# THE ANTHROPOCENE: THRESHOLD 8

***David Christian*** *is a distinguished professor of history at Macquarie University in Australia and the co-founder, with Bill Gates, of The Big History Project, which has built a free online syllabus on the history of the universe and is taught in schools all over the world. He is also co-creator of Macquarie University Big History School, which provides online courses in Big History for primary and high school students. He received his PhD from the University of Oxford. He has delivered keynotes at conferences around the world including at the Davos World Economic Forum, and his TED Talk on the history of the universe has been viewed over 7 million times.*

# THE ANTHROPOCENE: THRESHOLD 8

by David Christian

*"In the twentieth century, we humans began to transform our surroundings, our societies, and even ourselves. Without really intending to, we have introduced changes so rapid and so massive that our species has become the equivalent of a new geological force. That is why many scholars have begun to argue that planet Earth has entered a new geological age, the Anthropocene epoch, or the 'era of humans.'" David Christian presents a highly modern, scientific version of Cosmic Education using university interdisciplinary language. Like Montessori education, the Anthropocene chapter is an exercise in complexity theory.*

---

*Reprinted from* Origin Story: A Big History of Everything. *London: Allen Lane/Penguin Random House (2018): 259–283. Reprinted with permission from the author.*

> *"We're no longer in the Holocene. We're in the Anthropocene."—Paul Crutzen, outburst at a conference in 2000*
>
> *"Man the food-gatherer reappears incongruously as information-gatherer. In this role, electronic man is no less a nomad than his paleolithic ancestors."—Marshall McLuhan,* Understanding Media

In the twentieth century, we humans began to transform our surroundings, our societies, and even ourselves. Without really intending to, we have introduced changes so rapid and so massive that our species has become the equivalent of a new geological force. That is why many scholars have begun to argue that planet Earth has entered a new geological age, the Anthropocene epoch, or the "era of humans." This is the first time in the four-billion-year history of the biosphere that a single biological species has become the dominant force for change. In just a century or two, building on the huge energy flows and the remarkable innovations of the fossil-fuel revolution, we humans have stumbled into the role of planetary pilots without really knowing what instruments we should be looking at, what buttons we should be pressing, or where we are trying to land. This is new territory for humans, and for the entire biosphere.

### The Great Acceleration

If we stand back from the details, the Anthropocene epoch looks like a drama with three main acts so far and a lot more change still in the works.

Act 1 began in the mid-nineteenth century as fossil-fuel technologies began to transform the entire world. A few countries in the Atlantic region gained colossal wealth and power and terrifying new weapons of war. A huge gap opened between the first fossil-fuel powers and the rest of the world. That gap in power and wealth would last for more than a century and start closing only in the late twentieth century.

These differences created the lopsided imperial world of the late nineteenth and early twentieth centuries. Suddenly, countries of the Atlantic region, which had been marginal for much of the agrarian era, began to dominate, and sometimes rule, much of the world, including most of Africa and much of the territory once ruled by the great Asian empires of India and China. Outside the new Atlantic hub zone, the first impact of fossil-fuel technologies was mainly destructive because the new technologies arrived in the military baggage of foreign invaders. The *Nemesis,* the first iron-hulled steam-powered gunship, with its seventeen cannons and its ability to sail fast in shallow waters, helped England win control of China's ports during the First Opium War, from 1839 to 1842. The Chinese navy, once the greatest in the world, had no defense against such weapons.

Within decades, Europe's commercial and military power had undermined ancient states and lifeways. Textile production using spinning and weaving machines powered by steam engines ruined artisan textile producers in India, which had been the agrarian era's leading producer of cotton cloth. As Britain gained political and military control of the Indian subcontinent, it locked in these imbalances by keeping Indian textiles out of British markets. Even the building of India's major railroads benefited Britain more than India. Most of the track and rolling stock was manufactured in Britain, and the huge Indian rail network was designed primarily to move British troops quickly and cheaply, to export cheap Indian raw materials, and to import English manufactured goods. In the Americas, Africa, and Asia, growing demand for sugar, cotton, rubber, tea, and other raw materials encouraged environmentally destructive plantations, often worked by quasi-slave labor. In wars that pitted machine guns against spears and assegais, European powers carved up Africa and ruled it for the best part of a century.

Europe's economic, political, and military conquests encouraged a sense of European or Western superiority, and many Europeans began to see their conquests as part of a European or Western mission to civilize and modernize the rest of the world. To them, industrialization was a sign of progress. It was part of the transformative mission, first advocated in the Enlightenment, to "improve" the world, to make it a better, richer, and more civilized place for humans.

Act 2 of the Anthropocene was exceptionally violent. It began in the late nineteenth century and lasted until the middle of the twentieth century. During this act, the first fossil-fuel powers turned on one another. In the late nineteenth century, the Unites States, France, Germany, Russia, and Japan began to challenge Britain's industrial leadership. As rivalries intensified, the major powers tried to protect their markets and sources of supply and keep out competitors. International trade declined. In 1914, rivalry turned into outright war. For thirty years, destructive global wars mobilized the new technologies and the growing wealth and populations of the modern era.

Other parts of the world were sucked into these wars, and they were fought with as much brutality in China and Japan as they were in Russia and Germany. As the red mist of war descended over Europe, Africa, Asia, and the Pacific, warring governments competed to develop more destructive weapons. Science gave the combatants terrifying new weapons, some of which tapped the energies lurking within atomic nuclei. On August 6, 1945, a US B-29 Superfortress bomber flew from the Marian Islands in the Pacific and dropped an atomic bomb on the Japanese city of Hiroshima. It destroyed much of the city and killed eighty thousand people. (Within a year, another seventy thousand had died from injuries and radiation.) On August 9, 1945, a similar weapon was dropped on the city of Nagasaki.

Act 3 includes the second half of the twentieth century and the early twenty-first century. From the bloodbath of the world wars, the United States and the Soviet Union emerged as the first global superpowers. There were many local wars, most aimed at overthrowing European colonial rule. But there were no more major international wars during the era of the Cold War. By now, all powers understood there would be no victors in a nuclear war. But there were some close shaves. Soon after the Cuban missile crisis of 1962, President John Kennedy admitted that the odds of an all-out nuclear war had been "between one out of three and even."[1]

The four decades after World War II witnessed the most remarkable spurt of economic growth in human history. This was the period of the Great Acceleration.

Global exchanges were renewed and intensified. In the forty years before World War I, according to one influential estimate, international trade increased in value at an average rate of about 3.4 percent a year. For 1914 to 1950, that rate fell to just 0.9 percent; then, from 1950 to 1973, it rose at about 7.9 percent a year before falling slightly to about 5.1 percent between 1973 and 1998.[2] In 1948, twenty nations signed the General Agreement on Trade and Tariffs (GATT), which lowered barriers to international trade. Wartime technologies were now put to more peaceful uses. Oil and natural gas added to the energy bonanza of the nineteenth century, and so did nuclear power, the peaceful counterpart of nuclear weapons. Productivity soared, first in the leading fossil-fuel economies and then elsewhere. Consumption soared too as output rose and producers sought new markets at home as well as abroad. In wealthier countries, this was the age of the automobile, of TV, of suburban dream houses, and eventually, of computers, smartphones, and the Internet. A new middle class started to emerge. This was also when the industrial revolution began to spread beyond the old industrial heartlands. By the early twenty-first century, industrial technologies had transformed much of Asia, South America, and parts of Africa as completely and as fast as they had once transformed European societies. As other areas of the world industrialized, their wealth and power increased. There began to appear, once again, a world with multiple hubs of power and wealth. Within two hundred and fifty years of the first modern steam engine, fossil-fuel technologies had transformed the entire planet.

During the Great Acceleration, humans mobilized energy and resources on such an unprecedented scale that they began to transform the biosphere. That is why many scholars date the dawn of the Anthropocene epoch to the middle of the twentieth century.

### Transforming the World: Technologies and Science

Innovation, propelled by cheap energy, was the main driver of change. Innovations created steeper gradients of wealth and power that encouraged competition, which drove innovation, in a powerful feedback cycle. Entrepreneurs and governments hunted down the innovations that might give them an industrial or military edge and invested in the businesses and scientists, the schools, universities, and research institutes that could generate and disseminate new technologies and skills.

The wars of the early twentieth century drove a forced march of innovation. During World War I, Germany ran short of natural fertilizers, and German scientists, led by Fritz Haber and Carl Bosch, figured out how to draw nitrogen from the air to make artificial fertilizers. Nitrogen doesn't like to react, so this was not easy. Prokaryotes had solved the problem billions of years ago, but Haber and Bosch were the first multicellular organisms to successfully fix atmospheric nitrogen. The Haber-Bosch process uses huge amounts of energy to overcome nitrogen's reluctance to combine chemically, so it was viable only in a world of fossil fuels. But artificial nitrogen-based fertilizers transformed agriculture, raised the productivity of arable land through the world, and made it possible to feed several billion more humans. It turned fossil-fuel energy into food.

> . . . artificial nitrogen-based fertilizers transformed agriculture, raised the productivity of arable land through the world, and made it possible to feed several billion more humans. It turned fossil-fuel energy into food.

A liquid fossil fuel, oil, was first used in the late nineteenth century as a replacement for whale oil in lighting. The first internal combustion engines, developed in the 1860s and 1870s, showed how to generate mechanical force from oil. Unlike the steam engine, whose heat source was external to the engine's moving parts, in internal combustion engines, the heat from fossil fuels drove pistons or rotors or turbine blades directly. Internal combustion engines spread rapidly in the late twentieth century, largely because of their wartime use to transport soldiers and equipment and to power the first tanks. They were also installed in the first military aircraft, which pioneered the dark art of dropping explosives from the air. Once the wars ended, manufacturers of automobiles and planes turned to civilian markets to create a world in which more and more individuals owned and used cars or flew in planes. Global trade was transformed by oil tankers, container ships, and large planes.

Information lies at the heart of Anthropocene technologies. Information technologies were transformed when governments invested in a massive expansion of education and research, and businesses and corporations funded research to develop and disseminate new products and services. To break enemy codes, wartime governments funded research into the mathematics of information and computing.

This research, combined with the invention of the transistor in the late 1940s, laid the foundations for the computerization of science, business, government, finance, and everyday life in the second half of the century. Rocketry, also developed during the wars, would eventually send humans into space. Wartime governments had launched huge research programs to develop nuclear weapons. The American government's Manhattan Project developed the first atomic bombs, including the weapons dropped on Hiroshima and Nagasaki in 1945. These unleashed the energies of disintegrating uranium nuclei. The Soviet Union soon developed its own atomic weapons, helped by information leaked by spies from the Manhattan Project. Within a decade, the United States and the Soviet Union had also built hydrogen bombs, which released the much greater energies generated by proton fusion, the same mechanism that powers all stars. The first H-bomb was tested in 1952.

Much of this innovation was inspired by breakthroughs in the supercharged collective-learning environment of modern science. Albert Einstein developed his theory of relativity in the first two decades of the twentieth century. It improved on Newton's understanding of the universe by showing that matter and energy warped space and time, and this warping was the real source of gravity. Einstein also showed that matter could be converted into energy and that insight provided the scientific foundations for nuclear weapons and nuclear power. Quantum physics, developed in the same era, gave deeper insight into the strange, probabilistic world of atomic nuclei. Without that understanding, nuclear weapons, transistors, global positioning systems, and modern computers would not exist today. In the 1920s, astronomers such as Edwin Hubble found the first evidence that our universe began in a big bang. In biology, Darwin's idea of natural selection was combined with Mendel's understanding of heredity and the improved statistical methods of R. A. Fisher to lay the foundations for modern genetics.

These and many other new insights and technologies powered innovation and growth during the Great Acceleration. Increased productivity allowed human populations to grow faster than ever before. In 1800, there were nine hundred million humans on Earth. By 1900, there were one and a half billion. By 1950, when I was a child, there were two and a half billion humans, despite the huge causalities of the world wars. During my lifetime, human numbers have increased by another five billion. Such enormous numbers can numb the brain, so it's worth taking the time to grasp what they mean. In the two hundred years since 1800, the number of humans increased by more than six billion. Each additional human had to be fed, clothed, housed, and employed, and most had to be educated. The challenge of producing enough resources in just two hundred years to support an extra six billion humans was colossal.

Remarkably, the challenge was met with modern technologies, modern fossil fuels, and modern managerial skills. Productivity soared in agriculture, manufacturing, and transportation. Though food and other supplies did not always get to those who needed them, enough food was produced to feed more than seven billion people. The crucial changes were in the production of artificial fertilizers and pesticides, the use of fossil-fueled farm machinery, the building of thousands of irrigation dams, and the production of new, genetically modified crops. Modern farming technologies brought new land into cultivation, increasing the farmed area from half a billion hectares in 1860 to almost three times as much in 1960.[3] Fishing trawlers equipped with powerful diesel engines, sonar detection equipment, and massive nets sucked up most of the organisms in the area they fished. The fish catch rose from nineteen million tons to ninety-four million tons between 1950 and 2000, though overfishing means that many fisheries are now in danger of collapse.

Improved information technologies made it easier to accumulate, store, keep track of, and use the huge amounts of information that drove innovation and kept hugely complex modern societies running. Communications and transportation technologies transformed collective learning by creating, for the first time, a single, linked network of minds that that spanned the globe and could manage and track down new information in colossal electronic stores of information. The noösphere, the sphere of mind, became a dominant driver of change within the biosphere. Cheap but powerful networked computers gave billions of people access to more information than they could have found in all the libraries of the premodern world. When combined with the mathematically sophisticated techniques of modern statistical analysis, computers allowed governments, banks, corporations, and individuals to keep track of huge flows of resources. They also allowed instant communication between individuals anywhere in the world through telegrams, phones, and the Internet. If the sharing of information is what makes humans so powerful, computers multiplied that power many times over. As always, there were losses, too. Just as memory skills probably declined with the spread of writing, so calculating skills declined with the spread of computers and calculators.

By 2000, the fossil-fuel revolution embraced most of the world, including many older hub regions. The yawning gaps in national wealth and power of the late nineteenth century began to close. European powers, weakened by the world wars, grudgingly gave up their colonies, and older hub regions in Asia, the eastern Mediterranean, North Africa, and the Americas began to catch up in technology, wealth, and power.

Behind all these changes was the bonanza of cheap energy from fossil fuels. Coal production increased everywhere, but so did the production of oil and natural gas. New oil fields were developed in Arabia, Iran, the Soviet Union, and even along the continental shelves. In the Middle East alone, oil production increased from 28 billion barrels in 1948 to 367 billion barrels in 1972, just twenty-five years later. Natural gas came into its own during the Great Acceleration. Total energy consumption doubled in the nineteenth century and then rose by ten times in the twentieth century. Human consumption of energy rose much faster than human populations.

Total energy consumption doubled in the nineteenth century and then rose by ten times in the twentieth century. Human consumption of energy rose much faster than human populations.

### Transforming the World: Governance and Society

The very nature of society and government was transformed by the new energy flows and technologies of the Anthropocene. Once, all humans had been foragers, and *government* really meant family relationships. After farming appeared, more and more people lived in peasant villages and supported themselves by farming. In farming societies, *government* meant, above all, mobilizing energy and resources from peasants. Today, most humans no longer gather or farm to produce their food and other necessities. They have become wage earners. Like the potters of ancient Sumer, they live on wages earned by doing specialized work. And that transformed the nature of government, because now governments had to become involved in the day-to-day lives of all their citizens. This is because wage earners, unlike peasants, cannot survive without governments. Farming villages could exist quite happily beyond the borders of the great agrarian civilizations, but wage earners depend on the existence of laws, markets, employers, shops, and currencies. A specialist wage earner, like a nerve cell, cannot survive alone. This is why a world of wage earners is much more tightly integrated than a world of peasant farmers. Modern governments regulate markets and currencies, protect the businesses that provide employment, create mass educational systems that can spread literacy to most of the population, and provide the infrastructure for the movement of goods and workers. To do all this, they must draw more and more of their subjects into the work of government and administration.

> [Humans] have become wage earners . . . And that transformed the nature of government, because now governments had to become involved in the day-to-day lives of all their citizens.

We can see the changeover to modern types of government in the nineteenth century, as industrialization took off, more and more peasants became wage workers, and governments began to mobilize more of their populations. Revolutionary France, transformed by revolution and under attack from most of Europe, was one of the first modern states to recruit soldiers systematically from the entire population. The government of the United States was also forged in a period of war during which it had to mobilize much of the population. To do that, governments needed detailed records on the number of citizens, on their health and fitness, on their education, skills, wealth, and loyalty. These were problems most traditional governments had been able to ignore. The governments of revolutionary France and the United States began to mobilize the loyalty of their subjects through democratization, which brought more of the population into the work of government, and through nationalism, which appealed to people's sense of a shared national community. They offered increasing numbers of their subjects (wealthy men, other men, and women, in that order) some role in government through elections. Through schools and the rapidly developing news media, governments tried to reach into the minds of their subjects and generate new forms of loyalty. Nationalism proved a powerful way of uniting people with different traditions, religions, and even languages. It mobilized traditional instincts of kinship by constructing in the minds of citizens a vast, imagined family of millions of people to whom they owed loyalty, service and, in the extreme crises of war, perhaps even their lives.

The total wars of the early twentieth century turned governments into economic managers, as they tried to mobilize all the people and resources of modern industrial economies. We can roughly track the increasing role of government in economic management. In the late nineteenth century, the French government accounted for about 15 percent of French GDP, a very rough measure of total national production. At the time, that seemed like a lot. Contemporary governments in Britain and the United States accounted for less than 10 percent of their GDP. The wars of the early twentieth century forced governments to intervene more actively in economic management, and by the middle of the twentieth century, their economic role had increased everywhere. In the early twenty-first century, the average share of national expenditure controlled or managed by governments in the countries of the OECD (Organization for Economic Co-Operation and Development, founded in 1960) was 45 percent of GDP, with most richer countries falling in the range from 30 to 55 percent.[4] Some governments, such as the communist regimes of the Soviet Union and China, attempted to micromanage the entire national economy. Modern governments also wielded coercive power on a much larger scale than traditional governments had, through armies and police equipped with modern weaponry. Such power would have been unimaginable to the author of the *Arthashastra*, the ancient Indian treatise on statecraft. Modern governments have a scale, reach, power, and heft that make even the most powerful governments of the agrarian era look like featherweights.

In an increasingly interconnected world, governance also assumed more global forms. By the late twentieth century, there were many political structures—not yet governments—that managed, advised and administered on a global scale. They included the United Nations, the International Monetary Fund, and large numbers of corporations and nongovernmental organizations (NGOs) such as the Red Cross, whose activities range across many different countries. These institutions represent, in embryonic form, a new, global level of governance that would have been unimaginable just a few centuries ago.

### New Ways of Living and Being

Technological and political transformations have been accompanied by equally radical changes in human lifestyles—in the *experience* of life.

Modern humans live in ways that would have baffled, confused, and possibly terrified our ancestors. All the many different activities of a peasant household—plowing, sowing, harvesting, feeding livestock, milking cattle, cutting firewood, gathering mushrooms or herbs, bearing and rearing children, cooking the foods and weaving the fibers you have grown—dominated the lives of most people for thousands of years. Today, most farmers are entrepreneurs or wage earners. They work on huge industrial farms that specialize in just a few crops, some of them genetically engineered. They cultivate and transport their crops using lashings of fertilizers and pesticides and energy-hungry harvesters, tractors, and trucks. Modern farmers grow crops not to eat but to sell. They manage businesses. They borrow money from banks and buy their seeds, fertilizers, and tractors from large corporations.

Most people no longer live in villages but in towns and cities. Away from the fields, streams, and woods of the peasant village, they live in environments almost entirely shaped by human activity. As different jobs and skills and forms of expertise proliferate, people spend more and more time learning. Information—expert knowledge—is what counts, rather than the generalized skills of peasants. Increasing numbers of people enjoy levels of nutrition and health that were rare even a century ago, thanks to the productivity of modern agriculture and modern advances in medicine and health care. Modern anesthesia has ended the agony of most traditional medical interventions. (No longer is an amputation or tooth extraction made easier to bear by nothing but a shot of liquor.) Perhaps most remarkable of all, in just a century, these changes have more than doubled the average life expectancy of human beings.

Despite the wars of the twentieth century, interpersonal relations have also become, for the most part, less violent. There is a clear logic to this change, as coercion has become a less effective way of controlling behavior in the last century or two (when did you last see a public flogging?), and economic rewards and punishments have slowly taken their place (you probably *have* asked for a pay raise). Though today most people take for granted that slavery and domestic violence are wrong, it is important to remember that, as late as the eighteenth century, the slave trade remained quite respectable in most of the world; torture and execution were standard punishments even for petty crimes and widely regarded as a form of public entertainment; and beatings for corporal punishment were regarded as a normal and perfectly acceptable way of maintaining order within families and schools. Personal violence is still all too common, but, relative to the number of people in the world, it is much rarer than it used to be and no longer regarded in most of the world as an acceptable way of controlling behavior.

In a world of peasants, most lived close to subsistence, periods of shortage were familiar and common, and affluence meant, for most people, a solid home, freedom from debt, and enough money to pay taxes and feed and clothe a family. Today's consumerist world is utterly different. It is fueled by economic systems that, in the more affluent parts of the world, produce so much material wealth that their very survival depends on massive, sustained consumption by a rapidly growing global middle class. The idea of progress, which most of us take for granted, is also new. For the majority of human history, people assumed that, barring catastrophes, children would live much as their parents had.

Attitudes toward families and children have changed profoundly. In recent centuries, improved nutrition and health care began to lower child mortality, so more children survived into adulthood. Yet traditional peasant attitudes ensured that families kept trying to produce as many children as possible. Such attitudes, along with increasing food production, high fertility, and declining mortality helped drive the extraordinarily rapid population growth of recent centuries. Eventually, though, traditional attitudes began to change as families moved into towns, as educating and rearing children became more expensive, and as more children survived to adulthood. Urban families began to have fewer children, and fertility rates began to fall. The fall in fertility rates after the earlier fall in mortality rates is what demographers call the *demographic transition*: the emergence of a new demographic regime of low fertility and low mortality. And that explains why, in the twentieth century, rates of population growth began to slow, first in more affluent countries, and then throughout the world. It also helps explain fundamental changes in gender roles. Reduced pressure on women to spend their entire adult lives bearing or rearing children blurred traditional divisions between male and female roles and allowed women to take up roles from which they had been excluded during most of the agrarian era.

For anyone alive today, these aspects of modern lifeways are familiar, though the contrast with the now-vanished world of the peasantry may be harder to appreciate. Even harder to grasp is the staggering increase in the complexity of modern societies, the way every detail of your life is enmeshed in networks involving millions of other people who supply food and employment, health care, education, electricity, the fuel for your car, the clothes you wear. Each of these chains of interconnection may include thousands or millions of other humans linked together in networks of fabulous complexity. In idle moments at airports, I like to try to calculate how many people are involved in the project of building and maintaining an Airbus 380 and getting it from Sydney to London. Weaken any of these links, and our world can break down terrifyingly fast, as is apparent today in those parts of the world where state structures have collapsed. Kautilya, the author of the *Arthashastra*, would have said that humans in these places live under "the law of the fish."

## Transforming the Biosphere

The fossil-fuel revolution and the Great Acceleration did not just transform human societies; they are also transforming the biosphere. The activities of humans are changing the distribution and number of living organisms, altering the chemistry of the oceans and the atmosphere, rearranging landscapes and rivers, and unbalancing the ancient chemical cycles that circulate nitrogen, carbon, oxygen, and phosphorous through the biosphere.

It has taken researchers a long time to realize that the impact of human activities is now as great as that of the major biogeochemical processes that maintain the stability of the biosphere. Without really understanding what we are doing, we are fiddling with the biosphere thermostats that have kept Earth's surface within habitable temperature for four billion years.

Carbon is central to the chemistry of life, and its distribution in the atmosphere, the sea, and the crust has helped determine temperatures at Earth's surface through the planet's history. Today, as we tap the energy in fossil fuels, we are pumping huge amounts of carbon dioxide back into the atmosphere. But not until the 1950s did scientists seriously consider the impact this might have on the carbon cycle. Charles Keeling began measuring levels of atmospheric carbon dioxide in Hawaii in 1958. Within a few years, he found that those levels were rising fast. Before the fossil-fuel revolution, human emissions of carbon dioxide were not large enough to affect the levels of atmospheric carbon dioxide. Today, though, human activities are releasing about ten thousand megatons of carbon dioxide into the atmosphere each year, and it is estimated that, since the industrial revolution, the total emissions amount to about four hundred thousand megatons of carbon dioxide.[5] How significant these changes are became apparent when researchers found ways of measuring carbon dioxide levels over hundreds of thousands of years. One method was to study ice cores, which contain tiny bubbles, trapped year by year, that can tell us the composition of the atmosphere on geological time scales. These showed that, in the two centuries since the industrial revolution, levels of atmospheric carbon dioxide had risen to levels higher than any seen for almost a million years.

The changes Keeling noted were real; they were striking; and they were transforming the carbon cycle. Rising carbon dioxide levels will mean warmer climates, and warmer climates will mean more energetic hurricanes, storms, and wind currents and rising ocean levels that will flood low-lying cities. The effect will persist for many generations because, once released into the atmosphere, carbon dioxide stays there for a long time. But carbon dioxide is not the only important greenhouse gas whose atmospheric levels have increased as a result of human activities. Levels of methane have risen even faster in the past two centuries, driven largely by the spread of rice-growing in flooded fields and the increasing number of domestic livestock. Methane is an even more powerful greenhouse gas, though it breaks down faster.

In the late twentieth century, computers allowed climate scientists to build increasingly sophisticated models of the likely impact of such changes on the atmosphere. Their models suggest that, with a few decades as greenhouse-gas emissions create a warmer world, melting glaciers and ice caps will raise sea levels, drowning many coastal cities, and increased heat energy and evaporation will ensure more erratic, unpredictable, and extreme weather patterns and make agriculture more difficult. With a few decades, global climates will look very different from the relatively stable patterns of the Holocene. As one US climate scientist puts it: "The climate is an angry beast, and we are poking it with a stick."[6]

Nitrogen is as vital for life as carbon. In 1890, human impacts on the nitrogen cycle were insignificant. Each year, humans extracted about fifteen megatons of nitrogen from the atmosphere, mainly through farming, while wild plants extracted about one hundred megatons, or almost seven times as much. One hundred years later, humans and plants had swapped roles. By 1990, the area of farmed land had increased to such a degree that wild plants were extracting only about 89 megatons, while human extraction of nitrogen through farming and fertilizer production had risen to 118 megatons.

Our impact on other large mammals has also been profound. In 1900, wild land mammals accounted for the equivalent of about 10 megatons of carbon biomass. Humans already accounted for about 13 megatons, while domesticated mammals—our cows, horses, sheep, and goats—accounted for an astonishing 35 megatons. In the next century, these ratios would get even more warped. By 2000, the total biomass of wild land mammals had fallen to about 5 megatons, while that of humans had increased fast (not surprising, given what we know of population growth) to about 55 megatons and that of domesticated mammals to an astonishing 129 megatons. This is a powerful indicator of the extent to which expanding human activities have squeezed out other species of large animals by taking more and more of the biosphere's resources.

The point is a general one. *Most* species of animals and plants that are not of immediate value to humans are declining in numbers. They are declining so fast that some speculate that we may be witnessing the early stages of another mass-extinction event. Rates of extinction are now hundreds of times faster than in the past few million years and approaching rates not seen since the last mass-extinction event, 65 million years ago. We humans have even managed to drive our closest relatives to extinction, including, probably, our hominin relatives such as the Neanderthals. Our closest living relatives, the chimpanzees, gorillas, and orangutans, are close to extinction in the wild.

The fossil-fuel revolution has magnified the scale of human impacts in many other areas. Mining, road-building, and the spread of cities now move more earth than is moved by erosion and glaciation. Diesel pumps suck fresh water from aquifers ten times faster than natural flows can replenish them. We are producing minerals, rocks, and forms of matter that never existed before. They include plastics (made from oil, and now accumulating in landfills in cities and within the oceans), pure aluminum, stainless steel, and vast amounts of concrete, a human-made rock whose manufacture is not a major contributor to carbon emissions. Such a proliferation of new substances has not been seen on Earth since the appearance of an oxygen-dominated atmosphere, around 2.4 billion years ago.[7]

One of the most terrifying of these changes is the increasing productivity of human weaponry. Just a few centuries ago, our most lethal weapons were spears or, perhaps, rock-throwing catapults. From the late medieval age, the gunpowder revolution, pioneered in China, gave us muskets, rifles, cannons, and grenades. World War II spawned weapons that degrade the entire biosphere in just a few hours; weapons with the destructive power of the asteroid that did in the dinosaurs.

### Measuring Change in the Anthropocene

New flows of information and energy have woven humans, animals, and plants, as well as the chemicals of the earth, seas, and atmosphere, into a single system constructed primarily for the benefit of our own species. This system depends on huge flows of energy from fossil fuels. We can roughly measure the impact of these energy flows in the Anthropocene using figures in the statistical appendix [see chart at end of chapter].

The first thing that stands out is the sheer scale of change in recent centuries. In the past 200 years, human populations (Column B) rose from 900 million to more than six billion. That is the equivalent of adding 26 billion people in a thousand years, a rate of growth one thousand times faster than that of the agrarian era, in which, on average, about 25 million people were added each millennium. Such growth rates are unsustainable, and in recent decades, they have been slowing. Nevertheless, the figures illustrate the stunning impact on population growth of the fossil-fuel revolution.

Rapid population growth depended on huge increases in the energy available to our species (Column C). In the 8,000 years between the end of the last ice age and 2,000 years ago, human energy consumption increased by about 70 times. In just 200 years, between 1800 and 2000, total energy consumption rose by about 22 times, from 20 million gigajoules (20 exajoules) to 52 million gigajoules (520 exajoules). That rise is the equivalent of an increase of 2,500 exajoules every thousand years, a rate of increase 20,000 times as fast as in the agrarian era.

The energy bonanza from fossil fuels, like the energy bonanza from farming, paid for population growth, for the complexity taxes demanded by entropy, and, finally, for rising living standards but, on a much larger scale than in the agrarian era. And this time, the rise in living standards was not confined to a tenth of the human population but extended to a much larger emerging middle class.

Much of the energy bonanza for fossil fuels paid for increasing numbers of humans. It fed, clothed and housed the five to six billion people added to the world's population in the past two centuries. But the fossil-fuel bonanza was so much greater than that from farming that a lot more was left over for other uses. We know this because Column D shows that the energy available per person increased by almost eight times in the past one thousand years, while in the whole 8,000 years between the end of the ice age and 2,000 years ago, it had less than doubled. In the past 200 years, populations have grown at lightning speed, but energy flows have grown even faster.

A lot of the extra energy must have paid for the taxes demanded by entropy from increasingly complex societies. Much of that energy did no productive work or was dissipated as heat or in pollution or waste or the destruction of war. It was doing entropy's work of degrading complex structures. We have no good measures of the amounts involved, but they must be significant. Then there are the other complexity taxes, the energy and wealth that paid for the infrastructure of today's global societies. In the past 200 years, the size of the largest cities rose from about one million (a level that had barely changed in 2,000 years) to more than 20 million (Column F). Given the infrastructure of electricity, sewers, roads, and public transport needed for a modern city and the challenges of policing and regulating the activities of 20 million people crowded into a small area, it is apparent that this represents a quantum leap in social and technological complexity. Complexity taxes pay for the construction and upkeep of buildings, buses, trains and ferries, sewers and roads; they pay for garbage collection, the electricity grid, law codes, policing, prisons and courts, and the links by ship, plane, train, and the Internet that bind cities throughout the world into a single network. Without these different systems, all driven by huge flows of energy, the complex structures of a modern city would break down fast. And cities, in turn, are linked by a complex infrastructure of highways, laws, and electronic communications to hundreds of thousands of smaller towns, villages, and isolated settlements. Though we have no way of measuring it precisely, we can be sure that complexity taxes account for a large share of the energy from fossil fuels.

But the bonanza from fossil fuels was so massive that a lot of energy was left over for one more task: that of improving human welfare. As in the agrarian era, a disproportionate amount of wealth still supports a tiny elite, so, as in the past, we can allocate a significant share of the energy bonanza to elite consumption. But so huge was the increase in energy and wealth that, for the first time in human history, consumption levels began to rise for a growing global middle class of billions of people, far more people than the entire population of the world at the end of the agrarian era. Thomas Piketty estimates that in modern European countries, 40 percent of the population controls between 45 and 25 percent [*sic*] of national wealth. The appearance of this middle class was a new phenomenon in human history. And more and more people are joining the new middle class as the numbers of living in extreme poverty fall.

Paradoxically, increasing wealth also means increasing inequality, and even as the numbers living above subsistence are rising, the numbers living in extreme poverty remain higher than ever before in human history. Thomas Piketty estimates that in most modern countries, the wealthiest 10 percent of the population controls between 25 percent and 60 percent of national wealth, while the bottom 50 percent controls no more than 15 percent to 30 percent. This represents a decline in inequality in comparison with the era just before World War I. But in the early twenty-first century, inequality seems to be on the rise again, and the huge number of people alive now means that, in absolute terms, there are far more people living in extreme poverty today than there were in the past. In 2005, more than three billion people (more people than the total population of the world in 1900) lived on less than $2.50 a day. Most people in this group have seen few benefits from the fossil-fuel revolution and suffer from the unhealthy, unsanitary, and precarious living conditions of the early industrial revolution that were described so vividly by Dickens and Engels.

Nevertheless, a growing proportion of the human population is living well above subsistence. These flows have raised consumption levels and also levels of nutrition and health for billions of people. The measure that best captures this change is probably life expectancy (Column E). For most of human history, life expectancies at birth were less than 30 years. This was not because people didn't live into their sixties and seventies but because so many children died young and so many adults died of traumas and infections that would not have killed them today. Life expectancies barely changed for 100 thousand years. Then, in just the past 100 years, average life spans have almost doubled throughout the world because humans have acquired the information and resources needed to care for the young and old much better, to feed more people, and to improve the treatment and care of the sick and injured.

The contrast between the energy bonanzas from fossil fuels and from farming is striking. The energy bonanza from fossil fuels was so vast that, in addition to expenditure on reproduction, elite wealth, waste, and the infrastructure for complexity, there was enough left over to raise the consumption levels and living standards of an increasing proportion of humanity. This was a revolutionary transformation. It occurred mostly in just the past 100 years and primarily during the Great Acceleration of the second half of the twentieth century.

This is the face of the Good Anthropocene (*good* from a human perspective). The Good Anthropocene has generated better lives for billions of ordinary humans for the first time in human history. (If you doubt the improvement, think again about having surgery without modern anesthesia).

> The Good Anthropocene has generated better lives for billions of ordinary humans for the first time in human history.

But there is also a Bad Anthropocene. The Bad Anthropocene consists of the many changes that threaten the achievements of the Good Anthropocene. First, the Bad Anthropocene has generated huge inequalities. Despite colossal increases in wealth, millions continue to live in dire poverty. And though it is tempting to think that the modern world has abolished slavery, the 2016 Global Slavery Index estimated that more than 45 million humans today are living as slaves. The Bad Anthropocene is not just morally unacceptable. It is also dangerous because it guarantees conflict, and in a world with nuclear weapons, any major conflict could prove catastrophic for most of humanity.

> The Bad Anthropocene is not just morally unacceptable. It is also dangerous because it guarantees conflict, and in a world with nuclear weapons, any major conflict could prove catastrophic for most of humanity.

The Bad Anthropocene also threatens to reduce biodiversity and undermine the stable climate system of the past 10,000 years. The flows of energy and resources that support increasing human consumption are now so huge that they are impoverishing other species and jeopardizing the ecological foundations on which modern society is built. In the past, coal miners took canaries into mines to detect carbon monoxide. Today, rising carbon dioxide levels, declining biodiversity, and melting glaciers are telling us that something dangerous is happening, and we should take notice.

The challenge we face as a species is pretty clear. Can we preserve the best of the Good Anthropocene and avoid the dangers of the Bad Anthropocene? Can we distribute the Anthropocene bonanza of energy and resources more equitably to avoid catastrophic conflicts? And can we, like the first living organisms, learn how to use gentler and smaller flows of resources to do so? Can we find global equivalents of the delicate proton pumps used to power all living cells today? Or will we keep depending on flows of energy and resources so huge that they will eventually shake apart the fantastically complex societies we have built in the past 200 years?

## Notes

1. Graham Allison and Philip Zelikow, *Essence of Decision: Explaining the Cuban Missile Crisis,* 2nd ed. (New York: Longman, 1999), 271.

2. Angus Madison, *The World Economy: A Millennial Perspective* (Paris: Organization for Economic Co-Operation and Development, 2001), 127.

3. Tim Lenton, *Earth System Science: A Very Short Introduction* (Oxford: Oxford University Press, 2016), 82.

4. Ha-Joon Chang, *Economics: The User's Guide* (New York: Pelican, 2014), 429, based on figures from the World Bank.

5. Lenton, *Earth Systems Science*, 82, 96–97.

6. The Scientist was Wally Broecker. Cited in David Christian, "Anthropocene Epoch," in *The Berkshire Encyclopedia of Sustainability, Vol. 10: The Future of Sustainability,* ed. Ray Anderson et al. (Barrington, MA: Berkshire Publishing, 2012), 22.

7. Jan Zalasiewicz and Colin Waters, "The Anthropocene," in *The Oxford Research Encyclopedia, Environmental Science* (Oxford: Oxford University Press, 2015), 4–5.

**Statistics on Human History in the Holocene and Anthropocene Epochs***

| **ERA** | A: YEAR 0 = 2000 BCE | B: POP. (Mill.) | C: TOTAL ENERGY USE Mill. GJ/Yr (= .001 Exajoules) (= B*D) | D: PER CAP ENERGY USE GJ/ Cap/Yr (1st 3 = max. est.) | E: LIFE EXPECTANCY (Years) 1st 3 = max. est. | F: LARGEST SETTLEMENT POP. (1,000s) 1st = max. est. |
|---|---|---|---|---|---|---|
| **HOLOCENE** | – 10,000 | 5 | 15 | 3 | 20 | 1 |
| | – 8,000 | | | | | 3 |
| | – 6,000 | | | | | 5 |
| | – 5,000 | 20 | 60 | 3 | 20 | 45 |
| | – 2,000 | 200 | 1,000 | 5 | 25 | 1,000 |
| | – 1,000 | 300 | 3,000 | 10 | 30 | 1,000 |
| **ANTHRO-POCENE** | – 200 | 900 | 20,700 | 23 | 35 | 1,100 |
| | – 100 | 1,600 | 43,200 | 27 | 40 | 1,750 |
| | 0 | 6,100 | 457,500 | 75 | 67 | 27,000 |
| | 10 | 6,900 | 515,500 | 75 | 69 | |

*Columns A through E based on Vaclav Smil, *Harvesting the Biosphere*, loc. 4528, Kindle; Column F based on Ian Morris, *Why the West Rules—for Now*, 148–49, plus 10,000 BP data interpolated.