the mid-1960s, mainly on Macmillan's watch, air pollution laws and fuel switching (to oil and natural gas) made London's killer fogs a thing of the past.[23]

Oil burned cleaner than coal. Combustion of oil and its derivatives, such as gasoline, releases lead, carbon monoxide, sulfur dioxide, nitrogen oxides, and volatile organic compounds (VOCs). VOCs together with sunshine help brew photochemical smog. Oil made its main contribution to urban air pollution through tailpipes rather than chimneys. Vehicle exhausts provided the raw material for photochemical smog, which was first observed in Los Angeles during World War II. Photochemical smog developed where motorization took hold and where the Sun shone brightly. Cities at lower latitudes, especially those with nearby mountains that keep pollution from drifting off with the winds, were especially affected: Los Angeles, Santiago, Athens, Tehran, and the world champion, Mexico City.

Mexico City had one hundred thousand cars in 1950, when it was still renowned for its clear vistas of distant volcanoes. By 1990, by which time it was enveloped in a near-permanent haze, four million cars clogged its streets. Trucks, buses, and cars accounted for 85 percent of Mexico City's air pollution, which by 1985 was occasionally so acute that birds fell from the sky in midflight over the central square (the Zócalo). After careful monitoring began in 1986, it emerged that Mexico City exceeded legal limits for one or more major pollutants more than 90 percent of the time. In the 1990s, estimates suggested some six thousand to twelve thousand annual deaths were attributable to air pollution in the city, four to eight times the annual number of murders. Various efforts to curb air pollution since the 1980s have produced mixed results, but the death rate seems to have declined slightly since the early 1990s.

Both coal and oil turned out to be mass killers in the world's cities. In Western Europe around 2000, vehicle exhausts killed people at roughly the same rate as vehicle accidents.[24] Meanwhile, in China air pollution from all sources killed about five hundred thousand Chinese annually and, due to pollutants wafting eastward with the winds, another eleven thousand in Japan and Korea together.[25] In the 1990s, estimates had put the global annual death toll attributable to air pollution at about half a million. One study from 2002 put it at eight hundred thousand per year.[26] From 1950 to 2015, air pollution probably killed about thirty to forty million people, lately most of them Chinese, roughly equal to the death toll from all wars around the world since 1950.[27] Many millions more suffered intensified asthma and other ailments as a result of the pollution they inhaled. Fossil fuel combustion accounted for the lion's share of these deaths and illnesses.

In addition to these unhappy effects upon human health, fossil fuels, especially coal, were responsible for widespread acidification. Volcanoes and forest fires released quantities of sulfur to the atmosphere, but by the 1970s coal combustion emitted about ten times more. Sulfur dioxide in contact with cloud droplets forms sulfuric acid, which returns to Earth with rain, snow, or fog (commonly called acid rain). Acid rain often contains nitrogen oxides too, from coal or oil combustion. High-sulfur coal of the sort found in the Midwest of the United States, in China, in Bengal, and elsewhere, acidified ecosystems far and wide. Mountain forests and freshwater ecosystems showed the most acute effects, and some sensitive species (brook trout, sugar maple) disappeared altogether in high-acid environments. Broadly speaking, by the end of the twentieth century the world had three acidification hot spots:

northern and central Europe, eastern North America, and eastern, especially southeastern, China.

Acid rain became a policy issue by the end of the 1960s. For local communities the easiest solution was to require tall smokestacks that lofted the offending gases farther afield. In the 1970s acid rain became an international issue, as Canadians objected to the acidification of their lakes by (mainly) American power plant emissions, and Scandinavians discovered damage to their waterways attributable to British and German coal combustion. Poland and its neighbors, which used coal that was especially high in sulfur, splashed one another's landscapes with acid rain that occasionally reached the pH level of vinegar. Railway trains had to observe low speed limits in parts of Poland because the iron of the train tracks had weakened from acid corrosion. With the dramatic rise of coal use in China after 1980, transboundary acidification became a source of contention in East Asia too, as Koreans, Japanese, and Taiwanese felt the consequences of Chinese power plants and factories.

Beyond sensitive ecosystems, acid emissions also had modest effects on human health and major ones on buildings made of limestone or marble. Greek authorities found it advisable to put the most precious statuary of the Acropolis indoors to save it from corrosion by acid rain. In the Indian city of Agra, pollution from a nearby oil refinery, among other sources, threatened the marble of the Taj Mahal.[28]

Acidification, happily enough, turned out to be one of the easiest of environmental problems to address. In Europe and the United States, after some delay occasioned by the objections of coal utilities and their political allies, cap-and-trade schemes were devised that allowed polluters to choose their means of reducing emissions and to buy and sell permits to pollute. Beginning around 1990 this reduced sulfur emissions by 40 to 70 percent in short order, at a cost that turned out to be a small fraction of that anticipated. It takes a while for ecosystems to rebound from acidification, but in northern Europe and eastern North

America, by 2000 the recovery had begun to show. China, awash in acid rain, tried to address its sulfur emissions, but its heavy reliance on coal hamstrung the effort until 2006, after which date some reductions in sulfur emissions occurred. In northern China the consequences of acid rain were checked by the prevalence of alkaline dust (neutralizing acid), but in the south, soils and ecosystems proved as vulnerable as those of northern Europe and eastern North America.[29]

By and large, the rich world after 1970 achieved healthy reductions in its emissions of sulfur dioxide as well as other coal-based pollutants. Copenhagen, for example, reduced its SO_2 concentrations by 90 percent between 1970 and 2005.[30] London lowered its smoke and soot levels by 98 percent between the 1920s and 2005.[31] In 1950 the residents of Glasgow, Scotland, each inhaled about 1 kilogram of soot each year; by 2005 their lungs received almost none. In Japan, a polluter's paradise until the mid-1960s, even hotbeds of sulfur emissions such as the industrial city of Osaka managed to clear the air by 1990.[32] These remarkable changes in urban air pollution came about because of fuel switching (less coal, more oil and gas), deindustrialization, and new technologies made economically practical mainly by new regulations. In most cases, citizen agitation lay behind the new regulations. Germany shows the importance of citizen activism: In West Germany air pollution levels declined markedly from the 1960s onward; in East Germany, where the secret police provided citizens with good reason to keep their views to themselves, air pollution remained unchecked through to the end of the communist regime in 1989.

Fossil fuel combustion played a central role in another modification of the atmosphere, the relentless buildup of carbon dioxide. Here, in contrast to the story with sulfur dioxide, public policy to date has been ineffective. High-level international efforts, such as the negotiations at Kyoto (1997) and Copenhagen (2009), led to no significant reductions in carbon emissions. China's emissions alone after 1990 swamped what minor reductions could be achieved here and there around the world. The spectacular climb in fossil fuel use since 1950 is the main reason behind the parallel rise in atmospheric carbon.

The Strange Career of Nuclear Power

Unlike other forms of energy use, nuclear power has a birthday: December 2, 1942. On that day the Italian émigré physicist Enrico Fermi oversaw the first controlled nuclear reaction, in a repurposed squash court under the stands of a football stadium at the University of Chicago. The power of the bonds within atoms dwarfs that of other energy sources available to humankind. A fistful of uranium can generate more energy than a truckload of coal. This astonishing power was first used in bombs, thousands of which were built, and two of which were used, both by the United States and against Japan in August 1945, bringing the Second World War to a close.

Peaceful uses of atomic power soon followed. By 1954 the first reactor providing electricity for a grid, a tiny one near Moscow, opened. Much bigger ones started up in the United Kingdom and the United States in 1956–1957. In the middle of the 1950s the prospects for nuclear power seemed bright and endless. Scientists foresaw nuclear-powered visits to Mars. One American official predicted that electricity would soon be "too cheap to meter." In both the United States and the Soviet Union, visionaries imagined vast engineering uses for nuclear explosions, such as opening a new Panama Canal or smashing apart menacing hurricanes.[33] Nuclear technology enjoyed tremendous subsidies in many countries—not least a law in the United States that fixed a low maximum for lawsuits against nuclear utilities, allowing them to buy insurance, which otherwise no one would sell them. Between 1965 and 1980, the share of the world's electricity generated in nuclear power plants rose from less than 1 percent to 10 percent. By 2013 that figure approached 13 percent.

Countries with scientific and engineering resources but minimal fossil fuels converted most fully to nuclear power. By 2010 France, Lithuania, and Belgium relied on it for more than half their electricity; Japan and South Korea for about a quarter of theirs; and the United States for a fifth.

The rosy expectations for a nuclear future withered in the 1970s and 1980s due to well-publicized accidents. Civilian reactors had suffered dozens of accidents large and small in the 1950s and 1960s, the worst of them in the USSR. But they were kept as secret as possible. The 1979 accident at Three Mile Island in Pennsylvania attracted public scrutiny. It turned out to be minor, as nuclear accidents go, but came close to being much worse and was not hidden from view. It served to turn US public opinion away from nuclear power.[34] In the rest of the world the public at large took less notice, although the mishap invigorated antinuclear movements and watchdog groups in every country that had a nuclear industry. Their concerns about nuclear safety led to reforms, more stringent controls, and higher construction and operation costs. In March 1986 the British highbrow magazine *The Economist* opined, "The nuclear power industry remains as safe as a chocolate factory."[35]

Four weeks later, at Chernobyl in Ukraine (then in the USSR), a three-year-old reactor vessel exploded. The ensuing fire released a plume of radioactivity hundreds of times greater than those over Hiroshima and Nagasaki in Japan some forty-one years earlier. For days the Soviet government, led by Mikhail Gorbachev, tried to keep it secret and declined to warn local populations of the risks of venturing outdoors or drinking milk (one of the pathways of radioactivity goes from grass to cattle to milk). Radioactivity spread with the winds over Europe and eventually in small amounts over everyone in the Northern Hemisphere. Some 830,000 soldiers and workers ("Chernobyl liquidators") were dragooned into the cleanup effort; radiation poisoning quickly killed 28, another few dozen soon after, and in the course of time, many thousands more of these unfortunate liquidators died than actuarial tables would predict. Some 130,000 people were permanently resettled due to contamination of their homes, leaving a ghost zone that will host unsafe levels of radioactivity for at least two hundred more years. A few brave and stubborn souls still live there.

The Chernobyl Exclusion Zone has since become a de facto wildlife reserve teeming with wild boar, moose, deer, wolves, storks, and eagles, among other creatures. They roam in areas with radioactivity levels deemed unsafe for humans—because of the risks of predation and starvation, few wild animals live long enough to develop cancers. But from beetles to boars, all species show unusual rates of tumors, accelerated aging, and genetic mutations. Plant life in "the zone"—as locals call it—also shows high mutation rates. So do the tiny proportion of soil microorganisms so far studied. Because the average human body contains about 3 kilograms of bacteria, viruses, and microfungi, their modification by Chernobyl may prove to have interesting effects upon human beings. The zone became a curious biological contradiction in the wake of the catastrophe of 1986: abundant wildlife and resurgent vegetation, far more prolific than in surrounding precincts because free from quotidian human actions such as mowing, weeding, paving, and hunting—but at the same time less healthy than wildlife and vegetation elsewhere precisely because of the accident.[36]

The human health consequences of Chernobyl remain controversial. Cancer rates spiked in years after the disaster, especially thyroid cancers among children, leading to perhaps four thousand excess cases up to 2004. The toll could have been much lower without the government attempt to hush up the accident. This much is widely accepted. The full extent of Chernobyl's health consequences is much disputed.

Epidemiologists, often extrapolating from the experience of survivors of Hiroshima and Nagasaki, ventured many estimates of the likely mortality from Chernobyl. A conglomerate of UN bodies called the

Chernobyl Forum in 2006 estimated nine thousand deaths and two hundred thousand illnesses related to Chernobyl, totals its spokesmen found reassuring. These figures are at the low end of the spectrum of expert opinion. More recently, researchers from the Russian Academy of Sciences and Belarus Laboratory of Radiation Safety reported a welter of insidious effects. For example, they noted early aging and signs of senility among irradiated people, and spikes in the rates of Down syndrome, low-birthweight babies, and infant mortality all over Europe in the months after Chernobyl. In Ukraine by 1994 more than 90 percent of the Chernobyl liquidators were sick, as were 80 percent of the evacuees and 76 percent of the children of irradiated parents. So many people suffered weakened immune systems that health workers spoke of "Chernobyl AIDS." The most affected populations were those who received high doses of radiation because they lived near Chernobyl; the Chernobyl liquidators; and babies born in the months following April 1986—*in utero* was a very dangerous place to be that spring. Based on the elevated mortality rates in irradiated parts of the former Soviet Union, these researchers calculated that by 2004 Chernobyl had already killed some 212,000 people in Russia, Ukraine, and Belarus, and, they estimated, caused nearly one million deaths worldwide. These figures are toward the high end of the spectrum. But thanks to inherent difficulties in assessing causes of death and deliberate Soviet falsification of health records among Chernobyl liquidators, no one will ever know the true human cost of Chernobyl.[37]

Chernobyl came at the same time as a collapse in world oil prices. The ecological and economic logic of building nuclear power plants suddenly seemed less persuasive. The share of the world's electricity derived from nuclear power, which had been rising fast, leveled off for the next twenty years.

The chilling effect of Chernobyl on the nuclear industry lasted for decades, but not forever. In 1987 Italy had passed a referendum against nuclear power; in 2009 it revoked it. The ever-growing demand for electricity, especially in China, led authorities to build more nuclear power plants. As of 2010 about 440 were in operation around the world (in forty-four countries) and about 50 more were in the works, 20 of them in China, 10 in Russia, 5 in India. The fact that nuclear power contributes very little in the way of greenhouse gases made it popular with many people who took global warming seriously, despite concerns over safety, the dependence on government subsidies, and the as-yet unresolved problem of what to do with dangerous nuclear wastes. By 2010 the United States had accumulated about 62,000 tons of spent nuclear fuel and had nowhere to put it.[38] According to the US Environmental Protection Agency, after ten thousand years the problem would solve itself because the fuel would no longer pose a threat to human health. Despite arousing environmental anxieties and requiring subsidies to compete in the marketplace, nuclear power rose from the ashes of Chernobyl to become politically viable almost everywhere in the world by 2010.

Then came Fukushima.[39] In March 2011 a powerful earthquake, 9.0 on the Richter scale, launched a tsunami toward the northeastern coast of Japan. Towering waves—about 14 meters high—crashed ashore, killing about twenty thousand people and wreaking destruction on a scale likely to make it the most expensive natural disaster in world history.

The Fukushima Daiichi nuclear power plant, one of the world's biggest, had opened in 1971. It survived a 1978 earthquake. It was operated by the Tokyo Electric Power Company, known as TEPCO. But in 2011 the waves easily topped retaining walls built to withstand a tsunami less than half the height of this one. The six working reactors shut down, generators and batteries failed, and the plant lost all electric power, and thus the capacity to pump cold water over fuel rods—which generate heat even when a reactor is not functioning, due to the continuing decay of fission products. Fires and explosions followed. Three reactors melted down. TEPCO workers drowned the fuel rods in seawater, hoping to forestall the worst. The quantities of radiation leaked into the environment in the first month after the tsunami were about 10 percent of those from Chernobyl. Dozens of workers at Fukushima Daiichi absorbed heavy doses of radiation.

The government, which had initially sharply underestimated the severity of the disaster, eventually created an exclusion zone extending 20 kilometers from the plant. Some 350,000 people departed for safer ground. Just where that was initially seemed hard to specify. The government also officially determined that the water supply in Tokyo, some 200 kilometers south, was unsafe for infants due to radiation. Both TEPCO and the government came in for withering criticism in Japan for their unpreparedness and dishonesty.[40]

Small amounts of radiation floated around the Northern Hemisphere, tainting milk in North America and arousing anxieties everywhere. The German government announced a shutdown of some of its elderly reactors, and several countries announced reviews of their nuclear safety procedures. China, although closer to the catastrophe than most, kept up its record pace of nuclear power plant construction.

In Japan itself, sentiment surged away from support of nuclear power, and all fifty-four of the country's reactors were gathering dust within fourteen months after the disaster, although two have since returned to duty. Few local communities wished to host an active nuclear power plant. To make up for the resulting shortfall of electricity, Japan increased its fossil fuel imports by half, substantially raising its energy costs. Whether or not the tsunami at Fukushima's power plant will dampen enthusiasm for nuclear power for long remains to be seen.

The Contentious Career of Hydropower

In terms of output, hydroelectric power matched nuclear. In terms of controversy and tragedy, it trailed not far behind. People had used water power from ancient times for grinding grain, and for powering

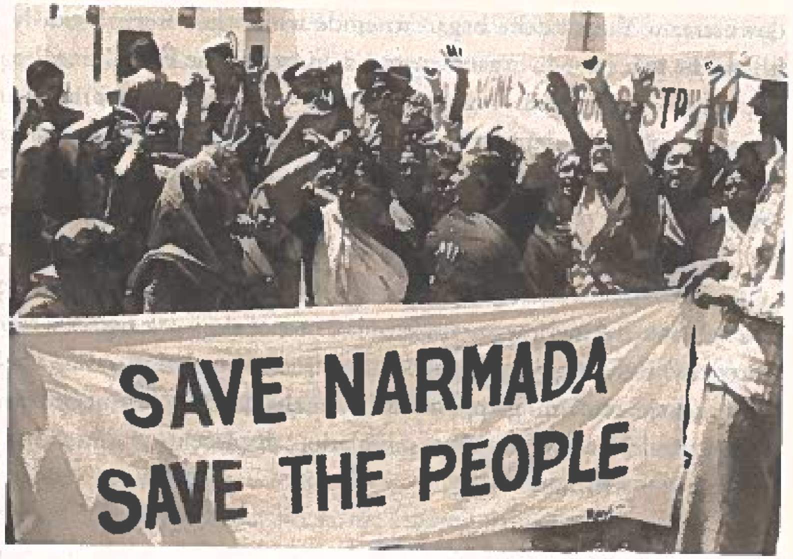
factories from the eighteenth century, but it was not until 1878 that water sent through turbines produced electricity. In Europe and North America, hundreds of small-scale hydroelectricity stations were built between 1890 and 1930. The United States—quickly followed by the USSR—pioneered giant hydroelectric stations in the 1930s. These behemoths became, like nuclear power plants, symbols of technological virtuosity and modernity. Jawaharlal Nehru, India's prime minister from 1947 to 1964, often called hydroelectric dams "the temples of modern India." The world went on a dam-building spree after 1945, peaking in the 1960s and 1970s, by which time most of the good sites in rich countries had been taken.

Hydropower offered great attractions. For the engineers, it held the advantage that it could deliver power at any time (except in the event of big droughts that starved reservoirs). The potential power, captive water, stayed put and available at no cost (except where evaporation rates were high, as in the case of Egypt's Aswan Dam reservoir, Lake Nasser). Moreover, reservoirs could serve multiple purposes, as sources of irrigation water, sites for recreation, or fisheries. For environmentalists, who often found big dams objectionable on many grounds, hydropower held the charm of releasing no greenhouse gases in operation. Dam construction was another matter, but even taking all phases into account, hydroelectricity was probably the best form of electricity generation from the climate-change point of view, and certainly far, far better than using fossil fuels.

Its drawbacks, however, were legion. Big dams could bring big accidents, as at the Banqiao Dam in China's Henan Province in 1975. During a typhoon the dam broke, unleashing a wave—an inland tsunami—that drowned tens of thousands. Subsequent starvation and waterborne epidemics killed another 145,000. Hundreds of other dams failed less catastrophically. More prosaically, dam reservoirs silted up, so that the useful life of a hydroelectric plant might be as little as ten or twenty years in some poorly designed cases, most of which were in China. Reservoirs also sometimes desecrated cherished landscapes, as when Brazil inundated a national park to cooperate with Paraguay on the Itaipu Dam, opened in 1982 on the Paraná River. Its power station is the world's second largest. Archeological treasures were obliterated by some reservoirs, notably the Aswan Dam in Egypt and Turkey's several dams on the Tigris and Euphrates in eastern Anatolia. "Salvage archeology" usually could rescue only a fraction of what disappeared beneath the rising waters.[41]

The most politically volatile aspect of dam building was the displacement of people. Reservoirs took up a lot of space—about twice the area of Italy in total. Some of the big ones, in Ghana or in Russia, are the size of Cyprus or Connecticut. Globally, some forty to eighty million people—twenty million in India alone—had to get out of the way for reservoirs, in rare cases fleeing for their lives without any advance warning.[42] In many cases ethnic minorities living in hilly districts with swift rivers were the ones relocated in the interests of electric power wanted elsewhere in their countries.[43]

In India, where dam building (for irrigation as well as electricity) formed a major part of the state's development plans after independence in 1947, peasant resistance to dams became a widespread movement by the 1980s. Resistance rarely deflected the state's ambitions, but in the case of dams along the Narmada River in western India, it led to huge protests, political tumult, and lengthy lawsuits. The Narmada scheme involved thousands of dams, large and small, on which construction began in 1978. Local resistance, occasioned mainly by displacements, grew more and more organized throughout the 1980s, and successfully reached out to international environmental organizations for support. In 1993–1994 the World Bank, a longtime proponent of dam building in India, withdrew its support. Foreign criticism stoked the fires of Indian nationalism. Indian novelists and actors got involved, both for and against additional dams. But India's Supreme Court stood by the government and the engineers, the work con-



Members of the Save Narmada Movement demonstrate against the US utility company Ogden Energy Group near the American Embassy in New Delhi, April 4, 2000. Hydroelectricity generated little pollution but typically required the construction of reservoirs that uprooted local people, as in the case of a string of dams on India's Narmada River. (Getty Images)

tinued, and so another hundred thousand or so Indians—"oustees" as they are known in India—moved to accommodate the Narmada's reservoirs.[44]

While Europe and North America had exhausted their best sites for hydroelectric development by 1980, the rest of the world continued to build dams apace. Half of the big dams built in the world after 1950 are in China. Between 1991 and 2009, China built what is by far the world's largest hydropower installation, the Three Gorges Dam on the Yangzi. Like the Narmada project, it too attracted environmental controversy, as roughly 1.3 million people had to make way for its reservoir. As the dam trapped most of the enormous silt load behind it, the

1970s solar appealed to many people due to the high oil prices. For remote places not connected to a power grid, solar panels proved very practical. After several slow years, resulting mainly from the oil price collapse of 1985–1986, investment in solar power surged ahead again after 2000. European countries that provided subsidies played a large role, notably Germany. The biggest single solar energy projects under construction in 2015, however, were in China, where western regions such as Xinjiang and Tibet have plenty of sunshine but are a long way from China's coal.[46]

Worldwide, wind and solar power together in 2015 accounted for less than 4 percent of electricity consumption, despite their recent exponential growth. Unlike fossil fuels, they are hard to store. They may be the best hope for cutting greenhouse gas emissions, but they have a very long way to go to challenge fossil fuels—especially in the transport sector, where oil's advantages are strong.

Indirect Effects of Abundant Energy

The fossil fuel energy path brought profound consequences for the world's air, water, and soil, as well as for human health. Beyond all that, the mere fact of cheap energy (cheap by the standards of the past) led to all manner of environmental change. Cheap energy, and the machines that used it, remade timber cutting and farming, among other industries. By and large, cheap energy expanded the scope of what was economically rewarding, thereby extending the scale or intensity of these energy-guzzling activities.

Consider timber harvesting. The surge of deforestation around the world since 1960, especially in moist tropical forests, is one of the great environmental transformations of modern history. Cheap oil enabled it. Had loggers used axes and handsaws, had they transported logs only by animal muscle and via waterways, they would have deforested far less than they did. Loggers with gasoline-powered chain saws be-

came one hundred to one thousand times as efficient at cutting trees than men with axes and crosscut saws. From the 1990s, huge diesel-powered machines that look like "insects from another planet" snipped off tree trunks at the base, allowing timber cutting with no human feet on the forest floor.[47]

Oil transformed agriculture even more fundamentally. In the 1980s one person with a big tractor and a full tank of fuel in the North American prairies could plow 110 acres (50 hectares) in a day, doing the work that seventy years before had required 55 men and 110 horses. Mechanization of this sort emptied the farmlands of North America and Europe of horses and people. In 1920 the United States had devoted nearly a quarter of its sown acreage to oats for horses; in 1990, almost none. Tractors transformed agriculture in parts of Asia too, where there are now more than five million tractors (Africa has perhaps two hundred thousand).[48]

Mechanization is only the most obvious change cheap energy brought in agriculture. The enormous use of nitrogenous fertilizers also depended on cheap energy. About 5 percent of the world's natural gas is devoted to fertilizer production. Many pesticides used oil as their chemical feedstock. Irrigation, too, especially when it involved pumping water up from aquifers, relied on cheap energy. All these practices of modern farming had profound ecological effects, and all of them needed cheap energy.

Cheap energy transformed the scale, intensity, and environmental implications of several other arenas of human interaction with nature, including mining, fishing, urban design, and tourism. Without cheap energy, it would not be practical for machines to grind through tons of Australian hillscapes in search of a few grams of gold. Nor would trawlers be able to scrape the seafloor with nets several miles across. Nor would cities such as Toronto and Sydney have sprawled over landscapes to the extent they have, gobbling up forests and farmland. Nor would millions of North Americans routinely fly to places such as Cozumel, or

Europeans to the Seychelles, or Japanese to Saipan or Guam—all of which in the past forty years were transformed, environmentally as well as economically and socially, by mass tourism. In these and dozens of other cases, the cheap energy involved usually came from fossil fuels, but had it come cheaply from any source, the outcome for mountains, fish, forests, farmland, and beachfronts would have been much the same. The indirect effects of energy upon the environment resulted from the massive deployment of energy, from its abundance and low cost, not from any specific attributes of the energy source.[49]

Although one cannot hope to disentangle all the forces and processes that shaped the Anthropocene, from almost any viewpoint energy seems to be at the heart of the new epoch. The quantities of energy in use after 1945 became so vast, they dwarfed all that went before. The specific qualities of fossil fuels, of nuclear energy, and of hydroelectricity etched themselves into the biosphere through pollution, radiation, reservoirs, and so forth. Cheap energy gave people new leverage with which to accomplish things, move fast and far, make money, and, if inadvertently and often unknowingly, alter the environment. Almost everyone who could take advantage of cheap energy did so.

The Population Bomb

The demographic history of humankind in the years after 1945 was unlike anything that came before. The increase in human numbers impressed contemporary observers from the late 1940s onward. Most of those who paid attention to the question decried population growth—sometimes, but by no means always, on environmental grounds. Perhaps the classic statement of population anxiety came from Paul Ehrlich, a Stanford University biologist who popularized the term *population bomb* in a book of that title published in 1968. Ehrlich was wrong in many of his predictions, but he was right that the human animal was then in the middle of a population explosion, by far the biggest in its long history.

The Second World War brought early death to about sixty million people. During the war, the world contained well over two billion people, and each year some sixty to seventy million babies were born. In China, Japan, the USSR, Poland, Germany, Yugoslavia, and a few other countries, wartime mortality, and suppressed fertility, did leave a sharp imprint on demography. But in global terms all this death was swamped by a rising tide of births.

Still, the war had some delayed demographic effects. Its end triggered baby booms in several parts of the world. More importantly, medical and public health techniques and procedures, learned or refined during the war, helped launch a boom in survival, especially among infants and children. War's exigencies had legitimated massive public health interventions and taught administrators and health professionals how to deliver vaccines, antibiotics, and sanitation to the masses at modest cost, even in difficult conditions. So after 1945 human demography entered upon the most distinctive period in its two-hundred-thousand-year history. In the span of one human lifetime, 1945 to 2015, global population tripled from about 2.3 billion to 7.2 billion. This bizarre interlude, with sustained population growth of more than 1 percent per annum, is of course what almost everyone on Earth now regards as normal. It is anything but normal.

The first billion was the hardest. It took our species many thousands of years, including a brush or two with extinction, to become one billion strong. That came around 1800 or 1820. By 1930 the human population had doubled to two billion. It took only another thirty years, until 1960, to add the third billion. Then the crescendo came. The fourth billion arrived in 1975, joined by another by 1987, and then another by 1999. By 2011 or 2012 the world counted seven billion people, and had been adding a billion every twelve to fifteen years for two human generations. Between 1945 and 2015, some two-thirds of the population growth in the history of our species took place within one human lifetime. Nothing like this had ever happened before in the history of humankind.

TABLE 3

Global population increase per year, 1950–2015 (in millions)

Period	Population increase per year
1950–1955	47
1955–1960	53
1960–1965	61
1965–1970	72
1970–1975	76
1975–1980	76
1980–1985	83
1985–1990	91
1990–1995	84
1995–2000	77
2000–2005	77
2005–2010	80
2010–2015	82

Data source: UN Population Division.

One way to look at this extraordinary burst of population growth is to consider the absolute increase in the number of people per year, the annual increment or the net of births minus deaths. From 1920 to 1945 the globe had added, on average, a little over twenty million people every year. By 1950 the annual increment approached fifty million, after which it surged to about seventy-five million by the early 1970s, stabilized briefly, then in the late 1980s reached what is likely to be its all-time maximum at about eighty-nine million per year—equivalent to adding a new Germany or Vietnam (at their 2010 populations) every twelve months. Table 3 summarizes this record from 1950 to 2015.

A further way to look at the great surge in population is to focus on growth rates. For most of human history, growth rates were infinitesimal. By one careful estimate, for the seventeen centuries before 1650, annual growth came to about 0.05 percent per annum. In the

TABLE 4

Global population growth rate, 1950–2015

Period	Population growth rate (%)
1950–1955	1.79
1955–1960	1.83
1960–1965	1.91
1965–1970	2.07
1970–1975	1.96
1975–1980	1.78
1980–1985	1.78
1985–1990	1.80
1990–1995	1.52
1995–2000	1.30
2000–2005	1.22
2005–2010	1.20
2010–2015	1.15

Data source: UN Population Division.

nineteenth century, growth attained a rate of about 0.5 percent per annum, and in the first half of the twentieth, about 0.6 percent.[50] A great spike followed the Second World War (summarized in Table 4). Growth reached its apex about 1970, at some 2 percent per year. Then the rate of growth declined again, very fast after 1990, so that by 2015 it came to 1.15 percent per year. What the future holds is anyone's guess, but UN demographers project that the growth rate by 2050 will slacken to 0.34 percent, slower than in 1800. In any case, the era from 1950 to 1990, when global growth exceeded 1.75 percent per year, amounted to a burst of reproduction and survival, never before approached and never to be repeated in the history of our species. If we did somehow keep it up for another few centuries, the Earth would soon be hidden inside a giant ball of human flesh expanding outward at a radial velocity approaching the speed of light—an unlikely prospect.[51]

So we are in the waning stages of the most anomalous episode in human demographic history. The main reason (there are several others) for the steep fall in fertility is essentially environmental: urbanization. City people almost always prefer to have fewer children than their country cousins. As the world has urbanized at a dizzying pace, our fertility rates have slipped.

Nonetheless, our recent biological success is remarkable. As of 2015 we outnumbered any other large mammal on Earth by a large margin. Indeed, our total biomass (about 100 million tons) outweighed that of any mammalian rival except cattle, of which there were about 1.3 billion, weighing in at 156 million tons. Humans (whose average body size increased by half between 1800 and 2000)[52] now account for perhaps 5 percent of terrestrial animal biomass, half as much as all domestic animals combined. Ants, however, easily outweigh us.

Why did this bizarre episode in our demographic history happen? On the most basic level, it happened because the global death rate fell rapidly, from about 30 to 35 per thousand per year in 1800 to about 20 per thousand in 1945, before plummeting to 10 by the early 1980s. It now stands at 8.1. The birth rate fell also, but more gradually. Globally the crude birth rate slid from 37 per thousand in 1950 to 20 per thousand in 2015, a notable fall, but less so than the precipitous decline in the death rate.

On a less elementary level, what happened was that techniques of death control temporarily outstripped techniques of birth control. In the course of the eighteenth century in some parts of the world, notably China and Western Europe, better farming techniques, improved government response to food shortage, combined with gradual buildup of disease resistance, slowed death rates. In the nineteenth century, these processes continued and were joined by revolutionary changes in urban sanitation, mainly the provision of clean drinking water, and in the early twentieth century by vaccinations and antibiotics as well. States (and colonial administrations) created public

health agencies that sought to impose vaccination and sanitation regimes wherever they could. Medical research also identified several disease vectors—lice, ticks, and mosquitoes, for instance—and in some cases proceeded to find ways to keep vectors and people apart. Successful mosquito control sharply curtailed the domain of diseases such as yellow fever and malaria. Moreover, food scientists in the 1920s and 1930s figured out the role of specific vitamins and minerals in checking malnutrition diseases, and agronomists figured out how to help farmers double and triple crop yields per acre.[53]

After 1945 all of these developments came together to lower death tolls very quickly in most parts of the world—hence, a tremendous surge in life expectancy, derived mainly from the survival of billions of children who in earlier times would have died very young. In the second half of the twentieth century, even poor people lived far longer (on average, about twenty years longer) than their forebears had a century previously. The gaps between rich and poor in life expectancy narrowed almost to nothing.[54]

This rollback of death was a signal achievement of the human species and one of the greatest social changes of modern times. The end of the twentieth century brought two exceptions that proved the rule. First, in Russia, Ukraine, and some of their smaller neighbors, life expectancy (which in the Soviet Union had lengthened rapidly between 1946 and 1965) declined after 1975, at least for males. This departure from the prevailing trend is usually attributed to alcoholism. Second, after 1990 in the most AIDS-ravaged parts of Africa, a parallel reverse of lengthening life expectancy occurred. These two exceptions had only a slender effect on the overall pattern of longer life and faster population growth. It was a pattern that provoked considerable worry, partly on environmental grounds.

Attempts to Curb Population

Even long ago some people worried about overpopulation. Around 500 BCE, the Chinese sage Han Feizi fretted, "Nowadays no one regards five sons as a large number, and these five sons in turn have five sons each, so that before the grandfather has died, he has twenty-five grandchildren. Hence the number of people increases, goods grow scarce, and men have to struggle and slave for a meager living."[55] The Latin author Tertullian (a North African and early Christian apologist) wrote around 200 CE: "The earth itself is currently more cultivated and developed than in early times. . . . Everywhere there is a dwelling, everywhere a multitude. . . . The greatest evidence of the large numbers of people: we are burdensome to the world, the resources are scarcely adequate to us . . . already nature does not sustain us."[56] For many centuries occasional voices repeated these concerns, and in 1798 Hong Liangji and Thomas Malthus each published essays giving a plausible theoretical underpinning to notions of overpopulation.[57]

Modern versions of these ancient anxieties gained currency in the 1940s, giving rise to sustained efforts to check population growth. For most of human history, when rulers concerned themselves with population in their domains, their aim was to maximize the number of their subjects in the interests of military strength. With the rise of social Darwinism after the 1870s, some thinkers developed doctrines of eugenics, in essence arguments that other (and "lesser") people should reproduce less. But after World War II, a chorus of voices arose warning of excess population, of impending mass starvation, of violent social unrest, and in some cases of environmental degradation—and their views attracted interest in the corridors of power.

These voices, the most prominent of which came from Europe and America, urged population limitation mainly upon the rest of the world, above all upon Asia. The motives involved were decidedly mixed,

TABLE 5
Crude birth rates (number of births per 1,000 people per year), India and China

Year(s)	India	China
1950–1955	43	44
1970–1975	37	29
1990–1995	31	19
2010–2015	21	13

Data source: UN Population Division (http://esa.un.org/unpp/p2kodata.asp).

but in any case, in several Asian countries the same goal made sense to people coming into power as colonial rule gave way.

India, for example, an independent nation after 1947, by 1952 undertook to limit its own population. In the 1970s India even put a birth rate target in its economic five-year plan and tried to mandate sterilization for people who already had three children. This last measure encountered robust resistance, provoking violent incidents and contributing to the downfall of Indira Gandhi's government in 1977. Fertility reduction in India (see Table 5) happened much more slowly than its backers wished.[58]

In China, sterner measures brought stronger results. The People's Republic of China, born in revolution and civil war in 1949, traveled a meandering road to birth control. For millennia Chinese emperors had favored high fertility, and later Chinese nationalists such as Sun Yat-sen and Chiang Kai-shek were equally pro-natalist. At the time of the revolution, Mao Zedong agreed, feeling, as most Marxists did, that birth control would be unnecessary in communist society because communes would unleash productive forces hitherto constrained by capitalism, yielding a cornucopia of food. Soon after, he also judged that World War III was imminent and reasoned that China would need all the people it could get. In 1958 the Communist Party's second in command, Liu Shaoqi, looked forward to the day when China might have six billion people, but allowed that in this rosy future everyone would have to share beds. Others among Mao's lieutenants saw matters differently, thinking that further growth of China's huge population imperiled the economy, and after the horrendous famine of the Great Leap Forward of 1959–1961 their views acquired greater weight. But the Cultural Revolution (1966–1976), a violent political movement that plunged China into administrative and economic chaos, prevented any effective policy. In 1970 China began to encourage birth control by distributing free contraceptives. In the course of the 1970s, engineers trained in cybernetics (rocket guidance systems in particular), influenced by dour ecological forecasts of the Club of Rome, worked out the scientific rationale for drastic reductions in fertility. Through personal connections with party leaders, their views gradually prevailed, first in a series of carrots and sticks devised to encourage small families, and in 1979 in the "one-child policy." This gave party cadres great power to determine who would be allowed to have children in any given year, and imposed stiff penalties (loss of job, loss of apartment, loss of educational opportunities) on couples who did not follow instructions. Urban couples by and large fell into line; villagers sometimes did not and eventually were permitted greater leeway. The policy made exceptions for ethnic minorities, who likely would have resisted it strenuously. In China, extended families and heads of lineages had long exercised influence over when couples might have a child. This tradition made the concept of state-regulated fertility easier for Chinese to accept than it was for Indians. With these measures, among the most forceful efforts at social engineering anywhere in modern history, China reduced its annual population growth from about 2.6 percent in the late 1960s to 0.4 percent by 2015. The success of its population policy assisted China's economic miracle.[59]

A billboard promoting China's "One Child Policy," Chengdu, 1985. Implemented in 1979 by Chinese leaders fearful about overpopulation, China's program is the largest-scale effort in world history to restrict demographic growth. The policy has had many critics, but without it the world would have several hundred million more human inhabitants. (LightRocket/Getty Images)

Other East and Southeast Asian societies, notably South Korea, Singapore, and Malaysia, introduced less-draconian population limitation policies in the 1970s and 1980s, and also saw their demographic growth rates decline precipitously. This has probably helped them become much richer on a per capita basis than they otherwise would be, a matter of some consequence for their environmental history. They were swimming with the tide: Fertility declines happened almost everywhere in the post-1970 world, with or without state policies. They happened fastest in East Asia, and fastest of all in China, where unquestionably state policy played a large role.

By the 1980s the great majority of countries around the world had some sort of population policy. In Europe it usually consisted of ineffective measures to raise fertility. In most of the rest of the world, it consisted of measures, sometimes in vain, sometimes powerful, to defuse the population bomb by lowering fertility. Without these policies the world would likely have several hundred million more people, many of them Chinese.

Population and Environment

At first glance it stands to reason that population growth, especially at the rampant pace of 1945–2015, is disruptive to the environment. This has been an axiom in most strands of modern environmentalism. Its logic is straightforward: more people mean more human activity, and human activity disturbs the biosphere. As a first approximation this is true. But it turns out that it is not true always and everywhere. When and where it is true, the degree to which it is true is extremely variable. The main reason for this is that the notion of "environment" is capacious, so what may be true for soil erosion may not hold for air pollution. For example, population growth probably had a great deal to do with the clearing of West African forests since 1950 but almost nothing at all to do with nuclear contamination at the Soviet atomic weapons sites.

Population growth played its strongest role in the environment through processes connected to food production. The threefold growth in human population (1945–2010) required a proportionate expansion in food production. But even here the matter is not straightforward. Soils provide a fine example. Without a doubt, population growth pushed upward the demand for food, and also the demand for agricultural land. In China, for example, growing population and food requirements helped inspire a state-sponsored push onto the grasslands of the north, converting steppe pasture into grain fields. Frontier expansion had a long tradition in Chinese history, but rarely did it proceed at the pace achieved in the decades after 1950.[60] As is often the

case when year-round grass is replaced by annual crops, the Chinese surge onto the steppe led to heightened rates of soil erosion, desertification, and downwind dust storms. Population pressure also helped push farmers onto semi-arid lands in the West and Central African Sahel (the southern fringe of the Sahara), a strategy that worked well enough in the 1960s, when rains in the region were plentiful, but turned disastrous in the 1970s when rains failed.

Population pressures also played a role in driving people to cut and burn tropical forest in search of new farmland. In Guatemala, Côte d'Ivoire, Papua New Guinea, and a hundred places in between, frontier farming edged into old forests. The effects on soils were often profound and enduring. Wherever the farmers cleared sloping land, they invited spates of soil erosion, not via the wind as on the world's grasslands, but via running water. Moreover, in many settings soils with high concentrations of iron oxides quickly turned to laterite, a brick-hard surface, when exposed directly to strong sunshine. Tropical deforestation, with its attendant effects upon soils, was not always mainly a matter of population pressure. Indeed, in Latin America and Southeast Asia, quests for ranch land and timber played a larger role. But everywhere, especially in Africa, population was part of the equation.

In a few places matters worked out very differently, because population growth actually helped to stabilize landscapes. Where farmers had carved new fields out of sloping lands, they put soils at high risk to erosion. But where there was enough labor, farmers could secure their soils by cutting terraces into the hillsides. In the Machakos Hills district of Kenya's highlands, for example, rapid population growth provided the labor power for the Akamba people to build and maintain terraces and thereby reduce erosion from their fields and plots. (The soil conservation service of Kenya helped out too.) Agricultural terraces, ancient and modern, are widespread around the world, especially in the Andes, the Mediterranean hills, the Himalayas, and East and Southeast Asia. In these settings, high population densities could keep fossil fuel use (about three-quarters) and the burning of forests (one-quarter). Population growth no doubt increased demand for fossil fuels and helped drive the encroachment on the world's forests. So to some degree, population growth has led to growth in carbon emissions. But how much?

As we will see later in more detail, carbon dioxide concentrations in the atmosphere climbed after the Industrial Revolution. By 1945 they stood at about 310 parts per million, and in 2014 surpassed 400. In that span, carbon emissions (not concentrations) increased about eightfold. So at a first approximation, given the tripling of population in the same time period, one might suppose that population growth is responsible for about three-eighths, or 37.5 percent, of the accumulation of carbon dioxide.

But that can stand only as a first approximation. Afghanistan, which showed high population growth, emitted very little carbon, less than 2 percent of the United Kingdom's total. The carbon consequences of population growth depended heavily on where it happened. Not only did an additional person in the UK lead to more carbon emissions than the addition of a person in Afghanistan, but there was a difference between an Afghan in Kabul (more likely to use more fossil fuel) and one in a remote village. And when population growth happened mattered too. In the rich countries after 1980, programs of energy efficiency, fuel switching away from carbon-rich coal, deindustrialization, and other developments meant that the impact of each additional person was less than it had been in the 1950s. For the years 1975–1996, one mathematically inclined scholar found that population growth was a major force behind carbon emissions, but, interestingly, least so in both the very poor and the very rich countries. The sad truth is that there is no reliable way to calculate the impact of population growth upon carbon emissions over time.[67]

Sometimes Population Did Not Matter at All

While the important case of carbon emissions is an elusive one, it is easy to find examples of environmental change in which one can confidently say population growth scarcely mattered at all. Whaling, which in the years after 1945 brought several whales—blue, grey, humpback, for example—to the brink of extinction, bore only the smallest relationship to population. The great whaling nations—Norway, Iceland, Japan, the USSR—had slow population growth rates, and their whalers were responding to long-standing cultural preferences for whale meat rather than seeking more food due to population growth.

The corrosion of the stratospheric ozone layer, which occurred almost entirely after 1945, also had virtually nothing to do with population growth. The chemical releases that destroyed stratospheric ozone, mainly chlorofluorocarbons (CFCs), were used chiefly as insulation, refrigerants, aerosol propellants, and solvents. Very little in the way of CFC releases occurred where population growth was high. The only ozone-destroying substance used in agriculture, a pesticide called methyl bromide, was used mainly in places such as California for high-end crops such as strawberries and almonds, demand for which had everything to do with elevated tastes and improved shipping capabilities and almost nothing to do with population growth.

To take a final example, environmental disasters, frequent enough in the decades after 1945, had no discernible relationship to population growth. The great industrial accident near Seveso in 1976, which splattered dioxin over the countryside north of Milan, occurred in a region of extremely low population growth. In the worst industrial accident in history, in 1984, a Union Carbide chemical plant spewed 40 tons of lethal methyl isocyanate onto Bhopal, a city of one million in central India, killing several thousand people and sickening many more. It too had nothing to do with population growth.[68] The Chernobyl catastrophe occurred in 1986. The reactor existed to provide electricity; the accident occurred because of design flaws and human error. In the 1980s population growth in Ukraine was negligible.

Migration and Environment

Like population growth, migration had variable impacts upon the environment. The largest migration after 1945 was the stampede of villagers to cities, with myriad environmental effects. Migration from one city to another had much smaller effects, except in cases where new cities bloomed in formerly sparsely inhabited places. Migration from one rural area to another, however, often triggered profound environmental changes.

The decades after 1945 were an age of migration. Tens of millions moved from one country to another.[69] Even more moved within their countries, although often to very new environments. Millions of Americans moved from the "Rust Belt" to the "Sun Belt," to Florida, Texas, and California in particular. San Antonio, which had a quarter million inhabitants in 1940, by 2010 had nearly 1.5 million and had become the seventh largest city in the United States.[70] Cities such as Phoenix and Las Vegas grew from almost nothing into major metropolises, sprawling into surrounding deserts and siphoning off all available water for many miles around. Residents air-conditioned their homes and workplaces for most months of the year, leading electricity-intensive lives that encouraged additional fossil fuel use and the building of more hydroelectric dams, especially on the already overdrawn Colorado River.

A smaller, Chinese sunbelt migration took place into the even drier regions of Xinjiang and Tibet after 1950. Government policy had more to do with it than air conditioning. Millions of Chinese went to Xinjiang in northwest China, an autonomous region consisting of a string of oases thinly populated with ethnic minorities. Many of the migrants were compelled to go, especially during the Cultural Revolution

(1966–1976). In Xinjiang, ethnic Chinese are now probably a majority, despite having a much lower birth rate than the Uighurs and other local populations. These migrations led to cultural and ethnic frictions, but also to new environmental stresses such as water and fuelwood shortages and desertification. Increased water demand, partly due to the influx of migrants, has reduced Xinjiang's lake area by half since 1950.[71]

In Mao's time, few Chinese moved to Tibet, the elevated plateau region bordering on the Himalayas that was incorporated into China in the 1950s. But in the 1980s and 1990s several hundred thousand went, often as laborers on road and railway projects. Since the 1980s the government has encouraged Chinese migration. According to the official census, ethnic Chinese made up 6 percent of Tibet's population in 1953 and slightly more by 2000. But unofficial estimates suggest Han Chinese now outnumber Tibetans in Tibet—if one counts their actual rather than official residence. Unlike in Xinjiang, the migrants flocked mainly to the cities of Tibet, but also to mining enclaves and labor camps around construction projects. The delicate high-altitude ecosystems of Tibet are easily disrupted, and wetlands, grasslands, wildlife, and air quality all suffered from the population expansion and development projects. In recent years the government has tried to check the environmental disturbance caused by railroads, by, for example, building overpasses for migratory wildlife. It has also tried to settle Tibetan nomadic herders into villages in the name of ecological stability, on the grounds that Tibetans and their herds were degrading grasslands.[72]

Migrants altered rainforests in Brazil and Indonesia at least as much as they did arid lands in the United States and China. Again, state policies played crucial roles. Many states, including Brazil and Indonesia, often encouraged and subsidized migration. Moreover, states obliged or encouraged migrants to engage in certain activities that just so happened to carry powerful environmental consequences.

For centuries, outsiders had seen in Amazonia—nine times the size of Texas and nearly twice the area of India—a sprawling storehouse of riches and resources, awaiting development. A rubber boom (ca. 1880–1913) gave tantalizing evidence of the wealth one might tap. But even businessmen with the savvy and resources of Henry Ford failed in their quests to convert Amazonian nature into money. Ford tried to build an empire of rubber plantations, called Fordlandia, beginning in the mid-1920s, but fell afoul of his own delusions and uncooperative local conditions, especially a rubber-tree fungus. When Ford's grandson sold off the ruins of Fordlandia in 1945, Amazonia had only about thirty thousand people in it.[73]

In the 1950s and early 1960s, the Brazilian government undertook another development scheme for the two-thirds of Amazonia that falls within Brazil. It was, as the saying went, a land without men for men without land. The government—a military regime from 1964 to 1985—intended to relieve poverty (and deflate the recurrent pressures for land reform) in the dry northeast of Brazil. It also wished to populate the country's border regions with loyal Brazilians, and to mobilize the presumed natural wealth of the world's largest moist tropical forest. Thousands of miles of highways soon pierced the forest, and millions of migrants flowed into the region. They cut and burned patches of forest, mainly in order to run cattle on the newly cleared land. Parts of Amazonia increasingly became a land without trees for men with cattle. Soils in most of the region are low in nutrients, so ranchers usually found that after a few years they needed to move on, to cut and burn more forest to keep their cattle in pasture. Soybean farmers, increasingly prominent since the 1990s, found the same conditions. By 2010 about 15 to 20 percent of the forest area of 1970 had been cleared for grass or crops, but the rate of forest clearance had dropped sharply. The issue of Amazonian deforestation had become a perennial one in Brazilian politics and in global environmental politics as well.[74]

A section of rainforest in the Amazon Basin, Brazil, clear-cut for transformation into farmland, 2009. Forested area in Amazonia shrank by about 15–20 percent from 1965 to 2012. (© Ton Koene/Visuals Unlimited/Corbis)

Indonesia became an independent, if rickety, country in 1949. Most of the population, and all of the leadership, lived on the fertile volcanic island of Java. Most of the other islands had poorer soils and scant population, usually of minorities with no love for Javanese rule. Building on a small program pursued by their former colonial masters, the Dutch, the rulers of independent Indonesia launched the so-called transmigration scheme in 1949. Military men (like their counterparts in Brazil), they hoped that some fifty million politically reliable Javanese would resettle on the other islands, notably Borneo and Sumatra. The plan was to relieve population pressure and poverty on Java, harvest the natural resources of the outer islands, and swamp the local populations with durably loyal Javanese.

By 1990, when the transmigration program had wound down, something under five million Javanese migrants had taken the lure of free land on the outer islands. They found their rice-farming skills did not yield encouraging results on the poor soils of Sumatra and Borneo, and until 1984 the government decreed that they should raise only rice. Like ranchers in Amazonia, they had to move to new land frequently, burning as they went, in order to gain access to the nutrients stored in the ash of former forests. Coming from a thoroughly deforested island, the Javanese often found it comforting to eliminate what felt like an alien habitat. Their efforts added to the pace of deforestation in Indonesia, which from 1970 to 2000 was one of the world's most active frontiers of forest destruction.[75]

These great migrations, and others like them, led to environmental changes of considerable magnitude. The changes were mainly local and regional in scope, although deforestation anywhere added appreciably to the carbon dioxide loading of the entire atmosphere. Despite their limited scope, the environmental changes provoked by migration were often thorough and of much more consequence, where they occurred, than greenhouse gas accumulation or climate change—at least up to the present.

Migration also contributed to heating up the global greenhouse through the relocation of people to places where they could lead much more energy-intensive lives. Tens of millions left Central America or the Caribbean for the United States and Canada, or North Africa for Western Europe, or South Asia for the Persian Gulf. To the extent that they succeeded in adopting the lifestyles of their new homes—driving cars, heating and cooling their dwellings with fossil fuels—their migration added to global energy consumption and thereby to greenhouse gas accumulation and the warming of the planet.

The period 1945–2015 witnessed a great crescendo in the human population history of the world. No period of similar duration—one human lifetime—was anywhere near as peculiar as this one. If population growth ever mattered for environmental change, it surely should have done so in these decades.

And it did matter. But not always and everywhere, and not necessarily in clear and obvious ways. For some forms of environmental change, such as West African deforestation, population growth played a leading role. For others, such as whaling, it played only a small role at most. As is normal in human affairs, population growth was never the sole cause of anything, but always operated in concert with other factors.

The same was true of migration. The decades after 1945 saw an upturn in rates of long-distance migration. This too brought environmental consequences, especially in those cases where people went from one sort of environment to a very different and unfamiliar one. Their accustomed ways of doing things, whether growing rice or raising cattle, often carried unforeseen and dramatic environmental consequences in their new homes.

For more than fifty years now, environmentalists have anxiously pointed to population growth as a major cause behind environmental change. That claim has often been justified, but it falls well short of a universal truth. By unpacking the concept of "environment" into specific biomes and processes, one can get a little further than this blanket proposition. In fifty more years, if the demographers are right and population growth has slowed to zero or close to it, we shall have a firmer idea of its significance for environmental change, both in general and for the exuberant age of 1945–2015. Let us hope that no gigantic ecological catastrophe intervenes to complicate the analysis.

Conclusion

The Earth is now in a new epoch, the Anthropocene. Human history, likewise, may be in a new period, the Anthropocene, but that is less clear. The reason it is less clear is that the periodization of history is an anarchic business with no set criteria. Global history, in particular, has no consensus scheme of periodization, nor is agreement likely anytime soon. Moreover, in this one respect, the future will shape the past. If, on the one hand, turbulence in global ecology should prove disruptive to human affairs, then the Anthropocene will seem like a period in human history as well as an epoch in Earth history. If, on the other hand, humankind should find ways to pursue its customary routines despite a more turbulent climate and biosphere, then the Anthropocene will seem less like a historical period—even if it seems worthy of recognition as an epoch in Earth history. So, just as the past constrains the future, the future will constrain what we make of the past.

Our best guess is that the Anthropocene, in the fullness of time, will seem worthy both as an epoch in Earth history and as a period in human history, even if geologists and historians understand the term differently. Whether geologists will formally adopt the term Anthropocene will be decided by vote in the International Union of the Geological Sciences, probably in 2016 or soon thereafter. Whether historians will one day find the term and concept appropriate as a period in human history in general will take far longer to decide. However these professional communities decide, we maintain that the Anthropocene in global environmental history has already begun.

As we see it, the Anthropocene began when human actions became the main driving forces behind some basic Earth systems, such as the carbon cycle and the nitrogen cycle, and the general human impact on the Earth and its biosphere lurched upward to new levels. While it is futile to try to pinpoint this moment precisely, the weight of the evidence points toward a date in the middle of the twentieth century, something like 1945 or 1950.

Of course, people affected the environment before 1945. Hominins did so, with fire, before humans existed. Humans did so in the Pleistocene by helping to drive hundreds of species of large mammals to extinction. They did so in the mid-Holocene by clearing forests for farming. Although we do not do so, it is possible to define the Anthropocene so that it begins with any of these activities.

But to our way of thinking, it makes more sense to consider the Anthropocene as launched only by the Great Acceleration of the post-1945 period. Nearly every page of this book contributes to the proposition that the post-1945 period deserves to be marked off as different from what came before in environmental history. The first reason for that conclusion is that only after 1945 did human actions become genuine driving forces behind crucial Earth systems. Our carbon contribution pushed the CO_2 concentration of the atmosphere outside the boundaries of the Holocene–indeed, pushed it to heights not seen in the past 870,000 years, which is as far back as ice core evidence goes. (But 400+ parts per million *probably* is novel for at least the past three million years, since the Pliocene.) We revolutionized the nitrogen cycle, so that it operates in a way unprecedented in the history of our planet (and half the nitrogen in our bodies comes from the Haber-Bosch process). The second reason is that after 1945 the human impact on the biosphere and global ecology ramped up, as shown by the evidence on dam building, city growth, biodiversity loss, ocean acidification, the accumulation of plastic debris, and so on.

Thus, to date, the Anthropocene and the Great Acceleration coincide. But they will not for long. The Anthropocene will last long into the future, barring some calamity that removes humankind from the scene. Indeed, even if every human immigrated to another planet

tomorrow, our impacts of the past few generations will linger for millennia in the Earth's crust, in the fossil record, and in climate. But the Great Acceleration will not last long. It need not and it cannot. The burst in human population growth is already coming to an end. And, less clearly but no less surely, the age of fossil fuels will come to an end. These trends should be sufficient to decelerate the Great Acceleration and moderate the human impact on the Earth. That will not end the Anthropocene but will bring it to another stage.

So far humankind has influenced basic Earth systems only by accident, as an unforeseen and unintended by-product of actions undertaken for routine quests for wealth, power, and contentment. Late in the twentieth century many people noticed that humans were doing so, which in some circles seemed imprudent and alarming. Sometime soon people will likely moderate their impact on the Earth, partly by design and partly as an accidental by-product of reduced population growth and a shift away from fossil fuels. No one can say when or how fast such shifts will take place. But when they do, the Anthropocene will have entered a new stage, perhaps a less worrisome one—although one never knows what the future may bring. The history of the twenty-first century should give us a fair idea of what to expect.

Meanwhile, many adjustments to the Anthropocene are in order. Political, economic, and cultural institutions, evolved in a context of dramatic and unprecedented resource use and economic growth, must now evolve into forms more compatible with the Anthropocene—or give way to their successors. Closer to home, for historians, the work of those who claim to make sense of human affairs—social scientists and humanists—needs some updating.

Strangely enough, just as the Great Acceleration was shifting into high gear, academic social scientists and humanists chose to retreat from grimy and greasy realities into various never-never lands. They found all manner of discourses worthy of their studied attention, reveling in the linguistic and cultural "turns." But the extinction of species, the incineration of forests, the concentration of CO_2 in the atmosphere—all this seemed unworthy of their powers, interesting only for the discourses it aroused. Meanwhile, one species of social scientists, economists, jilted reality in favor of a different fantasy, one of ever-more-abstract modeling based on universalizing assumptions of individual behavior and state conduct, casually ripped from all historical and cultural, not to mention ecological, context. Social sciences and the humanities, especially in their most prestigious bastions, showed themselves scarcely more attuned to the advent of the Anthropocene than governments floundering with energy policy and climate politics. The intellectual flight from reality made it slightly easier for those in positions of power to avoid facing up to it.

Happily, recognition of the relevance of reality and the reality of the Great Acceleration has already begun to seep into the humanities and social sciences. Something of an "environmental turn" seemed afoot early in the twenty-first century, and the linguistic turn seemed destined to go the way of all academic fashions. Perhaps any environmental turn will run its course too, but to judge by prior academic twists and turns, it probably has a generation yet to go. Economists, less malleable than most to the whims of fashion, remained wedded to their venerable models, with the exceptions of a few heretics, the ecological economists of Chapter 3.

Societies in general, and their political institutions in particular, showed uncertain signs of adjusting to the Anthropocene. As our discussion of environmentalism explained, since the 1970s most societies found ways to regulate some but not all of their ecological impacts. In a few cases (for example, CFCs), bold and effective action proved to be within reach. With respect to the tougher nuts to crack, such as greenhouse gas emissions, the attitudes and policies of societies remained doubly inconsistent. They were inconsistent in the sense that some (few) societies favored vigorous efforts even at the cost of economic sacrifice, while others sternly opposed any departures from the status quo. And many were inconsistent in the sense that their positions changed from time to time, depending on new information or political winds. But in general, by far the greater part of systems of thought and ideologies, of customs and habits, of institutions and policies, remained firmly anchored in the late Holocene. Adjustment to the Anthropocene, on every level, has only just begun.

This should come as no surprise. Intellectual, social, and political inertia are normally powerful forces. Modern thought and institutions, evolved and nurtured in the late Holocene, fit comfortably with a world of cheap energy and stable climate. That world of roughly 1750 to 1950 was tumultuous in many respects, but people could know what to expect in terms of climate, as existing patterns did not change much. And more and more people found fossil fuels more and more affordable, apparently inexhaustible, and thus infinitely appealing as a centerpiece around which to construct everything else. Now that climate is less stable and the Earth system is charting a new course never experienced before, thought and institutions will evolve in new directions more compatible with the Anthropocene. Since we cannot exit the Anthropocene, we will adjust to it, one way or another.