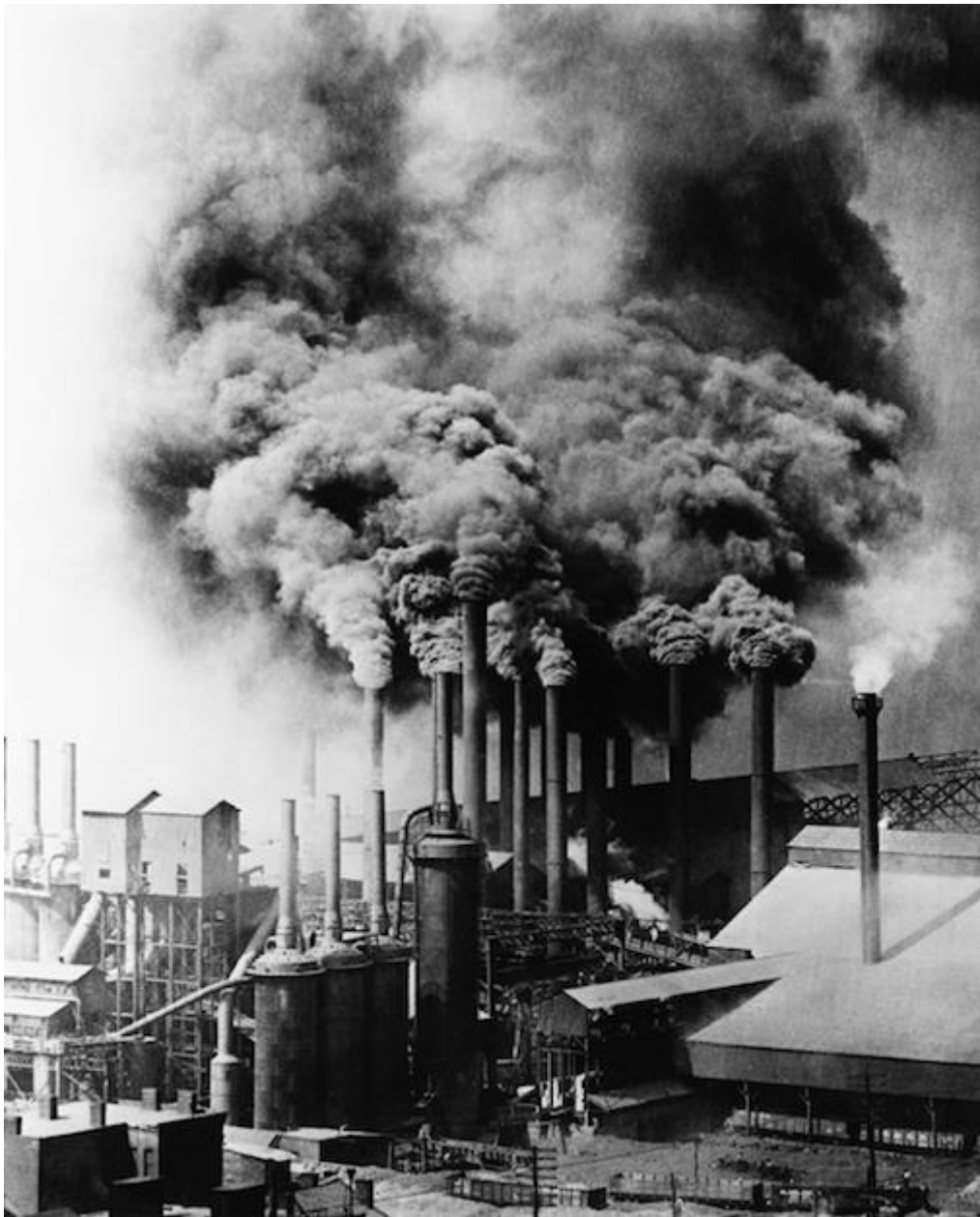


Fossil Fuels, Steam Power, and the Rise of Manufacturing

Abundant fossil fuels, and the innovative machines they powered, launched an era of accelerated change that continues to transform human society.



Smokestacks in Pittsburgh, Pennsylvania, 1890s © Bettmann/CORBIS

The Transformation of the World

Try to imagine what your life would be like without any machines working for you. Make a list of the machines in your household and on your person; you may arrive at a surprising number.

Now imagine earlier generations during their childhood years. How did they move from place to place? How did they communicate? What foods did they eat?

At one time, humans, fueled by the animals and plants they ate and the wood they burned, or aided by their domesticated animals, provided most of the energy in use. Windmills and waterwheels captured some extra energy, but there was little in reserve. All life operated within the fairly immediate flow of energy from the Sun to Earth.

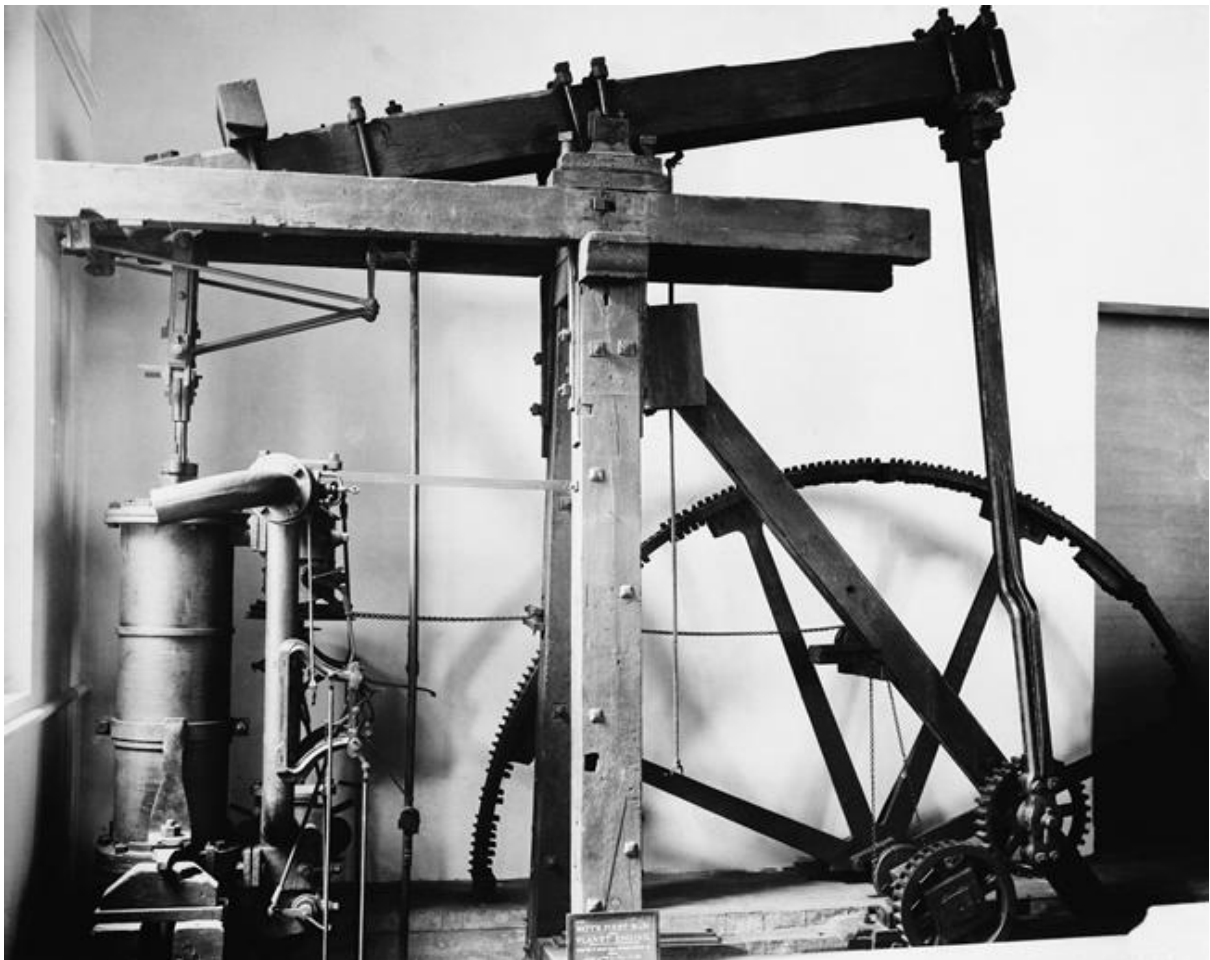
Everything changed during the Industrial Revolution, which began around 1750. People found an extra source of energy with an incredible capacity for work. That source was fossil fuels — coal, oil, and natural gas, though coal led the way — formed underground from the remains of plants and animals from much earlier geologic times. When these fuels were burned, they released energy, originally from the Sun, that had been stored for hundreds of millions of years.

Coal was formed when huge trees from the Carboniferous period (345– 280 million years ago) fell and were covered with water, so that oxygen and bacteria could not decay them. Instead, the pressure of the weight of materials above them compressed them into dark, carbonic, ignitable rock.

Most of the Earth's oil and gas formed over a hundred million years ago from tiny animal skeletons and plant matter that fell to the bottom of seas or were buried in sediment. This organic matter was compacted by the weight of water and soil. Coal, oil, and gas, despite their relative abundance, are not evenly distributed on Earth; some places have much more than others, due to geographic factors and the diverse ecosystems that existed long ago.

Early Steam Engines

The story of the Industrial Revolution begins on the small island of Great Britain. By the early 18th century, people there had used up most of their trees for building houses and ships and for cooking and heating. In their search for something else to burn, they turned to the hunks of black stone (coal) that they found near the surface of the earth. Soon they were digging deeper to mine it. Their coal mines filled with water that needed to be removed; horses pulling up bucketfuls proved slow going.



James Watt's "Sun and Planet" steam engine © Bettmann/CORBIS

To the rescue came James Watt (1736–1819), a Scottish instrument-maker who in 1776 designed an engine in which burning coal produced steam, which drove a piston assisted by a partial vacuum. (There had been earlier steam engines in Britain, and also in China and in Turkey, where one was used to turn the spit that roasts a lamb over a fire.) Its first application was to more quickly and efficiently pump water out of coal mines, to better allow for extraction of the natural resource, but Watt's engine worked well enough to be put to other uses; he became a wealthy man. After his patent ran out in 1800, others improved upon his engine. By 1900 engines burned 10 times more efficiently than they had a hundred years before.

At the outset of the 19th century, British colonies in North America were producing lots of cotton, using machines to spin the cotton thread on spindles and to weave it into cloth on looms. When they attached a steam engine to these machines, they could easily outproduce India, up until then the world's leading producer of cotton cloth. One steam engine could power many spindles and looms. This meant that people had to leave their homes and work together in factories.

Early in the 19th century the British also invented steam locomotives and steamships, which revolutionized travel. In 1851 they held the first world's fair, at which they exhibited telegraphs, sewing machines, revolvers, reaping machines, and steam hammers to demonstrate they that were the world's leading manufacturer of machinery. By this time the characteristics of industrial society — smoke rising from factories, bigger cities and denser populations, railroads — could be seen in many places in Britain.

Why Britain?

Britain wasn't the only place that had deposits of coal. So why didn't the Industrial Revolution begin in China, or somewhere else that boasted this natural resource? Did it start in isolation in Britain, or were there global forces at work that shaped it? Was it geography or cultural institutions that mattered most? Historians have vigorously debated these questions, amassing as much evidence as possible for their answers.

Possible reasons why industrialization began in Britain include:

- Shortage of wood and the abundance of convenient coal deposits
- Commercial-minded aristocracy; limited monarchy
- System of free enterprise; limited government involvement
- Government support for commercial projects, for a strong navy to protect ships
- Cheap cotton produced by slaves in North America
- High literacy rates
- Rule of law; protection of assets
- Valuable immigrants (Dutch, Jews, Huguenots [French Protestants])

Possible reasons why industrialization did not begin in China include:

- Location of China's coal, which was in the north, while economic activity was centered in the south
- Rapid growth of population in China, giving less incentive for machines and more for labor-intensive methods
- Confucian ideals that valued stability and frowned upon experimentation and change
- Lack of Chinese government support for maritime explorations, thinking its empire seemed large enough to provide everything needed
- China's focus on defending self from nomadic attacks from the north and west

Global forces influencing the development of industrialization in Britain include:

- Britain's location on the Atlantic Ocean
- British colonies in North America, which provided land, labor, and markets
- Silver from the Americas, used in trade with China
- Social and ideological conditions in Britain, and new thoughts about the economy, that encouraged an entrepreneurial spirit

By the way, if you're wondering what oil and natural gas were doing while coal was powering the Industrial Revolution, they had been discovered long before and were in use, but mostly as fuels for lamps and other light sources. It wasn't until the mid-20th century that oil caught up — and surpassed — coal in use.



Calcutta Harbor, c. 1860 © Hulton-Deutsch Collection/CORBIS

The Spread of the Industrial Revolution

Britain tried to keep secret how its machines were made, but people went there to learn about them and took the techniques back home. Sometimes they smuggled the machines out in rowboats to neighboring countries. The first countries after Britain to develop factories and railroads were Belgium, Switzerland, France, and the states that became Germany. Building a national railroad system proved an essential part of industrialization. Belgium began its railroads in 1834, France in 1842, Switzerland in 1847, and Germany in the 1850s.

Industrialization began in the United States when Samuel Slater emigrated from Britain to Rhode Island in 1789 and set up the first textile factory on U.S. soil. He did this from memory, having left Britain without notes or plans that could have been confiscated by British authorities. Francis Cabot Lowell, of Massachusetts, visited Britain from 1810 to 1812 and returned to set up the first power loom and the first factory combining mechanical spinning and weaving in the States. Railroad construction in America boomed from the 1830s to 1870s. The American Civil War (1861–65) was the first truly industrial war — the increasingly urbanized and factory-based North fighting against the agriculture-focused South — and industrialization grew explosively afterward. By 1900 the United States had overtaken Britain in manufacturing, producing 24 percent of the world's output.

After 1870 both Russia and Japan were forced by losing wars to abolish their feudal systems and to compete in the industrializing world. In Japan, the monarchy proved flexible enough to survive through early industrialization. In Russia, a profoundly rural country, the czar and the nobility undertook industrialization while trying to retain their dominance. Factory workers often worked 13-hour days without any legal rights. Discontent erupted repeatedly, and eventually a revolution brought the Communist party to power in 1917.

Industrialized nations used their strong armies and navies to colonize many parts of the world that were not industrialized, gaining access to the raw materials needed for their factories, a practice known as imperialism. In 1800 Europeans occupied or controlled about 34 percent of the land surface of the world; by 1914 this had risen to 84 percent.

Britain led the 19th-century takeovers and ended the century with the largest noncontiguous empire the world has ever known. (“The sun never sets on the British Empire,” as the British liked to say.) Britain exerted great influence in China and the Ottoman Empire without taking over direct rule, while in India, Southeast Asia, and 60 percent of Africa, it assumed all governmental functions.

In the last decade of the 19th century most European nations grabbed for a piece of Africa, and by 1900 the only independent country left on the continent was Ethiopia. After World War II (1939–1945) Europe’s colonies demanded their independence, which didn’t always happen immediately or without conflict but eventually took root. Now, in the early 21st century, Brazil, China, and India are becoming economic powerhouses, while many European countries are enduring troubled economic times.



Workers hauling coal near Fengjie, China, 2005 © Bob Sacha/CORBIS

Consequences of the Industrial Revolution

The statistics that reflect the effects of industrialization are staggering. In 1700, before the widespread use of fossil fuels, the world had a population of 670 million people. By 2011 the world's population had reached 6.7 billion, a 10-fold increase in a mere 300 years. In the 20th century alone, the world's economy grew 14-fold, the per capita income grew almost fourfold, and the use of energy expanded at least 13-fold. This kind of growth has never before occurred in human history.

Many people around the world today enjoy the benefits of industrialization. With so much more energy flowing through human systems than ever before, many of us must do much less hard physical labor than earlier generations did. People today are able to feed more babies and bring them to adulthood. Many people vote and participate in modern states, which provide education, social security, and health benefits. Large numbers of people enjoy levels of wealth, health, education, travel, and life expectancy unimagined before industrialization.

The benefits of industrialization, however, have come at great cost. For one thing, the rate of change (acceleration) is now so rapid that individuals and social systems struggle to keep up. And strong arguments can be made about depersonalization in the age of mass production.

The increased complexity of the industrial system has also brought increased fragility. Industrialization depends on the interaction of many diverse components, any one of which could fail. We know that many of the essential components of the industrial system, and the natural resources it depends on, are being compromised — the soil, the oceans, the atmosphere, the underground water levels, plants, and animals are all at risk. Will growth continue unchecked, or are we approaching the end of an unsustainable industrial era? Whatever the future holds, we'll be debating — and dealing with — the consequences of modernization for years to come.

By Cynthia Stokes Brown